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PART III
VOLUME I
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AD 142232

THE PHYSIOLOGICAL BASIS FOR VARIOUS CONSTITUENTS IN SURVIVAL RATIONS

Part III. The Efficiency of Young Men Under Conditions of Moist Heat

FREDERICK SARGENT, II, S.B., M.D., D.N.B.
VIRGINIA W. SARGENT, M.S.
ROBERT E. JOHNSON, M.D., D. PHIL. (OXON.)

UNIVERSITY OF ILLINOIS

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DECEMBER 1957

AERO MEDICAL LABORATORY
CONTRACT No. AF 18(600)-80
PROJECT No. 7156
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WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

The investigations described in this report were carried out during the summer of 1955. In the spring the detailed protocol was designed, and supplies and equipment were assembled. In June the test team and subjects moved to Camp Atterbury and for one week were indoctrinated. A 36-day metabolic investigation was made at that camp during late June and July. The biological specimens collected and the clinical observations made were analyzed in the laboratories of the Department of Physiology and the Health Service Research Unit, McKinley Hospital, University of Illinois, Urbana, between September 1955 and December 1956. The research was supported by Contract No. AF 18 (600)-80 with the Aero Medical Laboratory, Directorate of Research, WADC, Project No. 7156, "Flight and Survival Foods, Feeding Methods, and Nutritional Requirements," Task No. 71805, "Nutritional Physiology of Men under Air Force Operating Conditions and Emergency Situations," (formerly RDO No. 698-81, "Survival Ration Requirements"). The Contract Monitor was Doctor H. C. Dyme, Chief Nutrition Section; the Project Scientist, Lieutenant Colonel A. A. Taylor, USAF (VC); and the Task Engineer, 1/Lieutenant (now Captain) L. A. Whitehair, who served also as Liaison Officer during the field tests. Lieutenant Colonel Roy W. Otto, Chanute AFB, served throughout as the Project Officer. This report constitutes the results of the joint efforts of the responsible investigators, R. E. Johnson and F. Sargent, II, and a team of civilian and military associates to whom most of the credit should go for the success of these studies. A team roster is included in Section VII: Acknowledgements.

This investigation would not have been possible without the generous cooperation of the University Health Service, especially in making space available in the laboratories of the Health Service Research Unit at McKinley Hospital, University of Illinois.

We wish to acknowledge the generous cooperation received from the Air Research and Development Command, Air Training Command, Fifth Army, and the Purchasing Department of the University of Illinois. To Mrs. Frances Carter we extend our thanks for assistance in editing this report and typing the final copy. To Mr. Jack Gockel and Mrs. Marie Litterer we are indebted for the quantitative charts.

ABSTRACT

From June 22, 1955, through July 27, 1955, 100 volunteer airmen served as subjects in a study of survival rations in moist heat at Camp Atterbury, Indiana. The base laboratory was at McKinley Hospital, University of Illinois, Urbana. To establish physiological, biochemical, nutritional, and clinical judgments on the relative effects of work, water, calories, and protein/carbohydrate/fat ratio in all-purpose survival rations, numerous observations were made in two-week periods of adequate, restricted, and recovery diets, with luxus amounts of vitamins at all times. Twenty-one nutrient combinations could be rank-ordered, by 27 different tests, with respect to effects on organ function and body efficiency. Clinical findings could also be rated. By far the best regimen was that represented by the ideal control--Field Ration A. Of the experimental regimens, the worst was starvation; the best was a 3000-Calorie adequate ration. Below the 3000-Calorie ration, the highest score was attained both in hard work and in light work by a combination supplying unlimited water, 2000 Calories per day, and a distribution of calories of 15% protein, 52% carbohydrate, and 33% fat. Limitation of water, decrease of calories, or marked deviations in protein/carbohydrate/fat ratios resulted in measurable clinical or functional deterioration.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jack Bollerud

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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SECTION I

GENERAL INTRODUCTION

This report deals with the nutritional physiology of man exposed to moist heat; it represents the third phase of a comprehensive study of the problem of the all-purpose, all-environment survival ration. The first phase of this investigation was concerned with the reactions of young men subsisted on a variety of nutrient combinations under temperate conditions and performing only modern physical activity (Sargent et al.,1954). The second phase dealt with two additional major variables---hard physical exertion and exposure to cold weather in the field (Sargent et al.,1955). The third phase extends the previous work to include an investigation of the effects of moist heat. The investigation was designed so as to make possible valid judgments on the relative merits of a variety of nutrient combinations in sustaining maximally the "survival potential" (Kline and Dyme,1953) of castaways forced to survive, escape, and evade in hot weather.

The general planning of the hot weather test called for a mass metabolic study on 100 volunteer airmen observed continuously for a 36-day period at Camp Atterbury, Indiana. The organ function and bodily efficiency of the subjects were studied during 14 preliminary days, nine experimental days, and 13 recovery days by the same comprehensive battery of tests that had been employed in the 1953 and 1954 winter studies. Furthermore, during the experimental weeks, comparable regimens of total calorie intake, water intake, ratio of protein, carbohydrate, and fat, and inorganic nutrients were administered. Thus, it became possible to determine the impact of hard physical work and hot weather on nutritional stresses to which the castaway might be exposed.

This hot weather study, as in the cases of the temperate study and cold weather study, was planned to avoid the major criticisms which can be leveled at most of the previous studies on this question. A truly comprehensive investigation was made of the multiple nutritional interrelations which must be considered in any survival ration; viz., degree of water deficit, amount of caloric deficit, and varying ratios of protein, carbohydrate, and fat in the survival ration. The statistical validity was insured by adequate numbers of paired-fed controls; an adequate range of water deficit, calorie deficit, and nutrient combinations. Finally, the impact of hot weather and exercise was studied realistically in field survival situations.

The present study had two major aims. The first was to extend previous knowledge of survival rations by a systematic survey of the effects on human subjects of the possible combinations of water intake, calorie intake, and protein/carbohydrate/fat ratios in potential survival rations. Emphasis has been principally on efficiency of the body as a whole and the functioning of important organ systems. In other words, our emphasis has been on the health and welfare of the castaway himself, in addition to orthodox biochemical and nutritional interpretations of intakes, balances, and composition of blood and excreta. Second, the data were to be obtained under realistic field

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conditions in which volunteer airmen were exposed to hot weather and hard work. The impact of these two stresses could be interpreted in the light of control data obtained in 1953 (Sargent et al., 1954) in which normal young men were exposed to the same nutritional stresses, but under conditions of temperate environment and moderate exercise. As in 1953 and 1954, it was planned in 1955 to gather as much information as possible on rehabilitation of the rescued castaway and on the nutritional merits of the 5-in-1 ration.

Because a unique opportunity was arranged by the Air Force so that large numbers of subjects, excellent field facilities, and supporting personnel became available, it was possible to organize the present study for statistically valid conclusions from a wide variety of dietary, biochemical, physiological, and clinical observations. The concepts of controls were paramount in the ultimate design. Each subject was his own control in that he was subsisted for two weeks on an adequate ration under conditions of moderate environmental exposure and exercise, then for nine days on an experimental nutrient combination under field survival conditions, and finally for 13 days on rehabilitation regimens under conditions of moderate environmental exposure and exercise.

A second control concept was that of paired-fed control during the field phase not only for nutrient intake but also for water intake and work output. For this purpose the volunteer subjects were divided into four major groups:

Flight 1	Hard work, unlimited water
Flight 2	Hard work, limited water
Flight 3	Light work, unlimited water
Flight 4	Light work, limited water

The hard work group simulated castaways attempting to escape and evade with or without restricted water and the light work groups simulated castaways surviving in one spot with or without limitation of water. Within each flight two subjects subsisted on each of the ten nutrient combinations under study. Thus, within each flight there were paired-fed controls for each nutrient combinations.

Two additional control concepts were utilized in the study of nutrient combinations; viz., the concept of negative and positive control and the concept of ration control. Negative control consisted of starvation, in which presumably survival potential is least maintained. Positive control consisted of a 3000-Calorie diet very similar in composition (but lower in calories) to field rations used by Peary (1910) and Amundsen (1908, 1913) in their polar journeys. This ration was considered to maintain survival potential better than 2000- or 1000-Calorie regimens.

The ration controls were different from those used in the 1954 winter study. Twelve of the volunteer subjects were assigned by lot to this category. These men lived and worked with their fellow subjects, but were at no time subsisted on packaged military rations. Throughout the 36-day period these subjects were allowed ad libitum amounts of Field Ration A and

unrestricted intake of water. To the best of our knowledge, no other major field study has incorporated this kind of control in which presumably physiological and biochemical changes are conditioned solely by work and weather, not by nutritional stresses. Furthermore, the investigators were presented with a unique opportunity to compare and contrast a standard packaged military ration, such as 5-in-1, with a diet composed entirely of fresh and frozen foods.

No attempt was made to study and compare survival rations already in production. Rather the study was designed to establish conclusively underlying physiological and clinical principles upon which the technologists can build the best and most acceptable ration for survivors.

SECTION II

METHODS

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A. ADMINISTRATIVE ASPECT OF FIELD TRIAL

1. Background, Planning, and Organization

Preliminary discussions for a series of investigations on the physiological basis of constituents of the all-purpose survival ration began in January, 1951. At that time it was conceived that an investigation in three phases would yield the most information: (1) a control study in which the subjects engaged in moderate activity and received minimum exposure to the weather, (2) one field trial in which the subjects would be exposed to cold weather, and (3) a second field trial in which the subjects would be exposed to hot weather. In the latter two studies some subjects would be doing hard work, others light work. The control study and the cold weather study have been completed and reports have been submitted. In the present report the control study (Sargent et al., 1954) will be referred to as the 1953 or temperate study and the 1954 study will be referred to as the cold weather study (Sargent et al., 1955). The present investigation deals with the third phase, a field trial conducted during hot weather and it will be referred to as the 1955 or hot weather study.

The Air Training Command (ATRC) and the Air Research and Development Command (ARDC) agreed to collaborate with the Department of Physiology, University of Illinois, in furnishing (1) the sites for the field trial, (2) the required support personnel, (3) the supplies and equipment, (4) the volunteer subjects, and (5) the transportation facilities. The 3345th Technical Training Wing (ATRC) at Chanute Air Force Base, Rantoul, Illinois, was designated as being responsible for the administration of the military aspects of the hot weather study. Camp Atterbury, Indiana, was selected as the site for the test, as being available, convenient, isolated and likely to provide hot, humid conditions.

The key administrative personnel for the hot weather test were appointed in March, 1955---project officer, adjutant, supervisory investigator, first sergeant, supply sergeant, and clerk---and work was initiated on the detailed planning and organization. The organization chart utilized in the present study is shown in Figure II. 1. The project officer accomplished the following: (1) appointment of administrative personnel (adjutant, first sergeant, supply sergeant, transportation sergeant, mess sergeant, flight non-commissioned officers, and medical non-commissioned officers), (2) procurement of living facilities for support personnel and subjects, laboratory facilities, administrative and supply buildings, and messing facilities at Camp Atterbury, (3) procurement of necessary supplies and equipment for these facilities, (4) procurement of transportation vehicles to be used in moving to and from Camp Atterbury and for use at the camp, (5) arrangement for an air courier service between Chanute AFB and Bakalar AFB, located 14 miles from Camp Atterbury, and (6) arrangements for obtaining field rations for the support personnel through Bakalar AFB and Fort Benjamin Harrison.

The supervisory investigator was responsible for (1) planning of the scientific aspects of the trial, such as testing, work loads to be imposed,

and nutrient combinations to be fed, (2) ordering necessary supplies and equipment for testing and feeding the subjects and for collecting various biological specimens, (3) preparing forms and other devices for recording the scientific observations, (4) obtaining containers for the transportation of laboratory equipment and supplies and biological specimens, and (5) procuring facilities for the cold storage of biological specimens, both at Camp Atterbury and the University of Illinois.

The Aero Medical Laboratory furnished tentage and other accessory equipment and supplies for the field phase of the trial, a refrigerated van, and all rations and ration components used by the test subjects. Medical supplies, medicaments, and the devices for physical examination were provided by the 3345th USAF Hospital at Chanute AFB. ATRC and ARDC jointly supplied the four medical officers and the 12 non-commissioned medical officers. These commands also supplied other support personnel to supplement the group from Chanute, such as cooks, a weather observer, and flight non-commissioned officers. One hundred volunteer subjects were released from Lackland AFB, Texas, to participate in the trial.

Two trips were made to Camp Atterbury during the spring of 1955 by the project officer, the supervisory investigator, and the personnel from WADC. During these visits final arrangements were made for the actual areas in the camp to be used in the summer test. Buildings were selected and lists were prepared of equipment and supplies which could be furnished by the Quartermaster of Camp Atterbury. Arrangements were made with Bakalar AFB to furnish emergency medical and dental support and to provide for servicing and maintenance of motor vehicles.

2. Administration of Support Personnel

There were 75 individuals who directly supported the daily conduct of the trial. All these individuals reported to Camp Atterbury on or about 15 June, one week prior to the beginning day of the investigation. During this week these individuals were thoroughly briefed on the general purpose of the trial, the nature of clinical investigation, and the many problems that might be faced during the course of the study. These briefing sessions were held with specific groups (e.g., clinical laboratory personnel, flight non-commissioned officers, administrative personnel, etc.) so that the special aspects of their duties and responsibilities could be emphasized and specific questions answered.

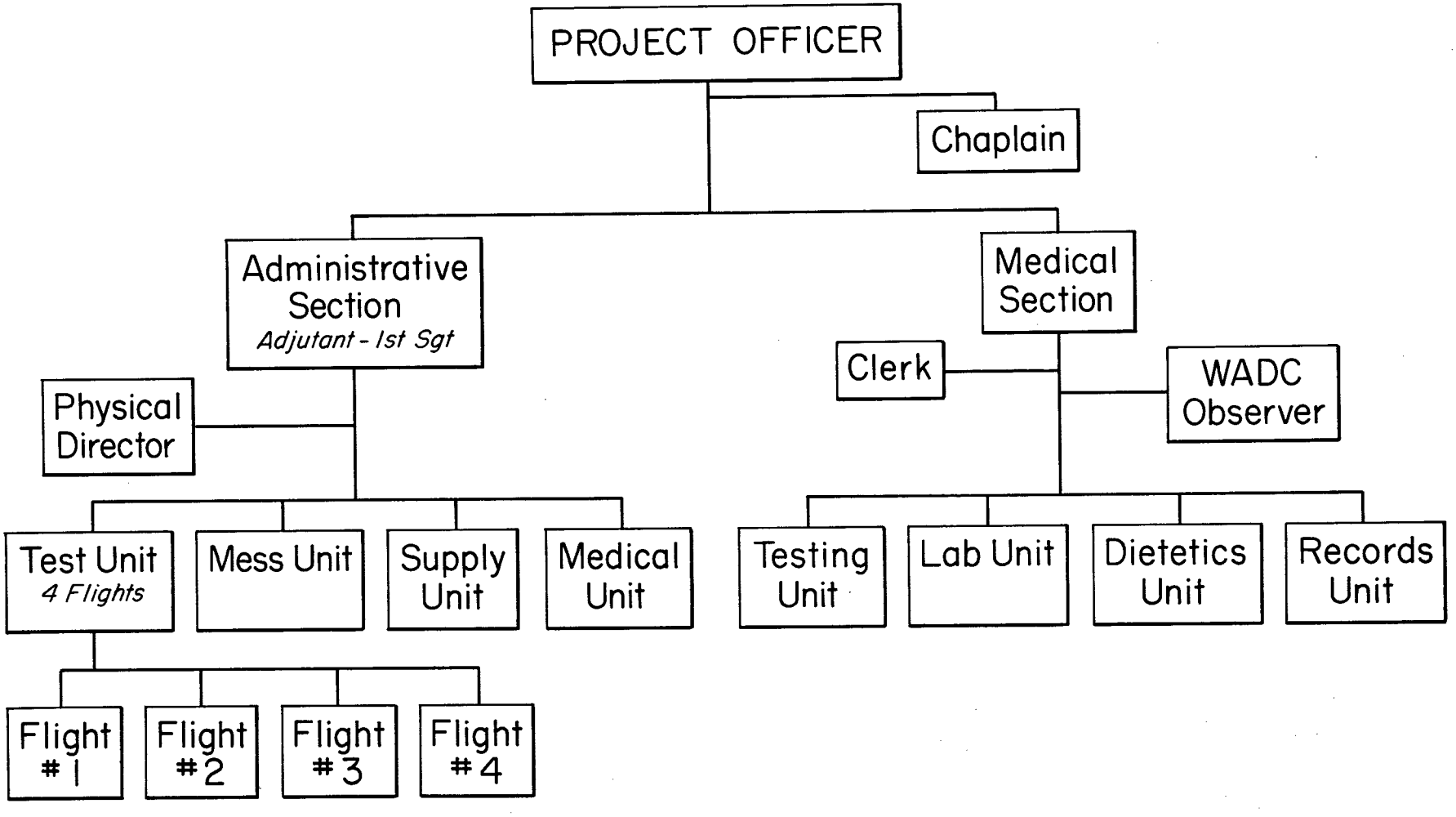
Once the study had actually begun, daily conferences were held with these groups or with representatives from the groups so that the next day's program could be explained in detail, orders could be issued, and special problems given prompt attention.

FIGURE II. 1. ORGANIZATIONAL CHART FOR THE HOT WEATHER TRIALS CONDUCTED JUNE AND JULY, 1955.

Figure II.1

USAF PROJECT No. 7156

SURVIVAL RATION STUDY: SUMMER 1955



3. Administration of the Subjects

The non-commissioned officers assigned to the flights had direct administrative control of the subjects. They were supported by a survival instructor, a recreational specialist and a chaplain, in the daily management of the activities in which the flight engaged.

Non-Commissioned Officers of Flights. There were four major groups of subjects designated as Flights 1, 2, 3, and 4. There were 25 subjects in each flight. Three NCO's were in charge of each. The ranking NCO in each was the flight leader. These 12 men were charged with the primary responsibility of maintaining control of the subjects which involved implementing the instructions given the subjects. (These instructions are detailed in a subsequent section.) In addition, they maintained a daily diary on each subject and on the activities of the flight as a whole. They were responsible for survival instruction, military training, and recreation of their charges. They had no mean task! It was due in large part to their enthusiastic support that the scientific data collected are entirely trustworthy.

These 12 men were given special intensive briefing before the trial began. During the trial it was through them that orders, schedules, and other details were passed on to the subjects.

Survival Instructor. One survival expert was assigned to the project from the Survival School at Chanute AFB. It was his responsibility to give survival lectures and demonstrations and lead the subjects in field survival practice.

Recreational Specialist. The recreational specialist was responsible for procuring recreational facilities and for organizing and leading the flights in recreational activities. Available at Camp Atterbury were an indoor gym, fields for playing baseball and volleyball, and courts for tennis and handball.

Chaplain. One chaplain was assigned and a chapel was made available to him in the headquarters area of the study at Camp Atterbury. The chaplain held religious services for the subjects and support personnel, arranged for clergymen of different faiths to visit the camp and hold services, participated in the recreational program, and was available at all times for giving sympathetic advice and encouragement to the subjects.

4. The Movement to and from Camp Atterbury

In contrast to the winter study, all three periods of the summer test were conducted at Camp Atterbury. Only two moves were made, from Chanute AFB to Camp Atterbury and from Camp Atterbury to Chanute AFB. There were two primary depots for the assembling of equipment and supplies to be used in the trial: (1) Chanute AFB, and (2) University of Illinois. The subjects arrived at Chanute AFB on or about 10 June. On 15 June the supplies and equipment were loaded into military vehicles and on 16 June the personnel, supplies, and equipment moved to Camp Atterbury. On 15 June an advance cadre went to Camp

Atterbury to begin the preparation of the headquarters area so that when the main body of personnel arrived, there would be available sleeping, messing, and supply facilities. Special materials and rations supplied by WADC were moved directly from Wright Field to Camp Atterbury. At the end of the summer tests the equipment and supplies, and the subjects, and support personnel were transported back to Chanute AFB. Administratively, this arrangement worked out much better than the plan which was followed in the winter test.

B. THE SUBJECTS

1. Selection of Subjects

The airmen who served as subjects in this investigation were obtained from Lackland AFB, Texas. The majority of these men were Airmen 3rd Class, who had just completed four months of basic training. Before volunteering for the project, these men had been part of a larger group which had been briefed on the nature of the ration study. The hundred who volunteered knew that they would be expected to subsist on unusual foods, that they might even have to starve, and that some of them would have to go for about two weeks on only one canteen of water a day. They also knew that the reward for participation in the field trial would be 14 days of convalescent leave. So far as we are aware, there was no special medical or psychological selection other than that the men had met the minimum medical standards for induction into the USAF. The volunteer subjects arrived at Chanute AFB on or about 10 June. They were assigned to the 3351st Student Squadron and placed under command of the project officer. Although replacements for physically unfit subjects were not available, it was decided to eliminate from the study any men whose health might be impaired by the rigors of the investigation. Accordingly the Forms 88 and 89 (history and physical examination) of each man were reviewed. An X-ray of the chest was taken. Any subject with questionable findings was interviewed and examined by the supervisory investigator. The men were given a dental examination and any who needed emergency extractions were so treated. There were some 25 subjects who had such poor dental health that one or more teeth had to be extracted before going to Camp Atterbury. None of the subjects had significant physical defects. Several of them were described as "emotional," "immature," or "mildly inadequate mentally." Flight leaders, however, felt that these men would present no disciplinary problems. Consequently, no subject was disqualified.

2. Handling of Subjects

Flights of Subjects. On arrival at Chanute AFB the volunteer airmen drew lots for their "Subject Code Number." The number automatically assigned them to a flight and to an experimental nutrient mixture. By this means the distribution of white and colored young men was randomized between the four flights.

The age, height, weight, race, and religion of these airmen have been detailed in Tables II. 1, II. 2, II. 3, and II. 4. The mean ages of the men are similar in the four flights and comparable to the mean ages of the men

TABLE II. 1

CHARACTERISTICS OF SUBJECTS: FLIGHT 1

Subject Code No.	Age yr.	Hgt. in.	Wgt. Kg.	Race	Faith
1	17	65.5	65.8	W	Prot
2	19	70.0	68.7	W	Prot
3	17	66.8	58.1	W	Cath
4	18	71.7	74.3	W	Cath
5	21	68.5	56.4	W	Prot
6	20	67.8	66.4	W	Prot
7	18	70.6	70.2	W	Prot
8	17	65.6	62.9	W	Prot
9	17	69.1	79.9	W	Prot
10	19	67.2	61.7	N	Prot
11	20	66.0	67.8	W	Prot
12	18	67.6	76.3	W	Prot
13	18	70.7	65.9	W	Prot
14	20	67.7	63.5	N	Prot
15	17	67.7	70.6	N	Prot
16	17	66.7	60.8	N	Prot
17	17	70.0	88.6	W	Cath
18	19	69.2	58.3	W	Prot
19	19	65.8	56.6	W	Cath
20	21	70.2	58.8	N	Prot
21	17	69.6	60.3	N	Prot
22	18	65.2	61.8	W	Prot
90	17	71.6	71.0	N	Prot
91	17	72.0	76.5	W	Prot
92	19	70.7	62.9	W	Cath
Mean	18	68.6	66.6		

TABLE II. 2

CHARACTERISTICS OF SUBJECTS: FLIGHT 2

Subject Code No.	Age yr.	Hgt. in.	Wgt. Kg.	Race	Faith
23	19	68.6	78.2	W	Prot
24	18	66.1	51.8	N	Prot
25	20	68.0	74.3	W	Prot
26	17	65.1	52.9	W	Prot
27	17	64.7	51.5	N	Prot
28	18	65.2	63.2	W	Prot
29	18	70.2	73.5	W	Prot
30	18	*	*	W	Prot
31	19	70.7	82.5	W	Prot
32	18	68.8	60.8	W	Prot
33	18	67.3	64.2	W	Cath
34	17	65.7	59.8	W	Prot
35	17	67.0	61.6	W	Prot
36	21	68.0	61.7	W	Prot
37	17	69.0	62.3	N	Prot
38	17	69.3	67.4	W	Prot
39	18	65.1	60.0	N	Prot
40	19	72.0	66.4	W	Prot
41	17	68.7	59.8	W	Prot
42	17	66.3	64.8	N	Prot
43	20	68.5	63.2	W	Prot
44	18	68.5	63.2	W	Prot
93	19	69.7	63.6	W	Prot
94	18	70.7	78.3	W	Prot
95	18	65.2	76.8	N	Prot
Mean	18	67.9	65.1		

*Ill at start of test

TABLE II. 3

CHARACTERISTICS OF SUBJECTS: FLIGHT 3

Subject Code No.	Age yr.	Hgt. in.	Wgt. Kg.	Race	Faith
45	27	69.1	64.1	W	Prot
46	17	69.2	75.9	W	Prot
47	18	66.6	68.2	W	Prot
48	19	71.3	76.0	W	Prot
49	18	69.1	61.9	W	Prot
50	17	66.6	58.5	W	Prot
51	17	72.3	77.0	W	Prot
52	18	71.3	67.4	N	Prot
53	19	64.5	63.5	W	Cath
54	18	66.3	64.6	W	Prot
55	17	65.5	55.4	W	Cath
56	19	68.0	64.1	W	Prot
57	19	70.0	70.7	N	Prot
58	18	68.8	66.9	W	Prot
59	20	69.5	68.8	N	Prot
60	21	71.0	78.6	W	Prot
61	18	71.5	67.3	N	Prot
62	19	70.5	68.5	W	Prot
63	17	70.8	72.7	W	Prot
64	19	70.6	75.1	N	Prot
65	19	71.2	72.4	W	Prot
66	17	72.5	72.6	W	Prot
96	17	74.3	82.8	N	Prot
97	19	70.5	78.0	W	Prot
98	21	65.8	64.2	W	Prot
Mean	19	69.5	69.4		

TABLE II. 4

CHARACTERISTICS OF SUBJECTS: FLIGHT 4

Subject Code No.	Age yr.	Hgt. in.	Wgt. Kg.	Race	Faith
67	20	66.7	59.6	W	Prot
68	19	67.2	65.5	N	Prot
69	18	70.1	67.8	W	Cath
70	17	69.5	65.3	W	Prot
71	19	67.6	61.3	W	Prot
72	20	68.7	69.0	W	Cath
73	21	65.0	59.1	W	Prot
74	18	72.1	70.8	W	Prot
75	17	64.6	69.9	W	Prot
76	18	65.1	55.5	W	Prot
77	17	65.6	65.0	N	Cath
78	20	71.0	69.7	W	Cath
79	17	65.8	65.3	W	Prot
80	17	65.7	61.2	N	Prot
81	19	69.5	66.6	N	Prot
82	17	69.5	59.7	W	Prot
83	17	67.0	63.5	N	Prot
84	20	69.6	62.8	W	Prot
85	20	69.6	68.2	W	Prot
86	19	66.7	61.7	W	Prot
87	17	70.7	86.8	N	Prot
88	18	70.0	63.6	W	Prot
99	17	66.5	65.3	N	Cath
100	19	69.8	85.0	W	Prot
101	17	71.5	65.0	W	Prot
Mean	18	68.2	66.1		

participating in the 1954 test. The four flights are closely alike with regard to height and initial weight. Within each flight there are approximately equal distributions of Whites and Negroes: Flight 1, 28%; Flight 2, 24%; Flight 3, 24%; and Flight 4, 28% Negroes.

The twelve subjects with code numbers beginning with "90" were designated as FRA subjects. These men were treated in an identical fashion to the other 88 subjects with regard to testing and collection of biological specimens. The activities that these men engaged in and the food that they ate will be discussed below. At this point it should be emphasized that these men did not differ in regard to age, height, or weight, from the other 88 subjects. Furthermore the distribution of Negroes was equal in the four groups of three subjects, i.e., one Negro FRA and two white FRA's in each flight.

Indoctrination of Subjects. The indoctrination of the subjects was done by flights; the administrative and medical personnel assigned to each flight attended the briefing of their respective flights. At each briefing the adjutant, the first sergeant, the responsible investigator, the supervisory investigator, and the chief dietitian shared the program so that all details of the trial could be explained. The adjutant and the first sergeant discussed such matters as command, discipline, pay, laundry, personal problems, mail, and convalescent leave. The responsible and supervisory investigators dealt with the scientific aspects of the trial, testing, collection of specimens, restrictions to be imposed, and duties. The dietitian discussed the problem of weighed diets and measured consumption of water.

Discipline, morale, and convalescent leave: Under the conditions of the present investigation it was essential that some incentive for cooperation by the subjects be offered. The project officer was authorized to give each subject who cooperated fully with the restrictions and responsibilities imposed by the supervisory investigator 14 days of convalescent leave, not chargeable against ordinary annual leave. This incentive served as a disciplinary measure, for when subjects did not cooperate it was possible to take from them a fraction of the full leave. Application of Section XV (Uniform Code of Military Justice) punishment for insubordination, fighting, petty larceny, etc., was not possible, for the subjects were living under rigidly controlled conditions. The experience of the project officer and the supervisory investigator indicated that the incentive of leave was generally an adequate disciplinary measure. Most of the subjects, in spite of their youth and brief military experience, cooperated exceedingly well in all aspects of the experiment. Penalties against the few who failed to cooperate helped to keep the morale of the group at a high level throughout the trial and the scientific success of the project was assured.

Specimens: The subjects were required to collect all of their urine and feces. The urine was collected for 24-hour periods in uncoated, gallon-sized, tin cans, which the subjects carried with them at all times. The flight leaders maintained a log of the morning urination times. Stool specimens were collected in one quart paraffin-lined cartons (Sealright). A separate carton was used for each bowel movement. Similar cartons were to be used if any subject vomited, an infrequent occurrence during the test. The living quarters

of the subjects and the mess hall were supplied with a quantity of these cartons. The tin cans were turned in daily at the clinical laboratory and the cartons were collected periodically by members of the test team.

Liquids and food: During the first two weeks and the last two weeks of the investigation the subjects were allowed free but measured consumption of water. Control was accomplished by issuing daily to each subject a canteen filled with water. The canteen was refilled at the mess halls at each meal as desired, and a record was made of the number of refills. Each morning the canteen was exchanged for a freshly filled container. Other liquids, such as cocoa, tea, and coffee were allowed only at meal times. No food could be eaten other than that issued at the mess hall and no subject was allowed to take uneaten food from the mess hall.

In the experimental period the subjects of Flights 1 and 3 were permitted unlimited water. Their canteens were refilled in the same manner as during the above four weeks. The subjects in Flights 2 and 4 were allowed no more than 910 ml liquids per day. One canteen holds this volume of water. If coffee or tea was desired at meal times, water from the canteen was exchanged for it. No water was deducted from the canteen to allow for pre-formed water already present in the experimental nutrient mixtures. Because of the acute dehydration produced by the hot weather of the summer tests, the water allowance of Flights 2 and 4 had to be increased during the first week. This matter will be discussed in detail in a subsequent section.

All subjects turned their canteens in every morning in exchange for a fresh one. The volume of water remaining in the canteen was measured and recorded.

Personal hygiene: During the first two and last two weeks of the investigation the men were allowed to brush their teeth daily. They were on their honor not to swallow the wash water. They shaved and washed daily and were allowed one shower each day.

During the experimental period the men generally practiced personal hygiene recommended for the castaway. They washed and shaved daily. They were not, however, allowed to brush their teeth or take a shower. At the end of the experimental period the subjects were permitted a shower.

During all phases of the trial the men were responsible for the cleanliness of their clothing. They washed their own fatigues, underwear, and socks.

Medical care; sick and emergency leave: Daily rounds were made by the medical officers. If a subject was found to be ill, he was placed in "Sick Bay" and given appropriate therapy. Collections were maintained and feeding was supervised by the flight leader or the medical NCO, who was assigned to the flight. If hospitalization or air evacuation was required, the subject was withdrawn from the restrictions of the project; collections were stopped and no record was maintained of the food eaten. If the subject required dental extractions during the investigation, the necessary treatment was administered,

but no alteration was made in the metabolic regimen. The hospital facilities, which were used during the course of the trial, were a dispensary at Bakalar AFB; Bartholomew County Hospital, Columbus, Indiana; the hospital at Fort Benjamin Harrison, Indianapolis; and the 3345th USAF Hospital at Chanute AFB. During the investigation there were numerous minor upper respiratory infections, and a rather large number of serious respiratory diseases which required hospitalization. This general problem will be discussed in a subsequent section. Only one subject had to withdraw from the project because of illness in his family. Shortly after completing the experimental period he withdrew with emergency leave and did not return.

Special instructions for field phase: Shortly before the experimental period began, a second briefing session was held with each flight. On this occasion the instructions given previously were reemphasized and the special problems to be faced in the experimental regimens were explained. Those men to be on limited water were instructed to ration their water. It was pointed out that all food issued had to be eaten: there would be no seconds and no weigh-backs. Only limited alterations could be made in the nutrient mixtures, such as manner of cooking the meat bar and variations in the candy items of the high carbohydrate regimens.

Duties of the Flight Non-Commissioned Officers: The many instructions given to the subjects were implemented by the three flight non-commissioned officers assigned to each of the four flights. A listing of their responsibilities serves to summarize the restrictions and duties of the subjects.

1. Control of subjects
   a. Complete collection of urine and feces
   b. Accurate labelling and timing of specimens
   c. Accurate records of water consumption
   d. Only food issued at mess hall may be eaten
   e. Prompt reporting for testing procedures

2. Messing
   a. Tray check for each man in flight
   b. Supplying subjects with seconds when allowed and recording same
   c. Observation of eating
   d. Participation in weigh-back operation

3. Testing
   a. Promptness in bringing flight to test areas
   b. Maintenance of order during tests
   c. Pacing the one-hour march of the heat acclimatization test

4. Observation
   a. Daily log of flight activity
   b. Daily remarks on condition of subjects

Typical Logs of Daily Activity. Because of the large group of subjects studied in this trial, it was necessary that their daily activity be regimented and scheduled. Completion of the many tests and continuous control of the subjects would have been otherwise impractical. No individual records or diaries of physical activity were maintained. Such records are difficult to convert into hourly caloric expenditure even when only a small group of men are involved, and it was felt that with this large group such observations would be impractical. Caloric expenditure rather could be estimated from logs of typical daily activity of the entire flight.

Pre- and recovery periods: During the pre- and recovery periods the daily activity of the subjects in each of the four flights was maintained as uniform as possible. A typical day within these two periods is presented in Table II. 5. At all times the subjects were under the constant supervision of the

TABLE II. 5

BASIC ACTIVITY SCHEDULE FOR PRE- AND RECOVERY PERIODS

Time	Kind and Degree of Activity
0525	Reveille
0525-0700	Morning routine: void; turn in urinary specimens; clean quarters
0700-0800	Morning meal
0800-0900	Sick call
0900-1200	Survival and military indoctrination; sports; close order drill; testing
1200-1300	Noon meal
1300-1730	Survival and military indoctrination; sports; close order drill; testing
1730-1830	Evening meal
1830-2200	Recreation: sports; movies; reading, writing letters; conversation
2200	Lights out; sleep

flight leaders or other members of the test team, and they were not allowed to leave the area of the project unless accompanied by an individual responsible for their conduct. The moderate activity in which most of the subjects engaged during these periods consisted of close order drill, marching in formation, and sports, such as baseball, volleyball, and basketball. Members of the flights were also responsible for policing the area, and participating in details, such as unloading trucks, opening rations, and pitching tents.

From time to time the subjects were given instructions in military matters and on the art of survival. Their recreation consisted of sports and movies. On these occasions the participation involved the whole group. There were also available time for the individual to entertain himself with such activities as reading, writing letters, or washing clothes. They were allowed to participate in special religious instruction and to attend church on Sundays. The religious activities at the camp were conducted by a chaplain.

During REC I all the flights engaged in a schedule which was quite

different from that shown in Table II. 5. Because of an epidemic of respiratory infection, which will be discussed more fully in a later section, the subjects lived under conditions of moderate isolation. Each flight was quartered in a separate barracks and was fed in the mess hall one flight at a time. When not engaged in tests, the subjects were confined to their barracks or the area immediately surrounding the barracks and engaged in only light activity. Participation in sports was not allowed. When it became apparent that the epidemic had subsided, daily activity such as outlined in Table II. 5 was resumed.

Experimental periods: During the nine experimental days of the trial the daily activity (Table II. 6) was altered considerably from that of the pre- and recovery periods. Two types of survival experiences were simulated: (1) light work, such as might be engaged in by the castaway remaining close to a disabled aircraft and (2) hard work, such as might be followed by the castaway seeking to "escape and evade." Flights 1 and 2 were exposed to the latter circumstances. They marched 12 miles daily, except on days when meals were omitted because of function tests. This marching generally required six hours a day. Flights 3 and 4 simulated the former situation. They marched three miles per day. The time required was about 1.5 hours. In order most efficiently to impose these work loads and to facilitate military control, the four flights were encamped according to the scheme shown in Figure II. 2. Flights 1 and 2 were placed 2.0 miles from the headquarters area; Flights 3 and 4, 0.5 mile. Three round trips daily resulted in 12 miles of marching for the former and 3.0 miles for the latter. The daily activity (Table II. 6) depended upon the length of time devoted to marching. Flights 1 and 2 had approximately four hours a day for camp details, recreation, or survival instruction; Flights 3 and 4 proportionately more. In order to maintain as sedentary condition as possible, the subjects of Flights 3 and 4 were strictly confined to the immediate vicinity of their camp sites. The subjects of Flights 3 and 4 showed little inclination to engage in more than light activity when they were in their camp sites; so all of the experimental subjects actually remained close to their encampments when not engaged in marching.

The subjects were under the constant supervision of the flight leaders. Each night the medical officers and the medical NCO's assigned to the flights slept in the field with the subjects.

3. Ration Controls

Twelve subjects served as ration controls. They were designated as the "FRA" subjects. Three were assigned to each of the four flights. Throughout the period of the study these men were treated in identical fashion to the experimental subjects in so far as collection of biological specimens and participation in function tests were concerned. The FRA's were always tested at the same time as other members of the flight. They were handled differently than the other subjects in two respects. First, throughout the entire period of the test they subsisted on Field Ration A, the same food as that fed the support personnel. Second, they were assigned to various duties in the headquarters area and engaged in these duties throughout the study. Most of them served as assistants in one or the other of the mess halls. Several of

TABLE II. 6

BASIC ACTIVITY SCHEDULE FOR EXPERIMENTAL PERIODS

Flights 1 and 2		Flights 3 and 4	
Time	Kind and Degree of Activity	Time	Kind and Degree of Activity
0400	Reveille	0500	Reveille
0400-0430	Clean up and void	0500-0545	Clean up and void
0430-0530	March to headquarters area	0545-0600	March to headquarters area
0530-0700	Morning routine; rest in barracks	0600-0700	Morning routine; rest in barracks
0700-0800	Morning meal	0700-0800	Morning meal
0800-0830	Sick call	0800-0830	Sick call
0830-0930	March to campsite	0830-0845	March to campsite
0930-1030	Rest and light activity about camp	0845-1145	Rest and light activity about camp
1030-1130	March to headquarters area	1145-1200	March to headquarters area
1130-1200	Rest to barracks	1200-1300	Noon meal
1200-1300	Noon meal	1300-1315	March to campsite
1300-1400	March to campsite	1315-1715	Rest and light activity about camp
1400-1600	Rest and light activity about camp	1715-1730	March to headquarters area
1600-1700	March to headquarters area	1730-1830	Evening meal
1700-1730	Rest in barracks	1830-1845	March to campsite
1730-1830	Evening meal	1845-2130	Rest and light activity about camp
1830-1930	March to campsite	2130-2200	Lights out; sleep.
1930-2000	Rest and light activity about camp		
2000-2100	Lights out; sleep.		

them worked as dieners in the chemical laboratory.

These subjects were handled as a unit during the work day, and they were under the constant supervision of two non-commissioned officers. These NCO's were charged with the responsibility for the daily conduct of the FRA subjects. The subjects were required to keep a daily record of the consumption of fluids; they drank from canteens in the same fashion as the other subjects. Every other week a dietary history was obtained for a seven-day period. On the basis of this history an estimate was made of the intake of nutrients.

During the experimental period the FRA subjects were housed in a barracks. They did not move into the field and live under conditions simulating survival.

4. Housing of Subjects

During the pre-periods the volunteer airmen and the non-commissioned officers were housed in conventional military barracks (Figure II. 3). Two barracks were used. One flight was assigned to each of the four floors. During the recovery periods, because of the epidemic which terminated the experimental period on day 9, the subjects were quartered in four barracks. Half of the flight lived on one floor and the other half on the other floor. The beds were separated by space of approximately five feet and the subjects slept alternately head to toe.

Survival was simulated during the experimental period. At that time the men were housed in pyramidal tents (Figure II. 4). Two tents were pitched for each flight. The only light allowed was that supplied by kerosene lanterns or flash lights. The men slept in standard mountain sleeping bags or under a single standard blanket (Figure II. 5). The subjects were protected from the ground by means of an air mattress (Figure II. 6).

In order to control insects the vicinity of the four camp sites was periodically sprayed with DDT.

5. Clothing of Subjects

Clothing presented no special problem during the summer test since the weather was warm throughout. The subjects wore fatigues and brogans most of the time (Figures II. 4 and II. 6). During rainy weather the standard USAF rain coat was allowed. The only special clothing issued were extra underwear and cotton socks.

The men did not sleep in their clothing. Prior to retiring they undressed down to their underwear and hung the discarded clothing up to air and dry during the night.

FIGURE II. 2. FIELD PHASE ORGANIZATION: SUMMER 1955

Figure II.2

FIELD PHASE ORGANIZATION

SUMMER 1955

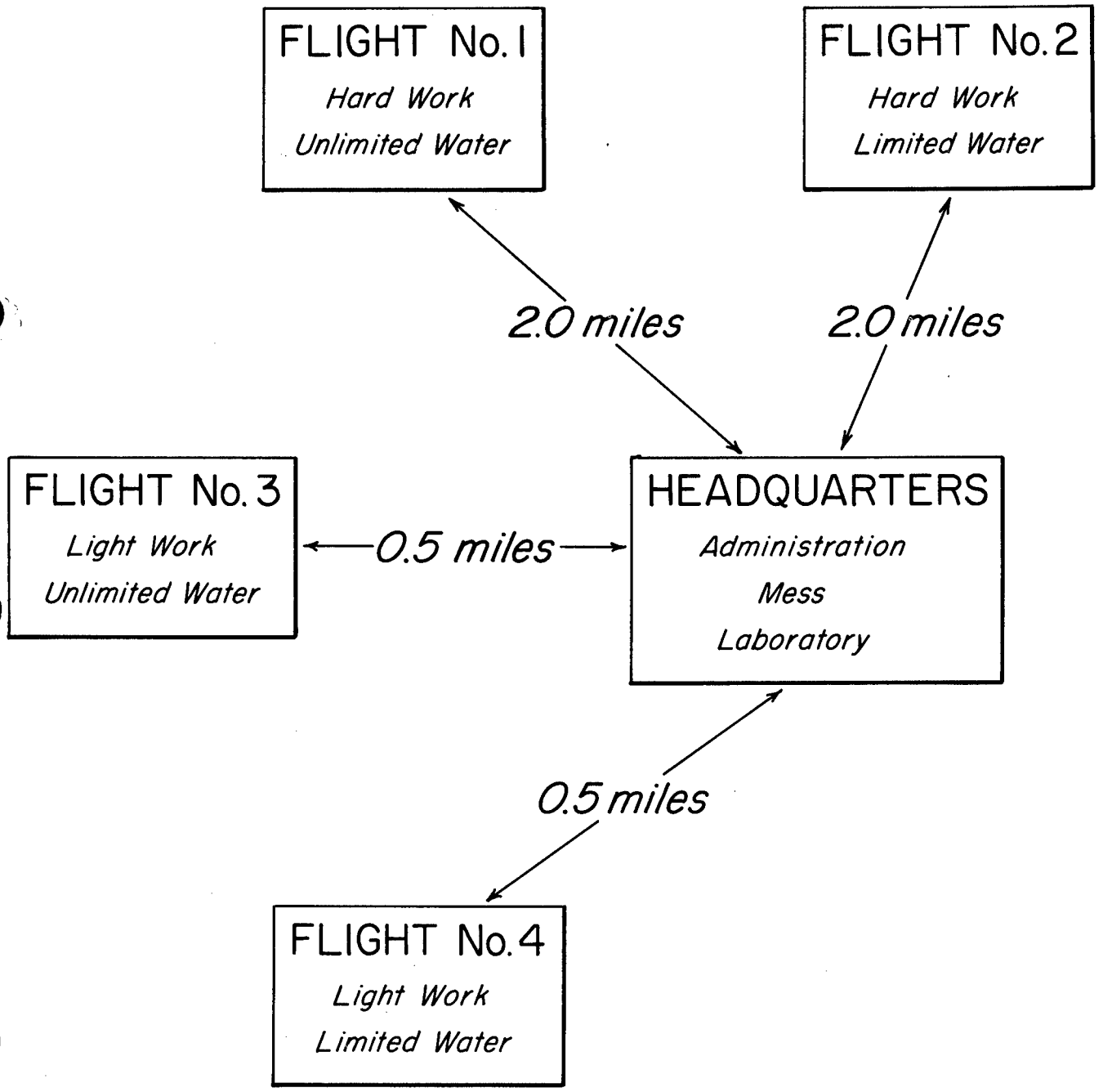


FIGURE II. 3. STANDARD BARRACKS AT CAMP ATTERBURY

FIGURE II. 4. ENCAMPMENT OF FLIGHT 2. PYRAMIDAL TENT IN BACKGROUND

FIGURE II. 5. MOUNTAIN-TYPE SLEEPING BAGS

FIGURE II. 6. SUBJECTS RESTING AT ENCAMPMENT OF FLIGHT 2. NOTE AIR MATTRESS IN FOREGROUND

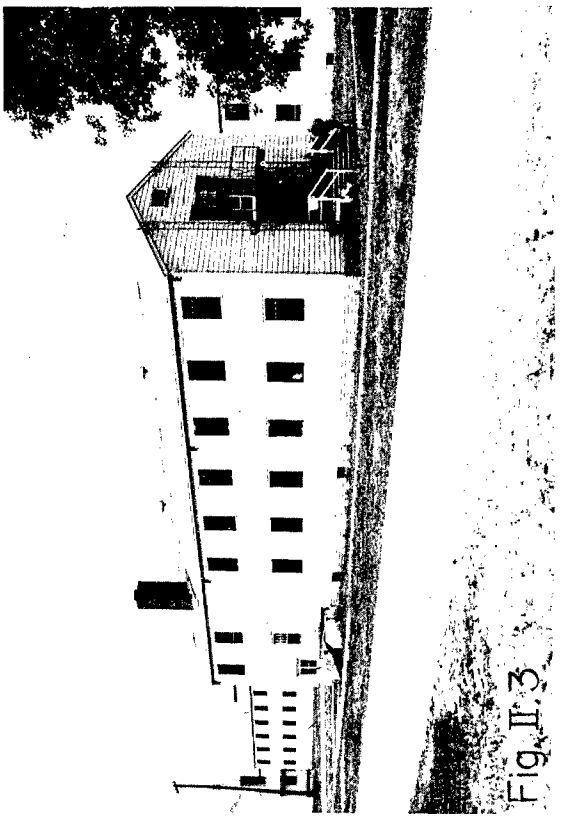


Fig. II 3



Fig. II 4



Fig. II 5



Fig. II 6

C. PROTOCOL OF COMPLETE STUDY

1. Flights of Subjects

The 100 volunteer airmen were divided into four flights which have been designated as Flights 1, 2, 3, and 4. During the experimental period the four flights were subjected to the following regimens: Flight 1, hard work, unlimited water; Flight 2, hard work, limited water; Flight 3, light work, unlimited water; Flight 4, light work, limited water (Figure II. 2). Within each flight each of the several experimental nutrient regimens under study were represented. The code numbers which the subjects drew at Chanute Air Force Base automatically assigned the men to a flight and to an experimental diet.

2. Periods of Investigation

The summer trial lasted 36 days. The pre-period was 14 days long and extended from 22 June through 5 July, 1955. The experimental period was nine days long and extended from 6 July through 14 July. The recovery period was 11 days long and extended from 15 July to 25 July. The first and second weeks of the pre-period were designated P I and P II respectively. The first week of the experimental period was designated EXP I, the 8th and 9th days as EXP II. The first three days of the recovery period was designated as REC I and the last 8 days as REC II. On 26 and 27 July the subjects ate Field Ration A. This period was designated REC III.

In the pre-period information was collected which was to be used to judge the effects of 40 experimental regimens on the volunteer subjects. This information comprised the base line from which the experimentally induced deviations were evaluated. In the experimental period the volunteers were subjected to predetermined regimens. In the recovery period subjects were rehabilitated and the rate and nature of recovery from the experimental regimens were investigated.

3. Scheduling of Scientific Procedures

An extensive battery of clinical tests was conducted on 100 subjects at approximately weekly intervals. With few exceptions the same procedures used in the winter study of 1954 were repeated (Table II. 7). The principle alteration was the elimination of the half mile run. In its place was substituted an exercise called the heat acclimatization test. This test will be described in considerable detail in a subsequent section. No determination was made of serum alkaline phosphatase. Serum urea was measured rather than serum N.P.N. The sweat and urine collected during the heat acclimatization test were subjected to a thorough chemical analysis which will be detailed below. The schedule followed for performing the several function tests is shown in Table II. 8.

4. Diurnal Cycle

In so far as it was practical all the subjects were tested at the same

time of day. The following schedule was used in all periods except EXP II. The three-hour test was conducted on Flights 1 and 3 between 0600 and 0900 hours on two consecutive days, and on Flights 2 and 4 between 0900 and 1200 hours on two consecutive days. The heat acclimatization test was performed on the afternoons of the same days used for the three-hour tests: Flights 1 and 3 between 1300 and 1500 hours and Flights 2 and 4 between 1500 and 1700 hours. In EXP II no heat acclimatization tests were performed, and Flights 1 and 2 were given the three-hour test in the late afternoon and evening. This deviation from the planned schedule was necessitated by the epidemic.

The resting metabolism test was conducted on two consecutive days. Flights 1 and 2 were tested on the first day and Flights 3 and 4 on the second day. Two whole days were devoted to this test and in the case of each subject the test was done at approximately the same time of day. The subjects in each flight were tested by the numbers, with the exception of the FRA's. One of these controls was tested in the late morning, another in the early afternoon, and a third in the late afternoon.

5. Physiological State of Subjects at Testing Times

Certain general remarks are applicable to the conditions under which the several function tests were carried out and to the status of the subjects at the time of testing.

Testing of the Subjects. The function tests, physical examinations, and body water tests were all conducted in standard barracks, which were not air-conditioned. Since most of the tests were conducted in the early morning hours and in the late afternoon, some uniformity of the ambient weather under which the subjects were tested was achieved. All biochemical work conducted in the field was also accomplished in an un-air-conditioned mess hall.

Condition of Subjects. Because of the large number of subjects it was not possible to test the men under basal conditions. All of the tests were made on the subjects at approximately the same time of day in the case of each individual. In the case of the resting metabolism test, the subjects were in a resting condition; i.e., they had been reclining at least 30 minutes. They were not, however, postabsorptive. In the case of the three-hour test the men were postabsorptive with one exception. This was the three-hour test conducted on Flights 1 and 2 in EXP II. In most cases the men were "fasting"; that is, they had had nothing to eat since 1800 hours on the day preceding the test. In the case of the water diuresis test, the men were also postabsorptive. According to the conditions which will be more fully detailed in a subsequent section, the men were not postabsorptive when they underwent the heat acclimatization test.

D. NUTRIENT MIXTURES AND DIETETIC METHODS

1. Nutrient Mixtures

As in the 1953 and 1954 studies two nutritional problems had to be solved

Table II.7

OBSERVATIONS - SURVIVAL RATION STUDY

(SUMMER 1955)

CLINICAL	METABOLIC BALANCE	BODY COMPOSITION	CLINICAL PATHOLOGY	LIVER FUNCTION
A. Physical Exam. B. Histories C. Cardiovascular *1. Lying and Standing B.P. and Pulse Rate* *2. E.K.G.* *3. Post-exercise Pulse Rate* D. Neurological Exams.	A. Intake *1. Gross* *2. Weighback* B. Balance *1. Energy* *2. Water* *3. Nitrogen* *4. Na, Ca, K* *5. Cl, P* *6. Acid-base* *7. Fat Absorption*	A. Weight B. Fat, LBM C. Water *1. D_2O Space* *2. Water Diuresis* D. Photographs E. Albright Calculations	A. Hematology B. Fecal Studies C. Blood Enzymes D. Blood Chemistry E. Urine Chemistry F. Urinalysis G. Sweat Chemistry *1. Qualitative* *2. Quantitative*	A. Serum Cholinesterase B. Serum Cholesterol C. Blood Sugar D. Clinical
ENDOCRINES	**NERVOUS SYSTEM**	**KIDNEY FUNCTION**	**G.I. FUNCTION**	**HEAT TOLERANCE**
A. Urinary 17-K.S. B. Eosinophils C. Resting M.R. D. Blood Sugar E. Serum Na, K, Ca, P F. Cholesterol G. Serum Amylase H. Urinary Creatine	A. Central *1. EEG* B. Psyche *1. Biological Time* *2. Diary* *3. Progress Notes* C. Clinical	A. Urinalysis B. Addis Count C. Creatinine Clearance D. Osmotic Clearance E. Urea Clearance	A. Fecal Weight B. Fecal Fat C. Occult Blood D. Formed Elements E. Clinical	A. Resting and Post-exercise Oral and Rectal Temperature B. Skin Temperature C. Sweat Rate D. Resting and Post-exercise Pulse Rate E. Kidney Function F. Clinical

TABLE II. 8

PROGRAM OF FIELD FUNCTION TESTS
(Summer, 1955)

Date	Day	Test Battery	Date	Day	Test Battery
6/22	1		7/13	22	
6/23	2		7/14	23	Three-Hour Test; D_2O
6/24	3	Resting Metabolism			
6/25	4	Test	7/15	24	Physical Exam
6/26	5	Three-Hour Test in A.M.	7/16	25	
6/27	6	Acclimatization Test in P.M.	7/17	26	
			7/18	27	
6/28	7	Water Diuresis Test	7/19	28	Three-Hour Test in A.M.
6/29	8		7/20	29	Acclimatization Test in P.M.
6/30	9	Resting Metabolism			
7/1	10	Test	7/21	30	Water Diuresis Test
7/2	11	Three-Hour Test in A.M.	7/22	31	Resting Metabolism
7/3	12	Acclimatization Test in P.M.	7/23	32	Test
			7/24	33	Three-Hour Test in A.M.
7/4	13	D_2O Test, Physical Exam	7/25	34	Acclimatization Test in P.M.
7/5	14	Water Diuresis Test			
7/6	15		7/26	35	Physical Exam
7/7	16		7/27	36	Final Day
7/8	17	Resting Metabolism			
7/9	18	Test			
7/10	19	Three-Hour Test in A.M.			
7/11	20	Acclimatization Test in P.M.			
7/12	21	Water Diuresis Test			

in setting up the protocol for this investigation: (1) the choice of a control diet and (2) the choice of foods from which to prepare the nutrient mixtures to be studied. The final choices were based on experience gained in the 1953 and 1954 studies. For the most part the same foods and the same nutrient mixtures were used in 1955 as in 1953 and 1954, exceptions being explained in detail below.

From the standpoint of nutrient mixtures, there were three distinct periods each with its own peculiarities; i.e., the pre-period (14 days), the experimental period (9 days), and the recovery period (13 days). In the pre-period, the subjects ate as much as they wanted of the 5-in-1 ration, with no supplements. The aim was to maintain a constant body weight. In the experimental period, the subjects were given fixed nutrient regimens (predetermined levels of caloric intake; calories provided from protein, carbohydrate, and fat; and water intake) and they were expected to consume no more or no less than that offered. During the first three days of the recovery period (REC I), the consumption of 5-in-1 ration was controlled. During the next eight days (REC II), the subjects were allowed to eat 5-in-1 ad libitum.

During the last two days (REC III), the subjects were fed Field Ration A. They were allowed to eat as much of this as they desired. The purpose of this third phase of recovery was to collect data bearing on the phenomena of "recovery diuresis" observed in the 1954 winter study (Sargent et al., 1955).

The nutrient mixtures are summarized in Table II. 9. There are shown the rations, ration components, and other foods used to formulate the several regimens, the average daily caloric intake in the various periods, the percentage distribution of calories, and the water allowances. At this point the symbols to be used throughout this report in subsequent tables and figures are also listed. The symbols have been set up so as to convey the maximum amount of information in a small space. For example, if a chart contains information on the relation between some physiological measure and a diet of pure carbohydrate, caloric intake 1000 Cal/day, water intake unlimited, the symbol would be "0/100/0 1000 U." The symbols are the same as those used in the temperate study of 1953 and the winter study of 1954, and they have been retained to facilitate comparison of charts and tables. In 1955 the nutrient mixtures and the water intakes were identical with those used in 1954.

Wherever the distribution of calories is mentioned throughout this report, it has one specific meaning: the proportion of calories provided by protein, carbohydrate, and fat, respectively. It does not refer to weight of these nutrients in the diet. It was calculated by the factors 4 Cal/gm of protein, 4 Cal/gm of carbohydrate, and 9 Cal/gm of fat.

The present investigation was not concerned with the influence of vitamins on nutrient balance or functions of systems and organs. All survival rations are supplied with vitamin capsules. It was also probable that even if vitamins had not been supplied, their absence would not have contributed materially to the physical deterioration of the castaway if he were rescued within the two-week period over which most rescue operations continue. To avoid possible changes caused by chronic hypovitaminosis, the subjects took daily one capsule which supplied them with generous quantities of known essential vitamins. Kapseals Combex with Vitamin C (Parke, Davis and Co.) were used. Each capsule contained: thiamine hydrochloride, 10 mg; riboflavin, 10 mg; vitamin B_{12}, 1 mcg; sodium panthothenate, 3 mg; niacinamide, 10 mg; ascorbic acid, 50 mg; liver concentrate (N.F.), 0.17 gm; liver fraction No. 2 (N.F.), 0.17 gm.

Ration and Ration Components of the Pre-Period. The 5-in-1 ration was used as the basic food for the pre-periods. There were several reasons for this decision. The primary one was that this particular ration offered the usual American dietary in a standard and analyzed form. A secondary reason was that the preparation of this ration would take a minimum of time, equipment, and personnel.

The 5-in-1 ration used in the 1955 tests was different than that used in previous studies. The ration represented a procurement of 1954. Menu #2 was omitted from the original order. No supplements were used, but fresh coffee, tea, and evaporated milk was substituted for comparable items in the

TABLE II.9

EXPERIMENTAL NUTRIENT MIXTURES

(SUMMER 1955)

EXPERIMENTAL RATIONS AND OTHER FOODS USED	CALORIC INTAKE	% DISTRIBUTION OF CALORIES	SYMBOLS USED IN TABLES AND FIGURES
Pre-Period: 5-in-1	3450	15%P/51%CHO/34%F	PRE, Day 0
Recovery: 5-in-1	4950	16%P/52%CHO/32%F	REC
Negative Control: Starvation	0		ST 0
Spice Drops, Starch Jelly Bar, Hard Candy	1000 and 2000	0%P/100%CHO/0%F	0/100/0 1000 0/100/0 2000
Saltines, Oleomargarine	1000 and 2000	3%P/17%CHO/80%F	2/20/78 1000 2/20/78 2000
Meat Bar	1000 and 2000	30%P/0%CHO/70%F	30/0/70 1000 30/0/70 2000
Meat Bar, 5-in-1 Crackers, Raisins, Catsup, Jam *(Positive Control at 3000 Cal/day)*	1000, 2000 and 3000	14%P/52%CHO/34%F	15/52/33 1000 15/52/33 2000 N 3000
Ration Control: Field Ration A	3680	14%P/45%CHO/41%F	FRA, CONTROL
Water Limited: 910 ml/day			L
Water Unlimited: *ad libitum*			U

ration. Salt and sugar packs were withdrawn and Sucaryl (Abbot) was substituted. The subjects were allowed two tablets per cup of liquid. This allowance was followed during all phases of the study. These measures were taken in order to allow an accurate estimate of the intakes of NaCl and carbohydrate. In order to insure constancy of body weights during the pre-period, any subject could have seconds of specific items: crackers, jam, and milk for cocoa, tea, and coffee. There was no restriction of fluid intake.

Rations and Ration Components of the Experimental Periods. Twenty different nutrient combinations were imposed during the two experimental weeks. Of the 88 subjects 70 completed the full period of their assigned regimens (Table II. 10). Table II. 11 gives the individual data for the 18 men who were not on their assigned regimen for the full period. The reasons for the men being removed are given in the table. It is evident that the majority were taken off the diets early because of infectious diseases which required air evacuation and special medical treatment not available at Camp Atterbury. One subject--originally designated as No. 30--became ill in the indoctrination period and was unable to participate as a subject. He was evacuated to Fort Benjamin Harrison for treatment of a neurodermatitis. Subject No. 93 was transferred by lot to his slot. Subject 30 returned to Camp Atterbury in Rec I and was utilized as an FRA. His code number was 102.

In addition, to a set pattern for clinical testing when a subject came off early, there was a predetermined pattern also for nutritional rehabilitation. In so far as possible this pattern was identical to that used in 1954. A number of subjects, however, because of their illness had to be confined to Sick Bay or air evacuated for relatively long periods of time. In these cases, in order not to lose valuable experimental information, the men were placed on Field Ration A for the duration of the study.

The individual experimental regimens have been described in detail by Sargent et al., 1955. In the 1955 summer test the regimens used were identical with those described in that report.

Rations and Ration Components of the Recovery Periods. Each of the three recovery periods was handled differently and they will be described separately.

Recovery I: On 14 July after Flights 1 and 2 had completed the three-hour test, the subjects were given their regular evening meal plus a supplement of two ounces of sucrose. Unrestricted water allowances were begun. On this day Flights 3 and 4 were maintained on their experimental regimens. On 15 July the subjects of Flights 1 and 2 were given a breakfast which consisted of two ounces of sucrose and water, tea, or coffee ad libitum. Flights 3 and 4, postabsorptive, underwent the three-hour test in the morning. At noon this day all volunteer subjects began rehabilitation. The basic ration was 5-in-1 without supplements. The plan followed for this three-day period was identical with that described by Sargent et al. (1955: Table II. 16, p. 36).

Recovery II: During this period the subjects were allowed to eat 5-in-1

TABLE II. 10

NUMBER OF SUBJECTS AND DURATION OF EXPERIMENTAL REGIMENS

Experimental Regimen		Flight 1		Flight 2		Flight 3		Flight 4	
		No.	Days	No.	Days	No.	Days	No.	Days
ST 0		1	9	4	9	5*	9	2	9
0/100/0	1000	1	9	2	9	2	9	2	9
0/100/0	2000	2	9	2	9	2	9	1	9
2/20/78	1000	1	9	2	9	1	9	2	9
2/20/78	2000	1	9	2	9	2	9	2	9
15/52/33	1000	2	9	1	9	2	9	2	9
15/52/33	2000	1	9	1	9	2	9	2	9
15/52/33	3000	2	9	2	9	2	9	0	9
30/0/70	1000	2	9	1	9	1	9	2	9
30/0/70	2000	2	9	2	9	2	9	1	9
Control		3	9	2	9	3	9	3	9

*See Subject No. 54. Table II. 11

TABLE II. 11

SUBJECTS FAILING TO COMPLETE EXPERIMENTAL PERIOD

Subject Code No.	Experimental Regimen			Work	Days on Regimen	Remarks
2	ST 0 U			Hard	4	Infectious disease (AE)*
3	ST 0 U			Hard	6	Exhaustion
4	ST 0 U			Hard	6	Exhaustion
5	0/100/0	1000	U	Hard	8	Infectious disease (AE)
13	2/20/78	1000	U	Hard	7	Infectious disease (AE)
16	2/20/78	2000	U	Hard	7	Infectious disease (AE)
20	15/52/33	2000	U	Hard	8	Infectious disease (AE)
31	30/0/70	1000	L	Hard	5	Exhaustion
40	15/52/33	1000	L	Hard	0	Infectious disease
41	15/52/33	2000	L	Hard	2	Infectious disease (AE)
54	30/0/70	1000	U	Light	0	ST 0, 9 days
58	2/20/78	1000	U	Light	0	Infectious disease
68	ST 0 L			Light	6	Exhaustion
70	ST 0 L			Light	6	Exhaustion
74	0/100/0	2000	L	Light	3	Anhidrosis; water "U" 6 days
77	30/0/70	2000	L	Light	2	Expired
87	15/52/33	3000	L	Light	3	Infectious disease (AE)
88	15/52/33	3000	L	Light	5	Infectious disease (AE)

*AE = Air evacuation

ration ad libitum. During the first day or two of this period there were no occurrences of acute nausea or vomiting. The absence of gastrointestinal disturbances was attributed to the controlled realimentation.

Recovery III. For the last two days of the period of study at Camp Atterbury, the subjects were allowed to eat Field Ration A. This procedure was adopted so that further information could be collected concerning the "recovery diuresis" described by Sargent et al. (1955). For these two days the subjects were allowed to eat all the Field Ration A they desired. No records were kept of the food intake, but a record was maintained of all liquids consumed.

2. Preparation of Food

The methods employed in the 1954 study were used again in 1955. Individual portions were packaged in aluminum foil trays, paper cups, and plastic wrap.

The actual preparation differed in a few instances because the same location was used for the complete study and because some ration items were changed. The most helpful change was the addition of the ten extra subjects (FRA's) as normal controls. These men worked alternately in each mess hall, and became well trained in the food preparation procedures. In 1954 a new "KP" group had to be trained every day.

To facilitate the food service, two mess halls were used. The mess sergeant, with three cooks and five FRA's, operated the support mess. He supervised the cook who worked with the three University dietitians in the subject mess. In addition, two NCO flight leaders and five FRA's were assigned to the subject mess.

Before food service began, the dietitians instructed the two NCO's and cook on the procedures of the food preparation and service. The NCO in charge of all ten FRA's was also in charge of the food preparation and the operation of the mess hall during meals. The cook was in charge of the operation of all kitchen equipment, making the coffee and tea, heating the food for each meal, and supervising the cleaning of the mess hall. When time permitted he helped with the food preparation.

Although the NCO in charge had never worked with foods before, he understood the need for the assembly-line production methods worked out by the dietitians (Figure II. 7). Within two days he could supervise the whole daily schedule of food production and service. This gave the dietitians free time to keep up with the paper work on individual food intakes. In addition the two assistant dietitians helped with the food production, and each was in charge of one meal a day. She helped each flight leader record the food taken by the men in his flight. In this way at least one dietitian was present at each stage of food preparation and service to answer questions and to help prevent errors.



FIGURE II. 7. PREPARATION AND PACKAGING OF FOOD. LEFT TO RIGHT: A/3C T. V. MOORE, JR., A/1C H. J. NEUFER, JR., NCO1C, AND A/3C M. STEWART.

Pre-Periods-Recovery Periods. A new pack of 5-1 ration was used for the pre-period and recovery period. This 1954 pack contained different menus and some completely new foods. In Table II. 12 the foods are listed by menu, as packaged. They were not used in this way, but were combined to give fourteen different daily menus. Sample menus are given in Table II. 13. These menus were prepared in advance of the trial so that daily work sheets could also be made out in advance.

As an example, for Day P-4, the intake forms (Sargent et al., 1955: Appendix VI) were typed in advance to fit the menu. At Atterbury the quantities needed and portion size were filled in by the dietitians during Day P-2 to leave on clipboards for use the next morning. When the NCO opened the mess hall, he had that day's work schedule ready. The stock list gave the number of cans of each food to be obtained from the storeroom. The work sheet gave the number of individual portions, the gram weight of each portion, and the kind of container needed. By the end of Day P-3 the food for P-4 was packaged and in the refrigerator, ready to be heated and served.

There were two main differences in food preparation between 1954 and 1955. The food analysis of the newer 5-in-1 pack had been changed for the

TABLE II. 12

THE FOUR MENUS OF THE 5-IN-1 RATION
(Procurement of July, 1954)

Menu #1	Menu #3	Menu #4
Hamburgers	Kidney beans-ham	Meat Balls--spaghetti
Ham and eggs	Hamburgers	Pork and gravy
Beef and gravy	Luncheon meat	Pork sausage links
Peas	Vegetable soup	Peas
Tomatoes	Applesauce	Corn
Shoestring potatoes	Pineapple	Apricots
Peaches	Cheese	Applesauce
Cherries	Fruit cake	Cheese
Pound cake		Peanut butter
Cheese		Cookies
Peanuts		

Menu #5	Items in All Menus
Pork and beans	Bread, white
Beef and vegetables	Crackers
Bacon	Jam
Chicken and gravy	Dried milk
Lima beans	Soluble coffee
Tomato soup	Cocoa
Shoestring potatoes	Sugar
Pears	Candy
Pound cake	Gum
Pecan roll	
Peanut butter	

vegetables to give the values of the solids only. This meant that vegetables could be drained, a procedure that helped both preparation and palatability. By experimentation beforehand it was found that 10 ml of vegetable liquid added to the individual container after weighing, would be enough to moisten the food during oven heating, leaving little or no residue. The second difference was that no special recipes were used. There was not the equipment available. Then, too, it was found from the year before that these non-veterans of 18 years had no objections to foods like "Spam". In fact, this luncheon meat was actually a favorite dish, with the portion size of one-half a can per man. The new packs of beef, hamburger, and pork contained much less fat, making them more edible without a special recipe.

In order to have enough food on hand for the recovery period, single portions of foods like meat, vegetable, fruit, and dessert were issued during the pre-period. Extra calories could be obtained from crackers and jam offered ad libitum. Approximately 1100 calories could be added by eating two crackers with a 50-gram portion of jam at each meal. (One subject consistently ate six at each meal.) During the recovery period, the meat, fruit, and desserts were prepared in double quantity. By keeping the same portion size, no food was wasted by those who wanted one serving, permitting others to have two, three,

TABLE II. 13

SAMPLE MENUS: PRE-PERIOD

MORNING	NOON	NIGHT
P-1 Ham and eggs, jam, crackers, coffee, cocoa	Beef-vegetables, corn, cheese, pound cake, jam, crackers, coffee, cocoa, tea	Luncheon meat, baked beans, peaches, tootsie roll, jam, crackers, coffee, cocoa, tea
P-2 Pork sausage, jam, crackers, coffee, cocoa	Beef and gravy, shoestring potatoes, peas, fruit cake, jam, crackers, coffee, tea, cocoa	Spaghetti-meat balls, cheese, pineapple, cookie, fudge bar, jam crackers, coffee, tea, cocoa
P-3 Pork sausage, jam, crackers, coffee, cocoa	Chicken and gravy, shoestring potatoes, lima beans, pound cake, jam, crackers, coffee, tea, cocoa	Hamburgers, corn, peanut butter, pears, caramel bar, jam, crackers, coffee, cocoa, tea
P-4 Ham and eggs, jam, crackers, coffee, cocoa	Pork and gravy, shoestring potatoes, peas, pecan roll, jam, tea, crackers, coffee, cocoa	Kidney beans-ham, applesauce, peanut butter, tootsie roll, jam, crackers, coffee, cocoa, tea
P-5 Bacon (44 men), jam, crackers, coffee, cocoa, (Flights 3,4)	Beef and gravy, shoestring potatoes, corn, peaches, jam, crackers, coffee, tea, cocoa (cheese, pound cake extra--Flights 1, 2)	Beef-vegetables, lima beans, apricots, chocolate discs, jam, crackers, coffee, cocoa, tea (peanut butter, cookie, extra--Flights 1, 2)
P-6 Bacon (44 men), jam, crackers, coffee, cocoa, (Flights 1, 2)	Hamburgers, shoestring potatoes, peas, pineapple, jam, crackers, coffee, cocoa, tea, (peanut butter, pound cake extra--Flights 3,4)	Luncheon meat, baked beans, pears, fudge bars, jam, crackers, coffee, cocoa, tea (cheese, cookie, extra--Flights 3,4)
P-7 (No breakfast)	Pork and gravy, shoestring potatoes, tomatoes, cherries, cheese, peanuts, jam, crackers, coffee, cocoa, tea	Spaghetti-meat balls, lima beans, peanut butter, fruit cake, jam, crackers, coffee, cocoa, tea

or even four servings. For vegetables, the portion size was increased by about one-third. Single helpings were usually all that were eaten.

Experimental Period. The preparation of the special diets was simpler and less time consuming than the 5-in-1 ration. However, a dietitian supervised the preparation of each diet, and saw that the correct diet letter and subject numbers were on each container. Three equal units were prepared 24 hours in advance for each man each day. They were stored or refrigerated until the following day's meals.

Every effort was made to suit the diets to individual taste. Some diets could be varied by temperature, others by adding water, or, as in the all-carbohydrate diet, by a choice of components. All of these variations could have been managed in a true survival situation. They helped with the acceptibility of the diets, which we were testing as mixtures rather than standard survival rations.

High carbohydrate (0/100/0): The gumdrops required no preparation, and, as in 1954, they were placed in the aluminum trays, sealed, and labeled.

High fat, low protein, low carbohydrate (2/20/78): The cracker and oleomargarine sandwiches were wrapped in labeled Saran. During the hot weather trial, the subjects preferred to have the diet chilled in the refrigerator. (During the cold weather phase the subjects preferred them warmed in the oven.)

High fat, high protein, low carbohydrate (30/0/70): The meat bar could be eaten as it came in the package with a choice of temperature. Ordinarily it was served at room temperature, but by mistake one day it was warmed in the oven. One flight preferred it that way and ate it the rest of the time warmed. The other variation was a choice of adding water, and heating. In 1954, the lack of oven equipment meant that it had to be hydrated and cooked in one large pot. In 1955, the stack ovens permitted hydrating each package by adding a weighed quantity of water to the weighed crumbled meat bar. When it was sealed and heated in the oven, the small amount of water steamed and softened the meat bar.

Normal mixture (15/52/33): Except for the meat bars in this diet, which could be eaten in any of the four ways listed for the diet above, the foods were prepared and served without variation. The crackers, jam, catsup, and raisins were packaged as during the pre-period.

Water (U and L): Fresh canteens were issued each morning and those from the previous day were turned in for weighbacks (Figures II. 8 and II. 9). Those on limited water started out with just this one canteen for the day. Those on unlimited water could have their empty canteens refilled whenever desired by their flight leader, who recorded them.

3. Meal and Service

The basic methods of the 1954 winter study were used again in 1955. Because the same mess hall was used for the whole study, the feeding routine was standard during all three periods.

In general, the men marched by flights to the mess hall, went through the line by number to receive their food, and had the food recorded by the flight leader and dietitian before going to their tables (Figure II. 10). At the completion of the meal, the food containers on each tray were weighed and recorded. As the result of experience gained from the 1954 study, the dietitians helped with weighbacks to train the subjects during the first two days. At the end of the fourth day, the subjects and flight leaders were able to complete the procedure without supervision (Figure II. 11). By the end of each day all meal sheets were checked, and amounts of each food eaten by each subject calculated. In this way, errors or omissions could be found and corrected while subjects and flight leaders could remember details. As in 1954, fresh canteens and vitamins were issued daily at breakfast.

Pre-Periods I and II. The first two weeks were similar in every respect to the 1954 study. Three meals were offered for ad libitum feeding, with extra helpings available on crackers and jam and liquids. On testing days, when certain flights had only two meals, extra food was offered to help make up the caloric deficit. (Table II. 13: P-5 and P-6.)

Experimental Period I and II. The messing procedures of the pre-period were continued. Because the diets had to be eaten completely, the flight leaders made a visual check of each tray to see that this had been done. During the first few days, if some food was left, a weighback was recorded. This happened in only a few cases, for most eating problems could be handled by either the military or university personnel.

In one case every kind of persuasion was used without success. Although the subject said he would eat another diet, without meat bar, a change could not be permitted for reasons of morale. This subject actually became a starvation subject.

Unlike the 1954 study, the subjects on starvation preferred to remain outside the mess hall, in a supervised group, to drink their tea or coffee. All the other subjects remained in the mess hall.

Recovery Periods I and II. During the first three days of the recovery period, the foods were limited to prevent overeating. Table II. 14 shows how the menus were arranged to permit feeding at three different calorie levels. Those who had been on the starvation diet could have approximately 1000, 2000, and 3000 on the three successive days, while those who had been on 1000 calorie diets had approximately 1500, 2500, and 3500 calories. They were not required to eat all of the food offered, but could not eat ad libitum until the fourth day. After the first three days (REC I) the menus (Table II. 15) were very similar to those of the pre-period. During REC II the subjects took only the foods they wished to eat and could come back for extra helpings as often as desired. The canteens of water were exchanged each morning as in previous periods.

4. Calculations

Forms for Recording Original Data and Calculations. A number of special

FIGURE II. 8. CANTEEN EXCHANGE. LEFT TO RIGHT: A/3C J. LEE AND A/3C J. L. HORNE

FIGURE II. 9. MEASUREMENT OF UNUSED WATER MISS M. R. HUNTWORK, ASSISTANT DIETITIAN.

FIGURE II. 10. SUBJECTS OF FLIGHT 1 IN MESS HALL.

FIGURE II. 11. WEIGH-BACK OF UNEATEN FOOD. LEFT TO RIGHT: T/SGT R. E. MILLER AND A/3C D. P. THOMAS.



Fig. II. 8

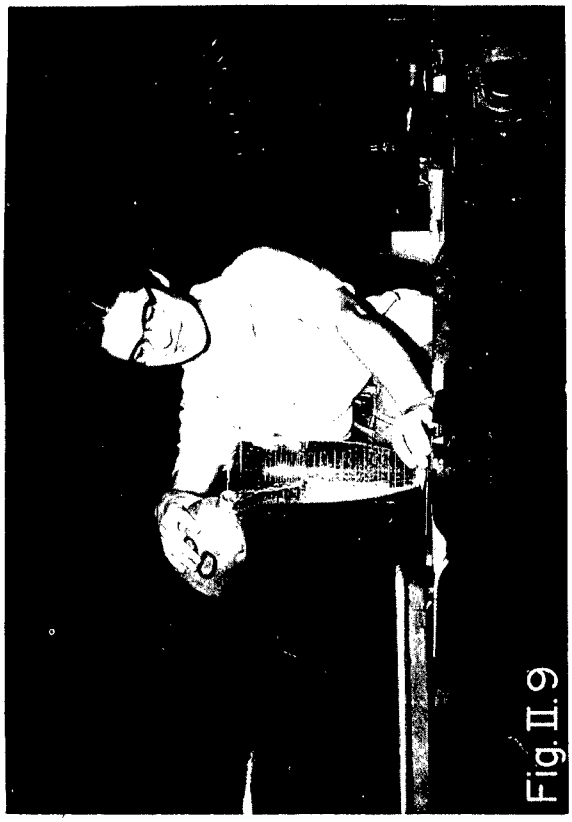


Fig. II. 9



Fig. II. 10



Fig. II. 11

TABLE II. 14

MENUS--RECOVERY PERIOD I (Controlled)*

	A.M.	NOON	P.M.
R-1			
(STO)**	No breakfast	Chicken noodle soup, 1 cracker, jam, peaches	Spaghetti-meat balls (200gm) 1 cracker, jam
(1000)	No breakfast	Chicken noodle soup, 1 cracker, jam, peaches	Spaghetti-meat balls (200gm) 1 cracker, jam, pineapple
(2000, 3000)	No breakfast	Beef-vegetables (250gm) 2 crackers, jam, peaches	Spaghetti-meat balls (300gm) 2 crackers, jam, pineapple
R-2			
(STO)	Ham & eggs 2 crackers, jam	Lunch meat (100gm) Peas, 1 sl. bread, jam	Beef-vegetables (250gm) 1 sl. bread, jam, cherries
(1000)	Ham & eggs 2 crackers, jam	Lunch meat (100gm) Peas, 1 sl. bread, jam, apricots	Beef-vegetables (250gm) 1 sl. bread, jam, cherries
(2000, 3000)	Ham & eggs 2 crackers jam	Lunch meat (175gm) Peas, 2 sl. bread, jam, peanut butter, apricots	Beef-vegetables (250gm) 2 sl. bread, jam, cherries, pound cake
R-3			
(STO, 1000)	Ham & eggs 2 sl. bread, jam	Spaghetti-meat balls 2 sl. bread, jam, pears	Kidney beans-ham 2 crackers, jam, pineapple
(2000, 3000)	Ham & eggs 2 sl. bread, jam	Spaghetti-meat balls 2 sl. bread, jam, cheese, pears	Kidney beans-ham 2 crackers, jam, pineapple, cookie

*Coffee, tea, and cocoa at all meals.
**Refers to caloric content of preceding experimental nutrient mixture.

TABLE II. 15

SAMPLE MENUS--RECOVERY PERIOD II (ad libitum)

A.M.	NOON	P.M.
R-4		
Sausage, cereal, bread, jam, coffee, cocoa	Hamburgers, shoestring potatoes, corn, cheese, pecan roll, candy, bread, jam, coffee, tea, cocoa	Chicken-gravy, peas, peanut butter, peaches, cookies bread, jam coffee, tea, cocoa
R-5		
Lunch meat, (40 men) bread, jam, coffee, cocoa (Flights 3, 4)	Beef and gravy, limas, apricots, cookies, candy, bread, jam, coffee, tea, cocoa	Kidney beans-ham, tomato soup, cheese, applesauce, fruit cake, bread, jam, coffee, tea, cocoa
R-6		
Lunch meat (40 men) bread, jam, coffee, cocoa (Flights 1, 2)	Chicken-gravy, shoestring potatoes, pound cake, peanut butter bread, jam, coffee, tea, cocoa	Spaghetti-meat balls peas, pineapple, cheese, cookie, candy, bread, jam, coffee, tea, cocoa
R-7		
No breakfast (All flights tested)	Hamburgers, shoestring potatoes, baked beans, cheese, fruit cake, candy, bread, jam, coffee, tea, cocoa	Lunch meat, limas, applesauce tomato soup, peanut butter, pecan roll, bread, jam, coffee, tea, cocoa

forms were devised for specific use in this study. They ensured reliability and facilitated the thousands of arithmetical calculations required in the breakdown of the daily food intake into its several nutrients. Sample forms different from those used in the temperate study of 1954 are collected in Appendix VI. The three forms below served for all daily data collection.

Daily menu sheet: The food each day was listed in three-meal menu forms. Used in duplicate, this form served as (1) a work sheet for food preparation, when number and size of portions were filled in and (2) a guide for food service for cook and NCO and a place for dietitians to note exact menu served.

Stockroom list: The foods from all the rations were listed, with a space in front of each one where the numbers of cans needed each day could be noted.

Flight intake sheets: Each of the four flights had a different color in-

take sheet. A new sheet was used for each meal. On this form were recorded the number of servings taken by each subject and the weigh-back of each food container. From these data sheets, analyses could be made. Two forms were used for this.

Individual daily dietary analysis form: From the intake sheets the amounts of each food eaten were listed as grand totals for the day. For example, several figures for the intake of crackers were totaled and listed as one value. A vegetable, such as peas, if used plain and in a recipe, was listed as one total figure. The data on the intake sheets and the analysis sheets were double checked for accuracy. On each of these three forms the dietitians did all of the computing and transferring of data.

After the total amount of each item consumed had been listed on the analysis sheet, clerical help was used to copy the analysis from specially prepared food tables and to summate the daily intake. The dietitians checked each total for accuracy, using the factors of 4-9-4 Cal/gm of carbohydrate, fat, and protein, respectively, to check against total Calories.

Individual summary sheets: The totals of each day's intake for each diet period were listed on this form. From these figures the dietitians made the averages for any period under consideration.

Analytical tables prepared for the 1953 study were used and expanded in 1954 and 1955. The analysis of each food was made for each gram from 1 gram to the largest size portion eaten, e.g., 200 gm or 500 gm. Thus there was no need to round-off intake figures for easy computation. For the candy bars and other things eaten, like crackers, cake, etc., standard figures were used, with gram by gram analysis made out for 1 gm to the single weight of each piece, to allow for partially eaten foods. The data came from the following sources:

1. Q.M. Food and Container Institute: Record of Nutritive Values. Ration Small Detachment, 5-in-1. MIL-R-10754 #A#(QMC), 22 Oct. 1953, w/ Amendment 2, 20 July 1954. (Summary sheet, Menu #1, Menu #2, Menu #3, Menu #4, Menu #5). Chicago, Ill. 12 November 1954.

2. Q.M. Food and Container Institute: Tables of Nutritive Value of Ration Items. April 1951.

3. Bureau of Human Nutrition and Home Economics, U. S. Dept. Agriculture: Table of Food Composition for the Armed Forces. Washington, D. C. (undated but current).

4. Bowes, A deP., and Church, C. F.: Food Values of Portions Commonly Used. 7th Ed. College Offset Press, Philadelphia, Pa., 1951.

The data published by the governmental agencies (1, 2, and 3) were used in calculations of the components of the 5-in-1 ration and the components of the survival rations. The data available were for calories, water, protein, carbohydrate, fat, and calcium. Since it was also necessary to know the intake of

sodium, potassium, chloride, and phosphorus, this information was obtained by direct chemical analyses of representative samples of the several components and local water supplies (see Tables II. 16 and II. 17 below). The data of Bowes and Church (Ref. 4) and information obtained by our own chemical analyses provided values for special foods (e.g., raisins and catsup) and for all the dietary intakes of men subsisted on Field Ration A. The information contained in the paper by Bills et al. (1949) provided valuable reference for checking the data we obtained on the electrolytes in food.

5. Chemical Analysis of Foods

Since a new procurement of the 5-in-1 ration was used in the summer tests, it was necessary to re-analyze the individual components. The chemical procedures followed were the same as those described in WADC TR 53-484, Part 2. Data for sodium, potassium, chloride, and phosphorus content of items in Menus 1, 3, 4, and 5 are summarized in Table II. 16.

Special foods were the same as those employed in the 1954 winter test and the chemical data have been detailed in previous reports (Sargent et al., 1954, 1955). There was one exception: Evaporated Pet Milk. Our analysis indicated the following concentrations of minerals: sodium, 96 mg/100 ml; potassium, 317 mg/100 ml; phosphorus, 206 mg/100 ml, chloride, 169 mg/100 ml. Values for nitrogen and calcium were taken from Bowes and Church (Ref. 4 above).

Three samples of tap water were taken. The results (Table II. 17) indicate a sodium content of 6 mg/1000 ml; potassium, 2 mg/1000 ml; and calcium, 55 mg/1000 ml. Chloride and phosphorus were not present in significant amounts.

E. COLLECTION AND PRESERVATION OF SPECIMENS

Three types of specimens were collected: (1) food, (2) excreta (urine, feces, sweat, and vomitus), and (3) blood. Each was handled in a standard fashion.

1. Food

Five-In-One. Since a new procurement of the 5-in-1 ration was used, it was necessary to reanalyze all of the components. One box of each menu (Nos. 1, 3, 4, and 5) was set aside for subsequent chemical study. No special methods of preservation were required, for chemical analysis was begun immediately after the components were opened.

Other Ration Components and Commercial Foods. Most of the components of the experimental diets were the same as those used in the winter study of 1954. Since most of the items were packaged, no special methods of preservation were required. Chemical analyses were done when other analytical data from other sources were not available.

2. Urine

Twenty-Four Specimens. A 24-hour specimen of urine was collected from each

TABLE II. 16

CHEMICAL ANALYSIS OF 5-IN-1 FOOD ITEMS
(Procurement of 1954)

Food	Sodium mg Na/100 gm	Potassium mg K/100 gm	Chloride mg Cl/100 gm	Phosphorus mg P/100 gm
Menu 1				
1. Cherries	16	195	39	27
2. Peaches	15	159	0	25
3. Tomatoes	14	258	34	29
4. Hamburger, Type I	732	445	817	203
5. Ham and Eggs	867	275	1124	192
6. Beef and Gravy	584	265	726	180
7. Bread	391	217	584	101
8. Crackers	1063	117	1494	147
9. Cereal Bar, Class 8	414	285	942	211
10. Pound Cake	274	63	335	122
11. Shoestring Potatoes	1490	1582	2483	197
12. Cheese	1620	73	1438	658
13. Jam	4	83	44	10
14. Dry Cream	569	99	0	376
15. Peanuts	907	670	1072	438
16. Cocoa	755	1830	1181	891
17. Chewy Chocolate Roll	140	147	260	86
18. Peas (solids)	279	110	319	81
Menu 3				
19. Applesauce	13	44	35	15
20. Pineapple	7	69	0	11
21. Kidney Beans and Ham	372	316	527	153
22. Lunch Meat	1180	241	1661	217
23. Cereal Bar, Class 6	736	442	1046	392
24. Fruit Cake	188	154	332	111
25. Vegetable Soup	761	274	1330	64
Menu 4				
26. Apricots	12	147	22	20
27. Spaghetti and Meat Balls	727	199	1142	114
28. Pork and Gravy	644	299	785	179
29. Cereal Bar, Class 5	846	560	1067	361
30. Cookies	330	71	234	89
31. Peanut Butter	462	704	546	427
32. Chocolate Fudge Bar	57	234	34	129
33. Corn (solid)	192	161	368	89
34. Sausage Links (solids)	1090	226	1291	153

TABLE II. 16 (CONTD.)

FOOD ITEMS
(Procurement of 1954)

	Sodium mg Na/100 gm	Potassium mg K/100 gm	Chloride mg Cl/100 gm	Phosphorus mg P/100 gm
Menu 5				
35. Pears	6	68	40	13
36. Beans and Pork	207	334	394	143
37. Bacon Sliced	2118	138	2924	64
38. Beef and Vegetables	514	249	717	109
39. Chicken and Gravy	484	99	546	84
40. Pecan Roll	313	92	272	131
41. Tomato Soup	652	151	1108	76
42. Chocolate Bar	79	365	100	220
43. Caramel Nougat Bar	165	189	190	126
44. Lima Beans (solids)	295	280	220	101
45. Raisins	43	815	0	133

TABLE II. 17

CHEMICAL ANALYSIS OF TAP WATER FROM CAMP ATTERBURY, INDIANA.

	Concentration, mg/100 ml				
Specimen	Sodium	Potassium	Calcium	Phosphorus	Chloride
1	0.36	0.09	4.7	0	0
2	0.64	0.23	5.5	0	0
3	0.68	0.25	6.2	0	0

of the 100 volunteer subjects according to the technique described by Sargent et al. (1955).

Handling the 24-hour specimens in the field: The daily specimens were turned in each morning at the laboratory. The volume was measured and recorded (Figure II. 12). Ten per cent of the daily volume was transferred to a gallon-sized brown bottle containing five ml of glacial acetic acid (Figure II. 13). Five-day pools were prepared; specimens collected on the days of the three-hour test, heat acclimatization test, and water diuresis test were omitted from the pool.

If a subject was taken off the experimental regimen early, the pool was closed and a new pool started. The latter was closed at the end of the regular pool-period; thus two pooled specimens were prepared during the period when a subject discontinued a diet early.

Because of the epidemic which abruptly terminated the experimental period, the regular pooling scheme broke down. EXP II was represented by a two-day pool; REC I, by a two-day pool; and REC II, by a four-day pool.

The pooled specimens were stored in an ice box maintained at about 40°F un-

til the period was completed. At this time the specimens were diluted to 3500 ml with distilled water and thoroughly mixed. Two one-ounce aliquots were taken in brown screw-capped bottles. The aliquots were packed for shipment to the University of Illinois and stored under dry ice in an insulated chest. Periodically the specimens were transported to the University either by air or by USAF truck transportation. The specimens were kept in dry ice during shipment. On arrival at the University the specimens were checked for breakage and then transferred to a cold room in the Horticulture Field Laboratory where they were maintained at -25°F until the chemical analyses were performed. During chemical analysis, the specimens were maintained in a refrigerator at about 4°C.

Other aliquots were also made from the raw 24-hour urinary specimens. (1) One-ounce aliquots were taken daily in brown screw-capped bottles from Day 13 through Day 25; one aliquot was prepared for each subject. The aliquots were handled in an identical fashion to that detailed above. (2) At times when deuterium oxide was administered, a special procedure was followed. Two four-ounce aliquots were prepared from the raw 24-hour urine passed during the day prior to the test. On the day of the test, two 12-hour specimens of urine were collected. From each raw specimen two additional four-ounce aliquots were taken. The remaining urine was pooled and a 10% aliquot was added to the pool. The raw aliquots were handled after the manner already described. This procedure was modified somewhat in the experimental period; the details will be discussed below in the section dealing with D_2O test.

Three-Hour Test Specimens. The timed urine of this test was taken to the laboratory. The volume was measured. A ten-ml aliquot was taken for the Addis Count and nine ml (a supernatant) was returned to the specimen. All specimens with volumes less than 300 ml were diluted to 300 ml. Three one-ounce aliquots were taken in screw-capped brown bottles. The aliquots were treated in the usual way.

Exercise and Post-Exercise Specimens. Two timed urines were collected during the afternoon of the heat acclimatization test: the exercise and post-exercise specimens. One one-ounce aliquot was taken from each and subsequently treated in the usual way.

3. Feces

Fecal specimens were collected from the 100 subjects in the same manner as in the 1954 winter test (Sargent et al., 1955). The periods were marked as usual with carmine and the pool-period was identical with that described for the 24-hour urine (vide supra). The paraffin cartons containing fecal specimens

FIGURE II. 12. MEASURING 24-HOUR URINARY VOLUME. LEFT TO RIGHT: A/2C R. A. BASS AND T/SGT K. M. SPRINGER.

FIGURE II. 13. POOLING ALIQUOTS. LEFT TO RIGHT: MR. N. MELTZER, MR. S. MIZELL, AND MR. R. ADAMS.

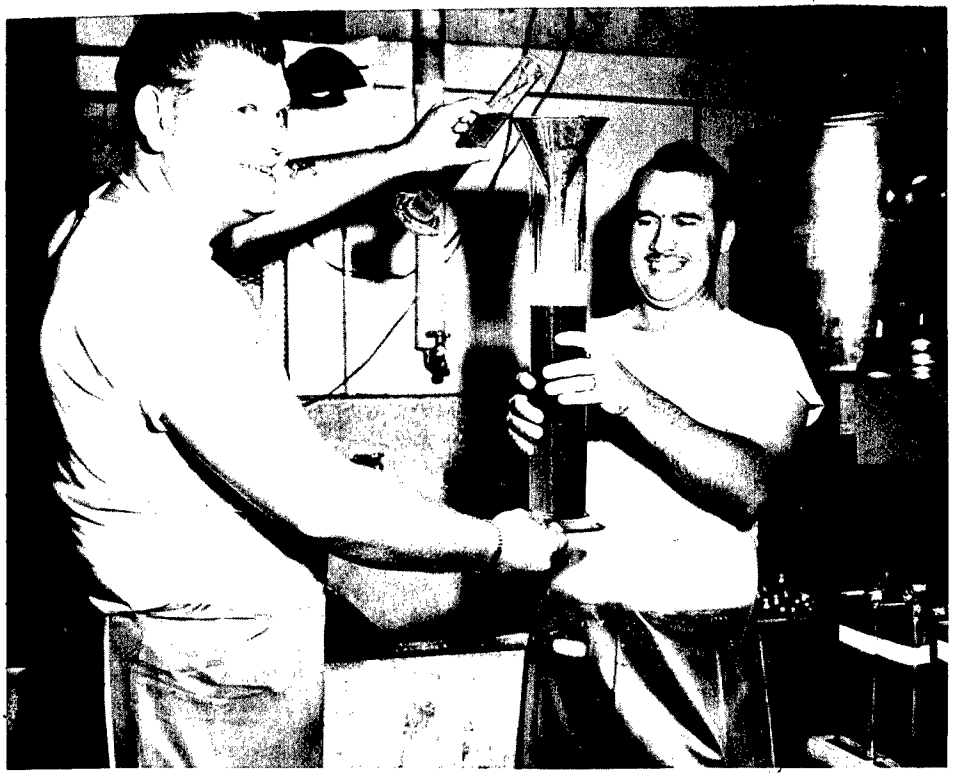


FIGURE II. 12



FIGURE II. 13



FIGURE II. 14. PREPARING TO POOL FECAL SPECIMENS (MR. S. F. MAROTTA).

were stored in a refrigerated van at 35°F until pooling was done (Figure II. 14). The fecal pools were prepared according to the method of Johnson, Pandazi, and Sargent (1954). The volume of the final homogenate was 6000 ml in all periods. Distilled water was used throughout in the preparation of these homogenates. Three one-ounce aliquots were taken from each homogenate. The aliquots were collected in brown screw-capped bottles. The fecal aliquots were handled and stored until the time for chemical analysis in the same fashion as that already described for the urinary aliquots.

4. Sweat

Sweat was collected in elbow-length rubber gloves worn on each arm by the subjects taking part in the heat acclimatization test (vide infra). The sweat from the two gloves was pooled in a four-ounce screw-capped brown bottle. After the volume had been measured, the sweat was transferred to one-ounce screw-capped brown bottles. All the sweat collected was saved. The one-ounce ali-

quots were treated in the usual fashion until chemical analyses were performed.

5. Blood

Venipuncture. All specimens of blood were taken during the three-hour test. The venipuncture was made as previously described by Sargent et al. (1955).

Whole Blood. Whole blood (Figure II. 15) was used for hematology and glucose determinations. The smears and specimens for hematological and chemical analysis were prepared as in the 1954 winter test (Sargent et al., 1955). All analyses of whole blood were done in the field laboratory (Figure II. 16).

Serum. Serum was taken according to the method used in the 1954 winter test (Sargent et al., 1955). An analysis for serum amylase was done in the field laboratory. The remainder of the serum was stored in two or three 15-ml screw-capped vials. These vials were processed in the usual fashion for aliquots of biological specimens until the time for chemical analyses.

6. Other Excreta

Paraffin-lined cartons were kept at designated areas for use in case of vomiting, which occurred infrequently. The individual specimens were diluted to 500 ml with distilled water and thoroughly mixed. One one-ounce aliquot was taken in a brown screw-capped bottle. The aliquots were treated and stored in the usual fashion until the time for chemical analyses.

F. NUTRIENT AND OTHER BALANCES

1. Nutrient Losses in Sweat

Sweat contributed significant losses of water, sodium, chloride, nitrogen, potassium, and calcium. In arriving at suitable correction factors, two measurements had to be considered. The first was the actual total sweat loss for each subject. This quantity varies according to work load, environmental conditions, and individual idiosyncrasy. The second was the nutrient concentration of the sweat of each subject. In the case of sodium and chloride, this quantity varies with work load, environmental temperature, dietary regimen, and individual idiosyncrasy. In the case of potassium, calcium, and nitrogen, variability with work load is small. If we adopt the review of Robinson and Robinson (1954a) as standard for these calculations, the summary data of Table II. 18 are pertinent for the present purposes.

TABLE II. 18

CHEMICAL COMPOSITION OF SWEAT
(After Robinson and Robinson, 1954a)

Nutrient and Units	Rest and Light Activity	Hard Activity	Effect of Diet
Sodium, mEq/l	30	60	Marked
Chloride, mEq/l	25	50	Marked
Potassium, mEq/l	4.5	4.5	?
Nitrogen, mg N/100 ml	40	40	Slight
Phosphorus, mg P/100 ml	0.02	0.02	?
Calcium, mg Ca/100 ml	5	5	?

Because of the important effect that rate of sweating has in controlling nutrient concentration in sweat, it is necessary to calculate separately sweating at rest, during light work, and during hard work. A series of observations was made to obtain data on these points, and it was decided that interindividual variabilities with respect to rate of sweating and chemical composition of sweat were so great that it would be necessary to compute sweat losses for each individual subject in arriving at a realistic balance with respect to sodium and chloride. There is not enough phosphorus in sweat to necessitate calculating its loss by this route. Calcium, potassium, and nitrogen concentrations in sweat are quite small and relatively constant, and therefore an assumed flat single concentration is probably justifiable for these three nutrients.

As described in the section on water balance, a "true sweat loss" could be calculated for each subject. This value permitted calculations of water, nitrogen, phosphorus, and calcium by a single assumed concentration for each. In the case of potassium, the subject's own sweat was analyzed weekly, and this value was multiplied by the "true sweat loss" for that metabolic period. In the case of sodium and chloride, the subject's own value for maximal sweating was known each week. This concentration was multiplied by the "true sweat loss" in hard work for the period. For light work, a value of one-half of the maximal value was multiplied by the "true sweat loss" in light work for the period. Phosphorus in sweat is negligible, and was not computed.

2. Caloric Balance

Intake. The caloric intake was calculated from food tables (Sargent et al., 1955).

FIGURE II. 15. PREPARING WHOLE BLOOD FOR CHEMICAL AND HEMATOLOGICAL ANALYSIS (MR. G. N. WOGAN).

FIGURE II. 16. FIELD CHEMICAL LABORATORY.

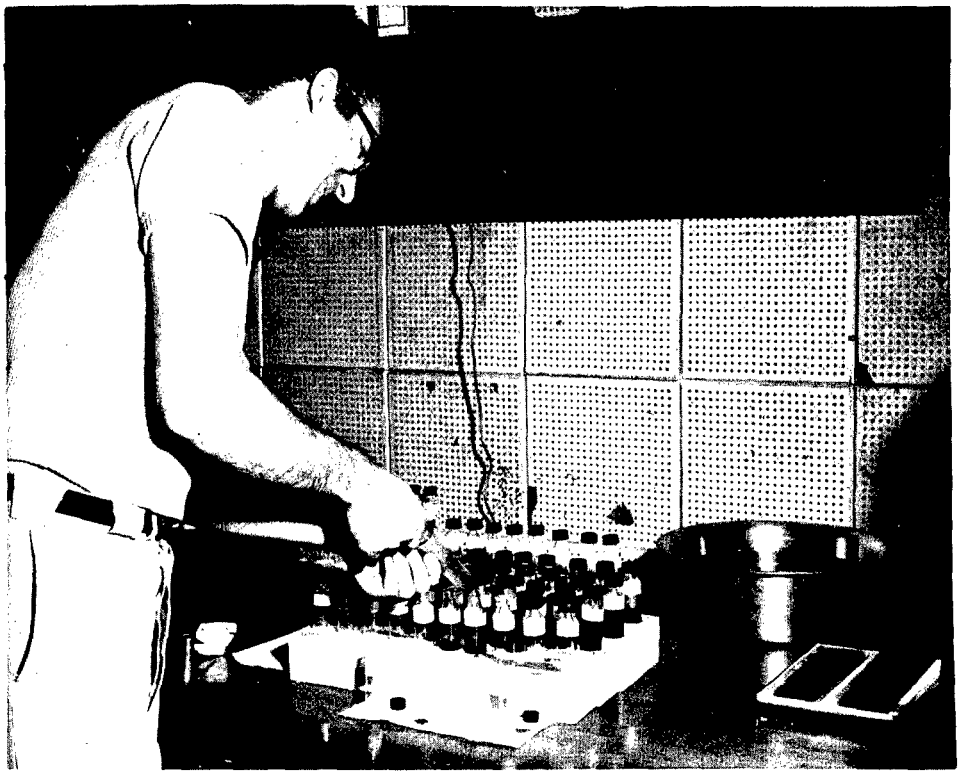


FIGURE II. 15

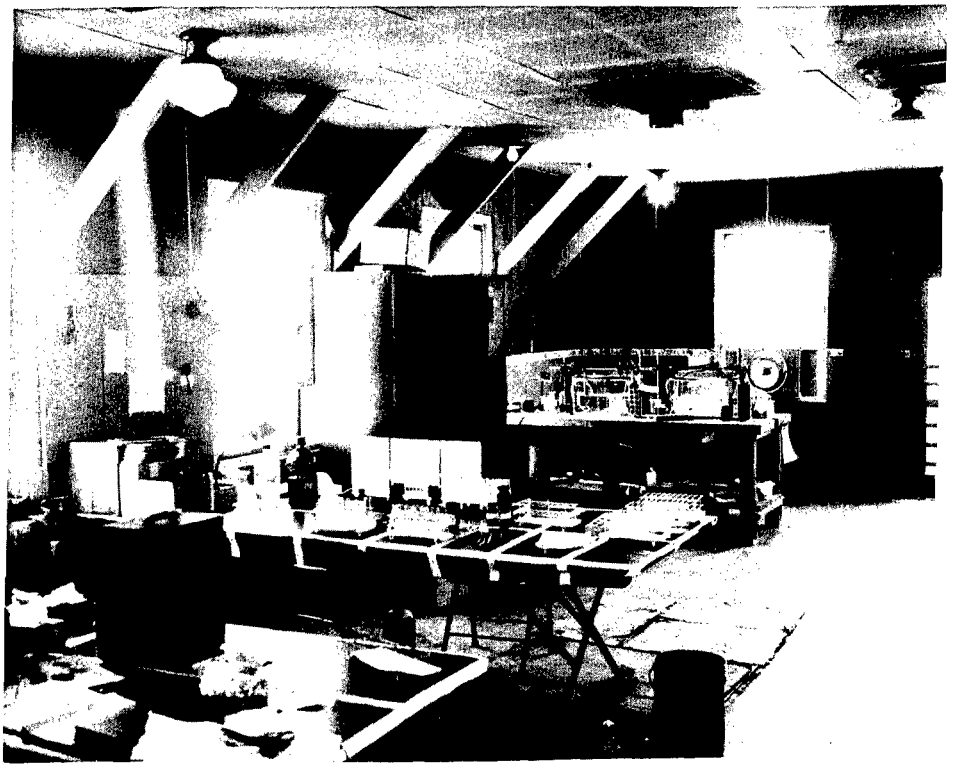


FIGURE II. 16

Output. The caloric output was estimated in the same fashion as followed in the 1954 winter test (Sargent et al., 1955).

Calculations. For each period, the average weight of each subject was calculated. From the flight logs, the average number of hours per day spent in hard work, light work, and resting were calculated (Table II. 19). For each kg of body weight factors of 4.0, 2.2, and 1.1 Cal/hour were used for hard work,

TABLE II. 19

CATEGORIES OF DAILY ACTIVITY

Resting	Light Work	Hard Work
1. Sleeping	1. Sitting (e.g., meals, classroom, movies)	1. Close-order drill
2. Resting during tests	2. Policing living facilities (e.g., barracks, campsites, etc.)	2. Heat acclimatization test
	3. Survival and military indoctrination	3. Prescribed marching to and from mess
	4. Reading, writing	4. Sports
	5. Washing clothes	
	6. "GI" party	

light work, and resting, respectively. Mean daily caloric expenditure was then calculated by the formula: (Mean Body Weight) x (Hr of Hard Work x 4.0 + Hr of Light Work x 2.2 + Hr of Resting x 1.1). Balance was calculated from the formula: Balance = Intake - Expenditure.

3. Water Balance

Intake. The water intake was taken as the sum of the known intake of fluid, the preformed water in the food, and the metabolic water from the food.

Output. Water is lost in urine, expired air, in sweat and insensible perspiration, and to a very minor extent in feces and other body fluids. Urine volume was measured daily. The insensible water loss (expired air plus insensible perspiration) was calculated for each subject from his body weight and data from the temperate study on rate of insensible sweating per kg. Sweat contributed as much or more water than did the urine. It was calculated for each subject from the hours of hard work, the hours of light work, and the hours of rest.

Calculations. Balance was calculated as (intake minus output).

Daily sweat loss was calculated by assuming that water balance was generally positive for PRE I and PRE II. Each subject's maximal rate of sweating in hard

work was known from the weekly heat acclimatization test. A "maximal possible sweat loss" was calculated by multiplying mean hours of hard work by the maximal value, and mean hours of light work by one third that value. "True sweat loss" was calculated from (intake minus the sum of urine, insensible water loss, and miscellaneous loss in feces and blood). The ratio "true sweat loss"/"maximal possible sweat loss" for each subject was used to multiply "maximal possible sweat loss" in all other periods to arrive at "true sweat loss" for all periods.

4. Nitrogen Balance

Intake. Nitrogen intake was calculated from analytical data for experimental regimens and all 5-in-1 items. FRA nitrogen intake was calculated from book values.

Output. Urine and feces were collected daily, pooled for the metabolic period chosen, and analyzed. Dermal losses were assumed, as in the temperate study of 1953, as to be 0.2 gm N per man per day. (Table II. 20.)

TABLE II. 20

BALANCE CALCULATIONS: NITROGEN LOSSES FROM MISCELLANEOUS SOURCES

Source	Flight	Period					
		PRE I	PRE II	EXP I	EXP II	REC I	REC II
Dermal Losses	1	0.2	0.2	0.2	0.2	0.2	0.2
Nitrogen,	2	0.2	0.2	0.2	0.2	0.2	0.2
gm N/day	3	0.2	0.2	0.2	0.2	0.2	0.2
	4	0.2	0.2	0.2	0.2	0.2	0.2
	FRA	0.2	0.2	0.2	0.2	0.2	0.2
Blood	1	0.4	0.4	0.4	1.3	0	0.4
Nitrogen,	2	0.4	0.4	0.4	1.3	0	0.4
gm N/day	3	0.4	0.4	0.4	1.3	0	0.4
	4	0.4	0.4	0.4	0.9	0	0.4
	FRA	0.4	0.4	0.4	1.3	0	0.4

Nitrogen losses in blood: The only nutrient lost in significant amounts in the weekly venipuncture was nitrogen, the value for which is taken as 3.0 gm N per 100 ml of blood. Weekly venipunctures of 90 ml were performed in PRE I, PRE II, EXP I, and REC II. The same amount of blood was taken in EXP II, the balance period for which lasted only three days. No blood was drawn in balance period RECI. Thus, a fixed correction calculated for each period was used (Table II. 20).

Calculations. Nitrogen balance, gm N/day = (Nitrogen Intake, gm N/day) - (Urinary N + Fecal N + Dermal N + "True Sweat Loss", liters, x 0.040 + Miscellaneous Loss).

5. Fat Absorption

True balance of fat cannot be calculated from intake and output because of the effects of intermediary metabolism. In the present studies, total daily fecal excretion of fatty acids is estimated chemically. Intake is calculated from book values. An index of fat absorption is (fat intake)/(fecal fatty acid excretion).

6. Minerals

Minerals include sodium, potassium, calcium, phosphorus, and chloride.

Intake. All experimental regimens and 5-in-1 items were analyzed directly by methods described in the report for 1954. Intake of minerals in fresh and frozen foods (FRA) was computed from book values.

Output. Urinary and fecal excretion of minerals was estimated by direct chemical analysis of samples covering each metabolic period. The methods have been described in a previous report (Sargent et al., 1955). Loss in blood was almost negligible but was computed. Dermal loss is assumed to be negligible. Loss in sweat was calculated differently for the several minerals. There is little if any phosphorus in sweat, so that no calculation was necessary. The concentration of calcium is rather constant, and it was safe to assume a standard figure of 50 mg Ca/liter of "true sweat". Potassium fluctuates very little in a given individual, but is widely different from individual to individual. Therefore, the subject's own value for a given week was multiplied by "true sweat loss" for that week. Sodium and chloride behave similarly to each other, and their loss was calculated as described in the section "Nutrient Losses in Sweat" above.

Calculations. The balance of a given mineral was calculated thus: Balance = (Intake) - (Urinary Loss + Fecal Loss + Loss in Sweat).

7. Vitamins

All subjects received daily therapeutic doses of all known vitamins. No measurements were attempted of vitamin excretion or vitamin tolerance. It was assumed that vitamin deficiency could not arise under the conditions of these experiments. It is now fairly well accepted that loss of vitamins in sweat is not large enough to pose nutritional problems, especially in very short periods (Mitchell and Edman, 1951). Hence, even the profuse sweating of our hard work subjects would not predispose to vitamin deficiency.

8. Acid-Base Balance

The term "acid-base balance" has quite different connotations from any orthodox nutrient balance. Historically, it has referred to the fluctuations of acidity of plasma and other body fluids. These changes are due to the mutual interaction of exogenous and endogenous acid and base, both inorganic and organic. In the present study, acid-base balance was measured solely by the pH and titrable acidity of freshly collected urine.

It is tempting to speculate that perhaps, when knowledge is more complete

than it now is, a complete study of dietary intake will enable a reliable estimate to be made of the acidity of body fluids, and particularly the regulation of urinary acidity. In our studies, such an attempt has as yet led to little success. The reaction of the organism as a whole is too complex for us to be able to predict it with accuracy.

9. Osmotic Balance

The concepts of osmotic balance and osmotic depletion are not to be found in the orthodox metabolic literature. They should be defined and used, for they are of the utmost importance in the interpretation of nutritional data.

As in the case of acid-base balance, endogenous factors are important in determining the osmotic state of the body as a whole. Osmotically active materials, mainly organic molecules of small molecular weight, organic acids, and ammonia, arise within the body and are excreted in the urine, sometimes in large amount.

A substance that has received very little attention in the osmotic literature is carbon dioxide. Considering the fact that the normal resting individual loses roughly one mol of CO_2 every two hours by way of the lungs, at a time when his total carbon consumption may amount to about 10 mol per hour, this osmotically active material may contribute appreciably to osmotic balance in the body. Exploratory studies on this point are in progress (B. Howell and R. Adams, Personal Communication).

All things considered, the term "osmotic balance" must be as meaningful from the standpoint of pathologic physiology as the term "acid-base balance" and should be as fruitful if systematically explored. We define osmotic depletion as a condition in which the intake of minerals plus nitrogen is abnormally low, leading to an abnormally low urinary excretion. In the healthy subject a very high correlation exists between the intake as thus defined and the output as thus defined, even though it is recognized that endogenous factors, such as ketonemia may be very important in determining urinary osmotic excretion.

In the present study, as in our previous ones, we have used the daily or hourly osmotic excretion as measured by freezing point depression, as an index of osmotic balance.

G. CLINICAL PATHOLOGY

1. Hematology

The hematological determinations were made by standard procedures of clinical pathology. The blood used in these analyses was venous blood. Venous blood was collected by venipuncture with a minimum of stasis. The subjects were postabsorptive in all periods except EXP II. The first few drops of blood from the needle were placed on glass slides and smears were prepared for staining. Five ml of the blood was placed in a screw-capped vial containing a standard amount of dried double oxalate (sodium and ammonium oxalate, prepared according to Hepler, 1949). The hematological measurements were all completed

in the field within a few hours after the samples were obtained. The following analyses were made according to procedures described in WADC TR 53-484, Part 1: (1) white blood cell count, (2) differential leukocyte count, and (3) hematocrit.

Reticulocyte Count. The dry preparation method as described by Ham (1952) was used for reticulocyte counts. The glass slide rather than the cover glass method was employed. A total of 1,000 RBC were counted and the reticulocytes were expressed in per cent.

Erthyrocyte Sedimentation Rate. Blood was received and E.S.R. determination started within an hour of the time blood had been drawn. Wintrobe tubes (I.D. 3mm) were filled with blood, placed in the rack, and then put into a water bath kept at 100°F ± 1°. The level of the erythrocytes was read and recorded every 10 minutes for one hour. The greatest difference between any two ten-minute readings was selected as the maximum E.S.R. The Wintrobe tubes were placed in an angle-head centrifuge and centrifuged for one hour at 3170 R.P.M. The hematocrit was then read and recorded. Corrected E.S.R. was determined from the nomogram prepared by Rourke and Ernstene (Consolazio, Marek, and Johnson, 1951).

The effect of temperature on the erythrocyte sedimentation rate has been known for some time (Nichols, 1942). The temperature of the laboratory during the 1954 winter study was uncontrolled, and to this fact was attributed the erratic behavior of the E.S.R. (Sargent et al., 1955). In the present investigation, in order to eliminate this variable, all determinations were made at the same temperature. The temperature in the field was expected to approach 100°F; so 100°F was arbitrarily selected as a bath temperature which could be maintained throughout the test period.

2. Blood Chemistry

Venous blood was collected with a minimum of stasis for all chemical analyses. For glucose the blood was delivered into screw-capped vials containing dried double oxalate. For all other analyses, the serum was collected after centrifuging clotted blood. The serum was transferred to screw-capped vials which were shipped to the University by the courier system described earlier in this report. The vials were stored as described above in the section dealing with specimens.

The following analyses of serum were conducted according to procedures detailed in WADC TR 53-484, Part 1: calcium, sodium, potassium, chloride, inorganic phosphate, amylase, and cholinesterase. Serum alkaline phosphatase was not estimated. Whole blood glucose and serum creatinine were measured according to the procedures described in WADC TR 53-484, Part 2.

Freezing-Point Depression. The freezing-point depression of serum was measured with the Fiske Osmometer. The device was calibrated with standard solutions of NaCl prepared according to directions published by the company. The concentrations were adopted from the International Critical Tables.

Serum Urea Nitrogen (Consolazio, Johnson, and Marek, 1951). Serum collected during the summer tests was analyzed for serum urea nitrogen, not for non-protein nitrogen. This decision was made so that it would be possible to calculate urea clearance and to study the relationship between the concentrations of urea in serum and in sweat.

Serum Total Cholesterol. Because of our experience with the anthrone procedure of Feichtmeir and Bergerman (1953) in 1954-1955, we abandoned this procedure and returned to the analytical method followed in 1953. The details of this procedure have been given in WADC TR 53-484, Part 1. Esters of cholesterol were not measured.

3. Urine Chemistry

The following measurements were made on the pooled specimens: total nitrogen, calcium, phosphorus, sodium, potassium, and chloride.

The following measurements were made on the two-hour urinary specimens: freezing-point depression, creatinine, creatine, pH (electrometric), titrable acidity, 17-ketosteroids, and urea nitrogen. On the exercise urinary specimens the freezing-point depression, creatinine, creatine, and urea nitrogen were measured. No chemical analyses were made on the post-exercise urinary specimens.

Special Urinary Specimens. As discussed in the section on "Collection and Preservation on Specimens", three specimens of undiluted urine were collected in connection with each of two measurements of body water by deuterium oxide. Each of these specimens was analyzed for D_2O by the "falling drop method" described in detail in Appendix I of WADC TR 53-484, Part 2.

Special aliquots were prepared from the three-hour test urine, the basal urine of the water diuresis test, and a pool of the four-hour specimens collected during the water diuresis test. These aliquots were treated according to the following procedure: 5 ml of urine were transferred to screw-capped vials containing sufficient glacial acid to bring the pH to approximately 4.0. The vials, after thorough mixing, were promptly frozen with dry ice. The frozen vials were stored in a deep-freeze facility available in Edinburg, Indiana. These frozen vials were later transported to the Aero Medical Laboratory where they were analyzed for anti-diuretic hormone (ADH) after the method of Clarke, Zuidema, Minton, and Reeves (Appendix I).

Aliquots for ADH were only collected from a few subjects. The purpose of these assays was to further investigate why subjects on limited water and pure carbohydrates diurese as abundantly as a subject on a similar regimen but with unlimited water. We, therefore, selected four subjects from Flights 1 and 2 for study. Two of the subjects subsisted on 0/100/0 2000, the other two, on 15/52/33 2000.

4. Urinalysis

Qualitative tests were made on the three-hour resting, the exercise, the

post-exercise, and the diluted daily urinary specimens according to procedures described in WADC TR 53-484, Part 1: albumin, glucose, urobilinogen, and ketone bodies. The sediment of the three-hour, exercise, and post-exercise urinary specimens was studied quantitatively by a modification of the method of Addis (Sargent et al., 1954).

5. Analysis of Feces

The qualitative and quantitative procedures detailed in WADC TR 53-484, Part 1, were followed: fecal fibers, occult blood, total nitrogen, calcium, phosphorus, potassium, and total fecal fat. Fecal sodium and chloride were not measured for they are present in negligible amounts (Sargent et al., 1954).

6. Analysis of Sweat

The glove sweat collected during the one-hour march was subjected to both qualitative and quantitative analyses. The qualitative analyses were: glucose, albumin, and ketone bodies. The sediment was examined microscopically according to the standard procedure of urinalysis. Quantitative determinations were: freezing-point depression, sodium, potassium, chloride, creatinine, and urea nitrogen.

7. Liver Function

The battery of liver function tests was quite comparable to that used in the 1954 winter study. The measurements used to appraise liver function were: serum cholinesterase, serum total cholesterol, fasting blood sugar, color of feces, and clinical examination. The rationale has been discussed in WADC TR 53-484, Part 1.

8. Renal Function

The function of the kidney was appraised by means of urinary volume, creatinine clearance, urea clearance, osmotic clearance, urine/serum osmotic ratio (U/S ratio), serum urea nitrogen, serum creatinine, modified Addis count, and urinalysis. The procedures used, the calculations made, and the rationale for these functional tests have been discussed previously in WADC TR 53-484, Parts 1 and 2.

9. Endocrine Functions

The measurement of the functional changes of the endocrine glands is an integral part of the methodological armamentarium of an investigation of stress. Two general types of procedure are available. (1) A fragment or metabolite of an original hormone or the hormone itself may be measured in a biological fluid, such as blood, urine, or feces. The method may be either chemical or biological (bioassay). (2) A process or function known to be, at least in past, regulated by the activity of an endocrine may be quantitated so that inferences may be drawn regarding the functional activity of the endocrine gland. Both types of approaches were employed in this investigation, and in general they did not

differ from those described previously in WADC TR 53-484, Parts 1 and 2.

The following measurements and analyses were made to serve as a basis for deducing functional changes in the endocrine glands: total urinary 17-ketosteroids; anti-diuretic hormone; serum sodium, potassium, calcium, inorganic phosphate, cholesterol, and amylase; blood glucose; resting metabolic rate; differential leukocyte count for neutrophils, lymphocytes, and eosinophils; water tolerance test; and urinary creatine.

The methods of analysis have been discussed elsewhere in this report. Two changes were made from the 1954 winter study. Serum alkaline phosphatase was omitted. Special urines were collected for measurement of anti-diuretic hormone by a bioassay. The reasons for measuring ADH have been mentioned above.

H. RESPIRATORY FUNCTION

1. Resting Metabolism

Resting metabolism was measured with the same apparatus that was used in the 1954 winter study. A considerable amount of further validation of this apparatus was conducted prior to the summer test, and we felt on the basis of these studies that the instrument should operate satisfactorily. A full discussion of the calculation of instrumental factors and validation of the procedures used will be found in Section III: Results, and in Appendix I: Methods. As in our previous investigations, we studied the subjects in a resting condition rather than in the more conventional basal state. The justification for this procedure has been discussed in detail in previous reports (Sargent et al., 1954-1955).

2. Hyperventilation Test

At the completion of the measurement of resting metabolism, a test was made of the ability of the subject to hyperventilate maximally. This procedure, which involves maximal expiratory effort for a period of 15 seconds, has recently been recommended by a number of investigators as an excellent index of pulmonary function. The rationale for this procedure will be included later with the results (Section III).

3. Respiratory Rate

The respiratory rate was measured during the course of two different tests. While the resting metabolic rate of the subject was being obtained, a count of the number of respirations per minute was made and recorded. A second count of the respiratory rate was made during the course of the three-hour test.

I. CARDIOVASCULAR FUNCTION

1. Blood Pressure

Blood pressure was measured with the mercury manometer and stethoscope according to standard clinical practice. Measurements were made with the subjects in two postures during the three-hour test: (1) after at least 15 minutes

of reclining flat on the back (Figure II. 17) and (2) after one or two minutes of standing at attention (Figure II. 18). The standing measurements were added to the procedures followed in previous ration studies in order to make judgements on the development of such syndromes as heat syncope and heat exhaustion. A characteristic finding of these conditions is the development of orthostatic hypotension. At the time of measuring blood pressure the observer noted any clinical changes such as pallor, sweating, dependent cyanosis, or complaints of light-headedness, dizziness, and syncope. If the subject did faint, he was placed in the shock position. When recovery was achieved, the test was repeated.

2. Pulse Rate

The radial pulse was counted by palpation with the subject in the reclining and standing positions described above (Figures II. 17 and II. 18). A 15-second count was multiplied by four to give the pulse rate as beats/minute.

The pulse rate was also counted in the sitting position at the beginning and immediately at the end of the march of the heat acclimatization test. Here a 30-second count was made by palpating the carotid or brachial artery; the pulse rate as beat/min was then calculated.

3. Electrocardiogram

With the subject reclining during the three-hour test, the electrocardiogram was taken using only the three standard limb leads. Considerable difficulty was encountered with this procedure. In spite of repeated attempts to maintain adequate grounding of the apparatus, many records were invalidated because of 60-cycle interference. This result obtained whether a battery operated Sanborn Instomatic Cardiette or a line-operated direct writing Sanborn electrocardiograph were employed. Our only explanation is that these devices may not function properly in barracks during humid weather. No such trouble was encountered in the 1954 winter tests when the Sanborn Cardiette was used in a similar building either at Chanute AFB or Camp McCoy.

J. CENTRAL NERVOUS SYSTEM

The same procedures were followed as previously described by Sargent et al. (1955).

K. BODY COMPOSITION

Two techniques are available for studying changes in body composition: (1) direct measurement and (2) calculations from nomograms and empirical formulae. The latter are no more valid than the assumptions made in setting up the

FIGURE II. 17. MEASUREMENT OF RECLINING BLOOD PRESSURE. LEFT TO RIGHT: S/SGT. C. DE ROUEN, S/SGT. P. PADOVANO, AND VOLUNTEER AIRMAN.

FIGURE II. 18. MEASUREMENT OF STANDING BLOOD PRESSURE. LEFT TO RIGHT (FOREGROUND). MR. N. SPERELAKIS, A/3C P. R. BERRY, AND DR. F. SARGENT, II.



FIGURE II. 17

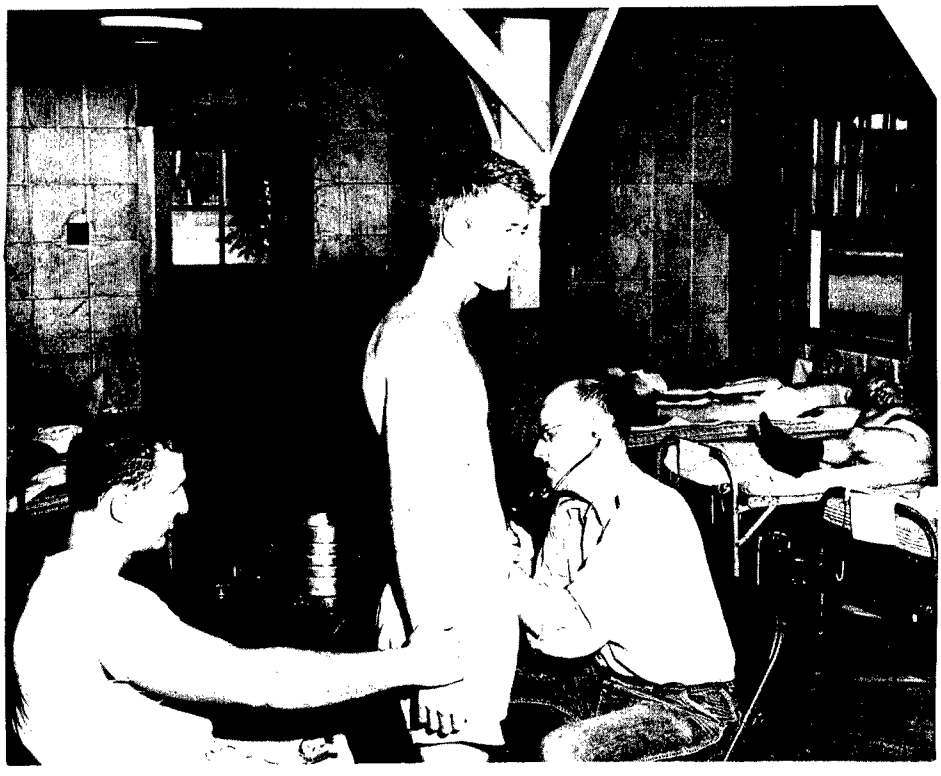


FIGURE II. 18

empirical formulae. The applicability of these assumptions to metabolic investigation is limited, for frequently the empirical conditions are not similar. The lack of fully validated broadly applicable procedures for studying changes in body composition is one of the most serious deficiencies of metabolic research generally. In so far as the present report is concerned, little use will be made of these empirical formulae.

1. Body Weight

The body weight of each subject was measured after passing the first morning urine and before eating breakfast. All weighings were made by members of the technical staff. The subjects, clothed only in shorts and "T" shirt, were weighed on a scale sensitive to the nearest ounce. The daily weights were converted to the nearest 0.1 kg by dividing the weight in pounds by 2.2.

2. Body Water (Deuterium Oxide Space)

The principal and rationale for using heavy water to measure the total body water of a man, has been discussed in considerable detail in WADC TR 53-484, Part 2. In general, we followed the same procedures detailed in that report. The chief variation was the administration of larger oral doses of heavy water in the two tests (Figure II. 19). In the first we gave 60 gm and in the second 40 gm (Table II. 21). Because of the epidemic the procedure for measuring the

TABLE II. 21

PROTOCOL OF DEUTERIUM OXIDE TEST FOR BODY WATER

Apparatus:

1. Heavy water in 100-ml ampules x 100.
2. 1 lined "Jerry" can with tight lid.
3. 2 500-ml graduates.
4. 1 large plastic funnel.
5. Distilled water.
6. 2 plastic pitchers, 2-qt. capacity.
7. 2 250-ml graduates.
8. Canteen cups.
9. Three large dish pans.

Procedure:

1. On Day 12 (PRE II) all subjects will void and turn in at the Specimen Receiving Station their gallon cans before supper. The voiding time will be recorded. A fresh gallon can will be issued. This can will be labelled "Pre-D_2O".

2. On the evening of this day, oral doses will be prepared. Each subject will be given 60 gm of deuterium oxide in 150 ml of water on Day 13.

3. Before breakfast on Day 13 (PRE II) the "Pre-D_2O" specimens will be collected and the subjects will be issued a gallon-can labelled "D_2O".

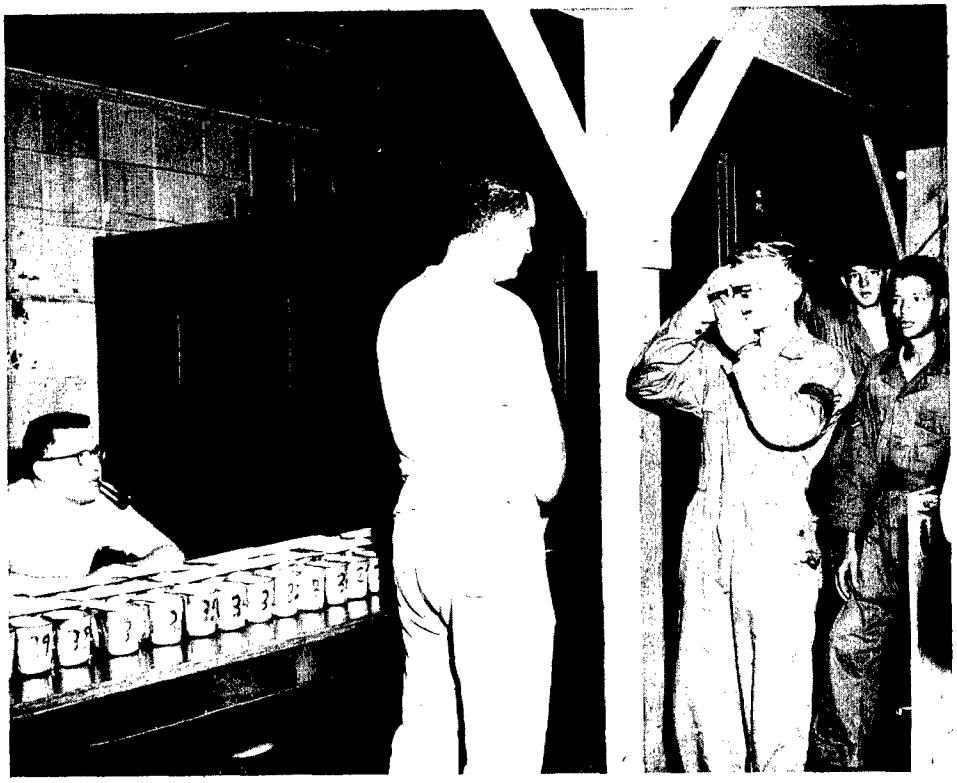


FIGURE II. 19. ADMINISTRATION OF ORAL DOSE OF HEAVY WATER. LEFT TO RIGHT: DR. R. E. JOHNSON, MR. N. SPERELAKIS, A/3C P. F. APPLEBY (DRINKING), A/3C T. E. EWING, AND A/3C B. F. HOLLEY.

TABLE II. 21 (Continued)

4. Prior to breakfast each subject will drink from his canteen cup 60 gm of deuterium oxide in 150 ml of water. This canteen cup will be retained for use at breakfast.

5. Before supper the subjects will void into their gallon cans. The time of voiding will be recorded. These cans will be turned in at the Specimen Receiving Station and fresh cans will be issued. These cans will be labelled "Post-D_2O".

6. The "Post-D_2O" specimens will be collected on the morning of the Water Diuresis Test (Day 14, PRE II).

7. On Day 26 (EXP II) step 1 will be repeated.

8. On the evening of this day, oral doses will be prepared. Each subject will be given 40 gm of deuterium oxide in 150 ml of water on Day 27.

9. Before breakfast on Day 27 (EXP II) step 3 will be repeated.

TABLE II. 21 (Continued)

10. Prior to breakfast each subject will drink from his canteen cup 40 gm of deuterium oxide in 150 ml of water. This canteen cup will be retained for use at breakfast.

11. Before supper on Day 27 step 5 will be repeated.

12. The "Post-D_2O" specimens will be collected on the morning of the Water Diuresis Test (Day 28, EXP II).

13. Special sample which must be collected. After the D_2O dilutions have been prepared, set aside two 25-ml specimens in one-oz. brown bottles. Label D_2O-DOSE PRE II or EXP II, as the case may be.

body water in EXP II had to be modified somewhat from that described in the table beginning with step 7. The "Pre-D_2O" specimen for Flights 1 and 2 was an aliquot taken from the urine collected between 0530 and 1600 hours on Day 23. The D_2O specimen was an aliquot taken from the three-hour test urine. The dose of D_2O was given in place of the regular priming dose described in the protocol for the three-hour test (Table III. 28). The "Post-D_2O" specimen was the urine passed from the end of the three-hour test up to 0530 on Day 24. In the case of Flights 3 and 4, the "Pre-D_2O" specimen was an aliquot taken from the 24-hour urine collected on Day 23. The "D_2O" specimen was an aliquot taken from the urine passed between the end of the three-hour test and 2100 hours, Day 24. The "D_2O" was administered in place of the priming dose of the three-hour test in exactly the same fashion as described for Flights 1 and 2. The "Post-D_2O" specimen was collected from 2100 hours, Day 24, to 0530 hours, Day 25.

3. Water Diuresis

In previous reports we have discussed in detail the rationale for the conduct of the water diuresis test. The protocol for the test as used in the present investigations is detailed in Table II. 22. This test was conducted in

TABLE II. 22

PROTOCOL OF WATER DIURESIS TEST

Equipment:
1. 6 1-liter pharmaceutical graduates.
2. 100 tin cans with 2000-ml capacity.
3. 500 tin cans with 500-ml capacity.
4. 4 500-ml graduated cylinders.

Procedure:
1. The subjects will drink all their water allowance on the day prior to the test by 1800.

2. They will void at 0630 in the morning completing their 24-hour period.

3. They will receive no breakfast. They will eat 50% of calories at

lunch and supper.

4. They will be handled by major groups of 25 men plus two observers each.

5. Each group will report to the assigned station at 0700.

6. They will recline during the entire test period and they will not be permitted to smoke.

7. At 0800 they will void into appropriately labelled cans (500-ml capacity). The voiding will be "by the numbers".

8. The oral dose of water will be administered between 0800 and 0845, the load having been prepared for each subject ahead of time: (Wt (lb) on day prior to test) x (9.1 ml/lb = (Total Water Load). These loads will be placed in cans of 2000-ml capacity labelled with subject's code number. The load will have been consumed within the period.

9. They will void into separate labelled containers at 0900, 1000, 1100, and 1200. Voidings will be "by the numbers".

10. After voiding at 1200 (or 1600 in EXP II) they will receive their gallon cans and then report to the mess hall.

11. The remainder of the 24-hour urine will be collected in the gallon-sized cans as usual and its volume measured.

Disposition of Specimens:

1. The volume of urine in the five specimens will be measured and recorded on the appropriate form (Appendix VI). The specimens will then be discarded.

2. The volume of urine in the gallon cans will be measured and recorded on the appropriate form as well as the "Water Diuresis Test" form. This urine will not be included in the 7-day pool.

Records:

1. The times of voiding beginning at 0630 will be recorded.

2. The oral load will be recorded.

3. The several volumes of urine will be recorded.

4. The calculations indicated will be completed.

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essentially the same fashion as in the 1954 winter test in PRE I, PRE II, EXP I, and REC I. We had planned to conduct a double water diuresis test in EXP II, but circumstances did not allow us to do so. The method of calculating REC was the same as that described in WADC TR 53-484, Part 1.

4. Body Fat

The percent body fat and the kilograms of body fat were calculated from measurement of the skinfold thickness as discussed by Sargent et al. (1954). All the measurements were made by the responsible investigators. This procedure was adopted because, in our experience, there is so great an interindividual variability in performing the measurement of the skinfold thickness as to invalidate the results when more than one operator measures.

Prior to beginning the experimental period and at the end of the experimental period, two photographs were taken (front view and profile) of each subject. These photographs were used to appraise qualitatively the loss of body tissue caused by the several experimental regimens. Examples of these alterations will be given in Section III.

L. HEAT ACCLIMATIZATION TEST

1. The Protocol

In order to study the heat tolerance of men subsisting on a variety of nutrient mixtures and restricted water, it was necessary to design a test which would differentiate between the various experimental regimens. This test had to take the form of a "standard work stress" which would clearly differentiate between a man's ability to do work while subsisting on various experimental regimens in hot weather, and yet, the test could not be so severe that it would be impossible for all the men to complete. It also had to be designed so as to be workable for a large group of subjects in a limited amount of time. The test, as designed, was termed the "heat acclimatization test" and consisted of a one-hour paced march at the rate of 3.75 m.p.h.

The measurements selected for the heat acclimatization test were those which were believed to be the most easily obtainable in the short time allotted for the testing of each subject--fifty men were to complete the test in the course of one afternoon--and yet furnish data which would significantly differentiate between the physiological effects of the experimental regimens including the limitation of water. The protocol detailed in Table II. 23 was found to be quite workable and was used five times during the 36-day period of study at Camp Atterbury.

This protocol was based on the concepts of Ladell (1951) for assessing "group acclimatization." A standard work load in a standard hot environment was imposed and from the observations made an acclimatization index was calculated. This index was the ratio of the sweat loss (adjusted to a standard body weight and surface area) in ml per 80 minutes to the increment of the rectal temperature in 80 minutes. The present test was patterned after Ladell's so that we would have some basis for making judgments regarding the heat tolerance of our subjects. Under field conditions we did not anticipate that we would achieve uniformity of ambient environmental conditions but we felt that if the weather did continue reasonably hot throughout the study, considerable useful data might accrue.

Our original plan for the test was found to be workable on two subjects tested at the University of Illinois. When a dry run was made on five subjects at Camp Atterbury, the results indicated that the protocol would require considerable modification. The alterations involved principally order of measurement and physical arrangement of the equipment required. A modified plan was evolved and a second dry run proved that it was workable (Table II. 23). In brief, the subjects rinsed their forearms in distilled water and then filed into a latrine

TABLE II. 23

PROTOCOL OF THE HEAT ACCLIMATIZATION TEST

Apparatus:

1. Scales for weighing subjects.
2. Pint cans with screw caps x 4 per subject.
3. Sargent Thermistor Thermometer mounted rolling table.
4. Thermistor for measurement of skin temperature.
5. Thermos devices with standard thermometers.
6. Elastic bands for rubber gloves.
7. Leeds-Northrup potentiometer with internal reference standard.
8. Selector switch for five rectal thermocouples.
9. Five thermocouples for measuring rectal temperature.
10. Basin with disinfectant for rectal thermocouples.
11. Elbow length rubber gloves x 2 per subject; gloves must be rolled.
12. Watch with sweep-second hand.
13. Metal funnels x 50.
14. Four-ounce bottles with screw caps for sweat x 2 per subject.
15. Distilled water.
16. Sling psychrometer (wet and dry bulb).
17. Anemometer.
18. Five pans for sweat-filled rubber gloves.

Spare Parts:

1. Batteries for Leeds-Northrup potentiometer.
2. Leeds-Northrup potentiometer with internal reference standard.
3. Thermocouples and thermistors for measuring skin temperature.
4. Thermometers for sling psychrometer.
5. One dozen rectal thermometers.
6. Lubricant (water soluble oil).

Procedure:

1. Subjects will be studied by flights on afternoons of the days they have the three-hour test. One flight at a time will be investigated, the total time being 3 hours; forty-eight hours prior to test, subjects will shave arms.

2. Subjects will be dressed in socks, underpants, T-shirt, cap and will wear brogans.

3. The flight will report to the three-hour test room, wash arms in distilled water in latrine, dry with paper towel, and each man will

occupy one bed. A group of five beds will be arranged in a pentagon with rectal thermocouples centrally located on a table in the center of the pentagon, and the first five subjects will start on those beds.

4. They will void into gallon cans and time will be noted.

5. In groups of five, the subjects will disrobe completely and will be weighed to the nearest 30 gm (1 oz). Numbered rubber bands will be placed high on right arm after weighing.

6. They will don their clothes and sit on the pentagon of beds, facing outward.

7. They will lie in enema position, facing outward. Rectal thermocouples will be installed, and the rectal temperature measured (one minute or until equilibrium is reached).

8. The rectal thermocouples will be removed, and the subjects will sit on the bed, facing outward.

9. Rubber gloves will be installed on both arms.

10. Pulse rate and skin temperature (right arm) will be measured. (Pulse rate for 30 seconds, carotid artery or brachial artery; skin temperature under glove, dorsal aspect of right forearm, midway between elbow and wrist; skin temperature above glove on dorsal aspect of right upper arm).

11. A rubber band will be placed around upper end of each glove; use numbered band and one additional band for left arm.

12. Subjects will march 15 quarter-mile laps at 3.75 m.p.h., paced by flight leaders. Four minutes will be allowed for each lap. An attending physician will be observing subjects at all times.

13. Five more subjects will go through steps 2-12.

14. Subjects, after march, will march to bed and sit down, facing outward.

15. Pulse rate and skin temperature will be measured as in step 10.

16. Gloves will be removed, sealed with numbered rubber bands and laid on bottom of pan under bed, hand-end in pan, arm over edge. (Two observers, one holding fingers, the other stripping the glove, will be needed.)

17. Subject reclines as in step 7 and rectal temperature is measured.

18. Rectal thermocouple is removed, and subject moved to bed in rear of

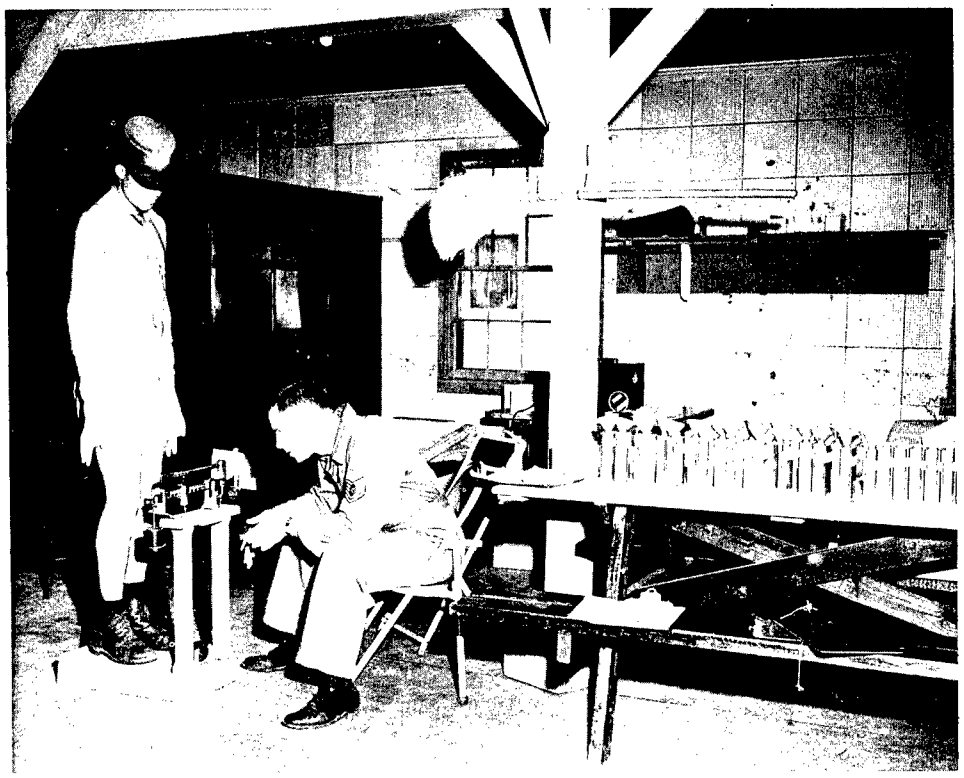


FIGURE II. 20. WEIGHING A SUBJECT BEFORE THE MARCH. LEFT TO RIGHT: A/3C J. W. HAMILTON (DRESSED FOR PHOTOGRAPH) AND T/SGT R. R. JOHNSON.

TABLE II. 23 (Continued)

room.

19. Body weight will be measured as in step 5.

20. Subjects will urinate as in step 4, but into a pint can, time being noted. Specimen "EX-U."

21. They will rest on a bed for one hour and then void into another pint can. Specimen "Post-Ex U." If they cannot void, carry a can until they do, and note time.

22. Measure wind velocity and wet- and dry-bulb temperatures every 30 minutes during the two-hour test period.

---

and voided. After voiding, they were assigned to a bed where they undressed. They were weighed nude (Figure II. 20). They then redressed and in groups of five were tested on the pentagon of beds. There measurements were made on pulse rate, skin and rectal temperatures, and the elbow-length gloves were put on (Figures II. 21, II. 22, and II. 23). These procedures consumed six to eight minutes. When one group of five had moved out to the marching course, a second group of five came to the pentagon of beds, and so on until all members of the flight had been tested. During the march the groups were



FIGURE II. 21. COUNTING THE PULSE RATE. LEFT TO RIGHT: A/3C B. F. HOLLEY AND T/SGT. R. R. JOHNSON.

staggered by two laps so that ample time would be available for completing measurements at the end of the march. At this time, the men went through the above procedures in reverse. After moving from the pentagon of beds, they undressed and were again weighed nude. They dressed and voided and then went to their barracks for an hour's rest. At the end of that hour they voided again.

2. The March

The subjects wore only shorts, socks, and brogans during the march; caps and light T-shirts were optional (Figures II. 21 and II. 24). The course was one-quarter mile long. About 50% of the time the subjects were protected from the sun by shade trees (Figures II. 24 and II. 25). Each lap was paced at four minutes. The subjects were expected to complete 15 laps walking at 3.75 m.p.h. The pacing was done by the flight leaders. At all times there was a medical officer on duty to care for possible casualties. Intravenous saline was on hand in case management of heat incapacitation required it.

3. Instrumentation

Sweat Loss. Body weight was measured before and after the march. The difference expressed as gm/hr was assumed to equal the sweat loss in ml/hr (Robinson and Robinson, 1956). Body weights were measured on a Howe scale

sensitive to 30 gm.

Skin Temperature. Skin temperature was measured with a Sargent Thermistor Thermometer. The device was calibrated against standard thermometers prior to each run. Since the use of the thermistor is a relatively new one in environmental physiology, some comment on its principle and on its reliability in our hands is perhaps warranted.

Principle and properties of thermistor thermometry (Becker, Green, and Pearson, 1946): Thermistors are thermally sensitive resistors with high negative temperature coefficients of resistance. The following are representative of the order of magnitude of resistance changes:

Temperature (°C)	Resistance (ohms)
0	145,000
25	46,000
50	16,000
75	6,700
100	3,200

The thermistors are manufactured from such semi-conductors as mixtures of manganese and nickel oxides or mixtures of oxides of manganese, nickle, and cobalt. In operation a very small current is passed through the resistor so that heating is negligible. Under these conditions the resistor obeys Ohm's Law. With continued use the resistor "ages." Most of the aging takes place with the first week. With subsequent use (and after pre-aging) thermistors increase in resistance about 0.2% per year. For the thermistor thermometer this means a change of temperature of 0.05°C. Thermistors mounted in an evacuated tube or coated with a thin layer of glass age less than 0.2% per year. (The thermistor probe of the Sargent device was encased in glass.) A well aged thermistor will maintain an accuracy of 0.01°C. Changes in resistance are measured on a Wheatstone bridge.

Validation: Several limitations to the Sargent Thermistor Thermometer were discovered when this device was validated. First, we checked the manufacturer's claim that there is a linear relation between amperes and temperature. We standardized (Appendix I) the instrument for ranges of 80° to 120°F and 90° to 110°F. Absolute linearity was not confirmed. The deviations were greater when the instrument was standardized for the range 80° to 120°F than for 90° to 110°F (Tables II. 24 and II. 25). Second, we found that several thermistors had slightly different properties. If the instrument was adjusted with one thermistor, considerable readjustment might be required when a second thermistor was attached. Furthermore, deviations from linearity varied from thermistor to thermistor. These observations indicated that thermistors were not interchangeable. In the event of breakage, the device would have to be recalibrated against standard thermometers. Since there was not always a linear relation between current and temperature, it would be necessary to translate current readings into temperature from a calibration curve prepared before each use. Experience confirmed the impression that a more linear relationship held for the smaller range and thus

FIGURE II. 22. POTENTIOMETER AND THERMOCOUPLES FOR MEASURING RECTAL TEMPERATURE.

FIGURE II. 23. MEASURING SKIN TEMPERATURE OF SUBJECTS ON PENTAGON OF BEDS. LEFT TO RIGHT: A/2C J. W. BAYLISS, MR. R. A. HUNTLEY, 1/LT. R. C. SMITH, JR., A/3C P. R. BERRY, AND A/3C D. P. THOMAS.

FIGURE II. 24. SUBJECTS OF FLIGHT 2 DURING MARCH.

FIGURE II. 25. SUBJECTS OF FLIGHT 3 DURING MARCH.

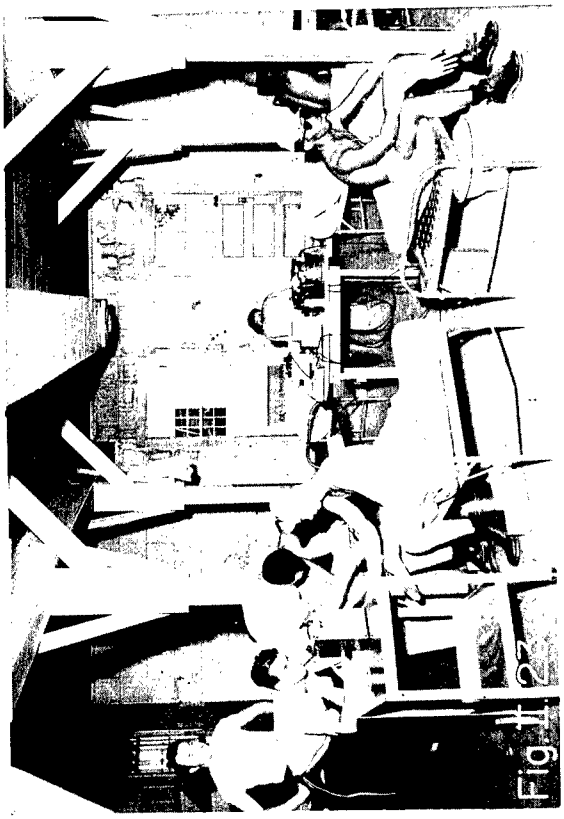


Fig. II.23



Fig. II.25

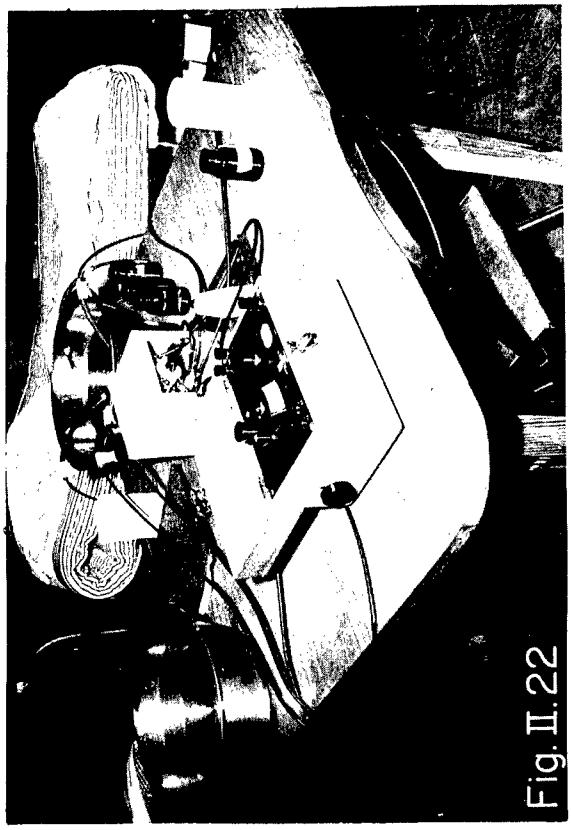


Fig. II.22



Fig. II.24

TABLE II. 24

VALIDATION I. TYPICAL RESULTS OF STUDY
WITH THERMISTOR THERMOMETER STANDARDIZED FOR RANGE 80° - 120°F

Thermistor and thermocouple compared with standard thermometer, each simultaneously inserted to equal depths in a thermos bottle; temperatures in °F.

Standard Thermometer	Thermistor Thermometer	Leeds-Northrup Thermocouple
80.0	80.0	80.0
85.0	85.2	84.9
90.0	90.8	89.9
95.0	96.2	95.2
100.0	101.4	99.8
105.0	106.2	105.3
110.0	110.8	109.3
115.0	115.8	114.9
120.0	120.0	119.9

Comment: Note lack of linearity between thermistor temperatures and temperatures registered on standard thermometer. The thermistor temperatures were calculated on the assumption of linear relationship such that 0.5 microamps was equivalent to 1.0°F.

TABLE II. 25

VALIDATION II. TYPICAL RESULTS OF STUDY
WITH THERMISTOR THERMOMETER STANDARDIZED FOR RANGE 90° - 110°F

Thermistor and thermocouple compared with standard thermometer, each simultaneously inserted to equal depths in a thermos bottle; temperatures in °F.

Standard Thermometer	Thermistor Thermometer	Leeds-Northrup Thermocouple
90.0	90.0	89.9
95.0	95.0	94.9
100.0	100.0	99.9
105.0	105.0	104.9
110.0	110.0	109.9

Comment: Note linear relation between thermistor and temperatures recorded on standard thermometer.

TABLE II. 26

VALIDATION III. TYPICAL RESULTS OF STUDY
WITH THERMISTOR THERMOMETER STANDARDIZED FOR RANGE 80° - 120°F

Skin temperatures of several sites measured with Sargent Thermistor Thermometer and Leeds-Northrup thermocouple.

Skin Site	Skin Temperature (°F) Thermistor	Thermocouple
Forehead	91.2	92.6
Chin	92.2	93.4
Forearm	91.6	92.2
Neck	93.9	94.8

Comment: Thermistor values average 1.0° lower than thermocouple values.

TABLE II. 27

VALIDATION IV. TYPICAL RESULTS OF STUDY
WITH THERMISTOR THERMOMETER STANDARDIZED FOR RANGE 90° - 110°F

Skin temperatures of several sites measured with Sargent Thermistor Thermometer and Leeds-Northrup thermocouple.

Skin Site	Skin Temperature (°F) Thermistor	Thermocouple
Forehead	93.0	92.8
Chin	93.3	93.1
Forearm	92.3	91.9
Thigh	92.2	91.8
Neck	94.8	94.4

Comment: The thermistor values average 0.3 F above the thermocouple values.

all standardizations were for 90° to 110°F. Furthermore, once the instrument was standardized, it was stable for at least one week.

When the instrument was standardized and temperatures read from a calibration curve, there was reasonable agreement between the Sargent instrument and a Leeds-Northrup portable potentiometer equipped with a thermocouple for measuring skin temperature. The agreement was better for the standardization range 90° - 110°F than 80° - 120°F (Tables II. 26 and II. 27).

Reproducibility of values was measured in three ways. First, with the thermistor thermometer standardized for 90° to 110°F, eight consecutive readings under water in a thermos were made at 95.0°, 100.0° and 105°F (as measured with a standard thermometer). The thermistor temperatures were $+0.45^{\circ} \pm 0.07^{\circ}$, $+0.44^{\circ} \pm 0.18^{\circ}$, and $+0.35^{\circ} \pm 0.09^{\circ}$, respectively. Thus the temperature readings

were reproducible within 0.2°F. Second, two areas, one on the upper arm and one on the forearm of two subjects, were marked. Using a 90° - 110°F standardized thermistor, ten consecutive readings were made in each of the four areas. Again the reproducibility was close to 0.2°F. Furthermore, this study revealed that the thermistor should gently touch the skin at an acute

	Forearm	Upper Arm
Subject A	95.9°±0.3°F	96.6°±0.2°F
Subject B	96.3°±0.0°F	97.0°±0.1°F

angle for most reliable and consistent results.

The third study dealt with the reproducibility of temperature measurements under the glove. In one study the glove was put on. Ten consecutive readings were taken but no special effort was made to touch exactly the same spot of forearm skin. The mean temperature was 96.2°F and the standard deviation was ±0.4°. In a second study every effort was made to touch the same skin site. The mean temperature was 96.1°F; the standard deviation was ±0.2°. Since in actual practice, the same observers always measured skin temperature, it is probable that approximately the same skin site was touched from time to time and from subject to subject.

In summary, then, it would seem reasonable to conclude that the Sargent Thermistor Thermometer in our hands could be expected to yield results reliable within 0.2°F. This level of reproducibility for the measurement of skin temperature agrees closely with similar data from the literature. See, for example, the reports of Stillwell, Hemingway and Kottke (1955), Stoll and Hardy (1949, 1950), and Whyte (1951).

Rectal Temperature. The rectal temperature was measured with a Leeds-Northrup rectal thermocouple attached to a direct reading portable potentiometer. The rectal thermocouple was inserted to a depth of five centimeters and held in place for one minute or until a stable reading had been obtained. This depth is one to two centimeters short of the depth recommended by Benedict and Slack (1911) and Mead and Bonmarito (1949) for maximum rectal temperatures.

In actual practice, five thermocouples were connected to the potentiometer through a selector switch. When compared to a standard thermometer, the rectal thermocouples placed under water in a thermos each consistently read 0.2°F low. Since the standard thermometer had a stem correction 0.3°F, the rectal temperature readings were all increased by 0.5°F.

Ambient Weather. A meteorological observer made measurements every 30 minutes during the march of a single flight. He was stationed in the approximate center of the oval course. A sling psychrometer was used for measuring the wet- and dry-bulb temperature and a wind-mill anemometer exposed at a height of five feet for measuring air motion. A total of four readings were taken during exposure of each flight--this because the flight represented staggered groups of five subjects each--and the average values were used as most representative of weather existing at that particular period. Notes were also

made on the state of the sky and amount of precipitation.

4. Sweat

Sweat was collected in clean elbow-length rubber gloves placed on both arms of each subject at the beginning of the test. The upper ends were closed with rubber bands. At the completion of the test the gloves were carefully removed so as not to spill the sweat. The accumulated material from both gloves was pooled in a four-ounce bottle. From the volume the glove sweat rate was calculated as ml/hr. During each test one glove was attached to the belt of a subject; this glove contained about 25 ml of distilled water. The procedure provided an adequate glove blank. The blanks and the sweat samples were subjected to an extensive battery of morphological and chemical analyses.

M. CLINICAL OBSERVATIONS AND METHODS

Each subject was given four complete physical examinations. The first examination was conducted just before the beginning of the pre-period; the other three examinations were conducted at the end of each of the three phases of the test. All examinations were made by the medical officer assigned to the flight. The examinations were conducted according to standard procedures of physical diagnosis (e.g., Pullen, 1944). Relevant histories were obtained at the same time. The observations were noted on special forms designed for the winter trials (Sargent et al., 1955, Volume II, Appendix VI).

Daily progress notes were maintained by the medical officers on the subjects in their flights. These notes documented both spontaneous and elicited complaints with reference to the health and well-being, physical and psychological, of the subjects, together with observations of the medical officer on the condition of the subjects individually or as a group.

Medication was given to the subjects as indicated and every effort was made to keep the use of medicaments for symptom relief to a minimum. Antibiotics were used for the management of upper respiratory infections and pulmonary infections, terpin hydrate for coughs, and kaopectinate and paregoric for diarrhea. An occasional subject required treatment with adrenal cortical preparations. A number of the men who became ill with serious infections of various sorts were also given appropriate intravenous fluids. Diagnostic procedures and hospitalization either at the field Sick Bay or in a military or civilian hospital were employed as circumstances so dictated. The case histories of the 100 subjects are given in Appendix III.

O. COMBINED TESTS

Because of the large number of subjects to be tested, it was necessary to devise systems for obtaining rapidly and accurately the desired metabolic and functional information. The many procedures described in the preceding pages were grouped into several tests, which we have called "combined tests." The protocols for these tests, as they were successfully employed during the summer trials, are discussed in the paragraphs to follow.

1. Three-Hour Test of Organic Function

The protocol for this test is detailed in Table II. 28 and represents a modification of a similar procedure used in the 1954 winter test.

TABLE II. 28

PROTOCOL OF THREE-HOUR TEST

Apparatus:

1. 100 paper cups with four-ounce capacity.
2. 100-ml graduate x 2.
3. 200 50-ml centrifuge tubes with rubber caps.
4. 100 oxalated vials with screw-caps.
5. 100 30-ml syringes, clean, dry, sterile.
6. 200 sterile 19-gage needles in constriction tubes.
7. 200 pint cans with screw-capped closure.
8. 100 metal funnels.
9. Rubber tourniquets.
10. 70% ethyl alcohol.
11. Sterile sponges (2 x 2" cheese cloth).
12. 1 sphygmomanometer.
13. 1 stethoscope.
14. 25 oral thermometers in ice bath.
15. Portable Instomatic Cardiette.
16. Watch.
17. Minnesota Skin Calipers for measurement of skinfold thickness.

Spare Parts:

1. Oral thermometers.
2. Batteries, fuses, and loaded film magazines for cardiette.

Procedure:

1. The subjects will be tested by flights on mornings of two consecutive days each week. One flight will be tested at a time. The subjects will be post-absorptive during the test; i.e., the men will have had no breakfast.

2. The test will be conducted from 0600 to 0900 hours and 0900 to 1200 hours in each of the six weeks of the trial.

3. On days of this test 50% of calories will be fed at two meals.

4. Twenty-five subjects will report to test-station at the assigned times. They will void "by the numbers" into their 24-hour specimen containers.

5. They will recline for 30 minutes during which time the skinfold thickness will be measured according to the method detailed in the Appendix I.

6. The oral temperature will be measured by leaving an oral thermometer under the tongue for five minutes. Thermometers must be issued from ice bath and immediately replaced in ice bath before final reading.

TABLE II. 28 (Continued)

7. The resting respiratory rate will be counted for one minute.

8. After 60 minutes, the subjects will again void into their gallon cans. The exact time will be recorded.

9. They will drink 100 ml of water.

10. They will recline for 15 minutes.

11. While the subject is reclining, the blood pressure and pulse rate will be measured.

12. The subjects will come to attention and again the pulse rate and blood pressure will be measured. This test of orthostatic hypotension (steps 11 and 12) will be conducted on the subjects one at a time.

13. After steps 11 and 12 have been completed, the electrocardiogram will be taken.

14. When the electrocardiogram has been completed a venipuncture will be made. With minimal stasis approximately 90 ml of venous blood will be withdrawn.

15. Five ml of the blood will be transferred to an oxalated vial, one drop to each of two glass slides for the preparation of a smear, and the remainder to two 50-ml centrifuge tubes. Record the time of venipuncture.

16. The subjects will remain reclining after these procedures have been completed.

17. The subjects will void at the end of 120 minutes into the labelled one-pint cans, the exact time of voiding being recorded. If the subject cannot void at 120 minutes he will be required to remain at the station until he can.

18. The blood specimens and urinary specimens will be delivered to the clinical laboratory station promptly for further processing.

Because of the frequent occurrence of rather large minute urinary volumes observed in that test, it was decided that the subjects should report to the testing station, void, recline for one hour, void a second time, and then recline for two hours during which period an accurately timed urinary specimen would be collected. The one-hour urine was added to the regular 24-hour volume. The results of this procedure justified our expectations. We also measured the oral temperature to make possible detection of early hyperpyrexia. The final modification was measurement of standing blood pressure and pulse rate. These measurements were made because it was thought that heat exhaustion might develop. A characteristic of heat exhaustion is an inability of the patient to maintain blood pressure on standing; that is,

they develop orthostatic hypotension. In other respects, the procedure was quite comparable to that used in the winter tests. In this three-hour period, therefore, information was collected on (1) hematology, (2) cardiovascular function, (3) liver function, (4) renal function, and (5) body composition.

2. Resting Metabolism Test

The protocol for this test is detailed in Table II. 29. We added one additional measurement; viz., determination of voluntary maximal hyperventilation. As in the 1954 winter test, information was also collected on (1) pulmonary ventilation, (2) resting oxygen consumption, (3) resting R.Q., (4) subject's judgment of the passage of time, and (5) electroencephalogram. Due to

TABLE II. 29

PROTOCOL OF RESTING METABOLISM TEST

Equipment:

1. Electroencephalograph.
   a. Scalp electrodes.
   b. Electrode paste.
   c. Spare rolls of recording paper.
2. Stop watches, two.
3. Two sets of three gas meters and accessories (see detailed instruction sheets in Appendix I).
4. Four cots, one in each of four rooms.
5. One gas meter setup for maximal ventilation.

Procedure:

1. The subjects will be taken four at a time.
2. They will not be post-absorptive.
3. Two subjects will begin test 30 minutes ahead of the other two. Thereafter, pairs can be run continuously through the sequence detailed below.
4. The tests will be conducted on each of two days between 0730 and 2030 hours by four teams of observers according to scheme shown below. The same subject will be tested at the same time of day during each of the six tests.
5. The subject will recline for 30 minutes.
6. During the first ten minutes of the rest place electrodes and measure the passage of time. During last twenty minutes record the electroencephalogram first on one subject and then on the

second subject.

a. Passage of time: The subject will be handed a stop watch face down and asked to estimate the passage of time-interval stated by the observer. When the subject is ready, he will activate the stop watch; when he judges the stated interval to have passed he will stop the watch and return it to the observer face down. The time will be recorded; the watch zeroed and returned to the subject. The subject may use any mental device he wishes to judge the interval. He may not use his pulse or respiratory rate. He must not be informed of his judgments at any time. The stated intervals will be 20 seconds, 45 seconds, and 70 seconds in that order, on trial being allowed per interval.

SCHEME FOR CONDUCTING RESTING METABOLISM TEST

Time	Team A&B	Team C&D	Team Working Time
0730-0830	1	1	0730-1230: A&C on
0800-0900	1	1	first day and B&D
0830-0930	1	1	on second day.
0900-1000	1	1	
0930-1030	1	1	
1000-1100	1	1	
1030-1130	1	1	
1100-1200	1	1	
1130-1230	1	1	
1200-1300	1	1	1230-1830: B&D on
1230-1330	1	1	first day and A&C
1300-1400	1	1	on second day.
1330-1430	1	1	
1400-1500	1	1	
1430-1530	1	1	
1500-1600	1	1	
1530-1630	1	1	
1600-1700	1	1	
1630-1730	1	1	
1700-1800	1	1	
1730-1830	1	1	
1800-1900	1	1	1830-2030: A&C on
1830-1930	1	1	first day and B&D
1900-2000	1	1	on second day.
1930-2030	1	1	

b. Electroencephalogram: This will be obtained only in week 2 and week 4. The recording electrode will be attached to the scalp above the ear. A three-minute record will be made while the subject is resting with eyes closed, then with the record still progressing the subject will hyperventilate for three minutes, and finally three minutes of record post-hyperventilation will be obtained. The three phases will be identified as R, H, and PH on the record together with the subject's number and the name and the data and time of the test.

TABLE II. 29 (Continued)

7. The subject will arise and move leisurely into a metabolism room and lie down on the cot.

8. The subject will breathe through the gas metabolism device for 2-4 minutes to flush the meters.

9. For ten minutes more, the pulmonary ventilation, oxygen consumption, and CO_2 production will be measured.

10. Between minutes 5 and 6, record respiratory rate. Measure the time for ten complete expirations by watching M_2. Compute respiratory rate, breaths per minute, from the formula breaths/min = (60/secs for 10 expirations) x 10. The attached table (Appendix VI) facilitates this calculation.

11. Record gas temperatures and station-level barometric pressure.

12. Repeat steps 9, 10, and 11.

13. At termination of second metabolism have subject move to a chair in front of the hyperventilation gas meter setup. Record maximal voluntary ventilation for exactly 15 seconds (See Appendix I).

14. Subject is now sent to next station.

15. At leisurely intervals, calculate:
    a. Pulmonary ventilation, liters/min, STP.
    b. Oxygen consumption, ml/min, STP.
    c. CO_2 production, ml/min, STP.
    d. Respiratory quotient, CO_2/O_2.
    e. Heat production, $Cal/m^2/hr$.

16. Record all data on Resting Metabolism Summary (Appendix VI).

the epidemic which occurred principally during the experimental periods, all measurement of resting metabolism was curtailed. Consequently, complete data are available for only PRE I, PRE II, EXP I, and REC II.

3. Program of Testing Subjects Coming Off Experimental Diets Early

It was anticipated that some of the subjects might have to be taken off the experimental regimens before the completion of the 14-day period. Since this exigency might arise at any time, it was essential that a plan be available for conducting all the function tests concurrently. The plan adopted is detailed in Table II. 30, and combines all the important steps of the water diuresis, three-hour, and resting metabolism tests.

TABLE II. 30

TESTING PROGRAM FOR SUBJECTS COMING OFF
EXPERIMENTAL REGIMENS BEFORE COMPLETION OF 14 DAYS

Apparatus:

Equipment required will be that detailed under Three-Hour Test, Resting Metabolism Test, Water Diuresis Test, and Deuterium Oxide Test. In addition, one Leeds-Northrup potentiometer with skin and rectal thermocouples.

Procedure:

1. Void into gallon cans; note exact time. Prepare two four-oz. aliquots labelled "Pre-D_2O."

2. Drink 100 ml of water.

3. Recline for 60 minutes. While reclining, make the following observations:
   a. Measure skinfold thickness according to the method detailed in the Three-Hour Test.
   b. The oral temperature will be measured by leaving an oral thermometer under the tongue for five minutes. Thermometers must be issued from ice bath and immediately replaced in ice bath before final reading.
   c. The resting respiratory rate will be counted for one minute.
   d. Measure rectal temperature with Leeds-Northrup potentiometer and rectal thermometer.
   e. Measure skin temperature of forehead, chest (near right nipple, back (tip of right scapula), right index finger (base of distal phalanx) and right big toe (base of distal metatarsal).
   f. After 20 minutes, the blood pressure and pulse rate will be measured.
   g. The subject will come to attention and again the pulse rate and blood pressure will be measured.
   h. After steps f and g have been completed, the electrocardiogram will be taken.
   i. When the electrocardiogram has been completed a venipuncture will be made. With minimal stasis approximately 90 ml of venous blood will be withdrawn.
   j. Five ml of the blood will be transferred to an oxalated vial, one drop to each of two glass slides for the preparation of a smear, and the remainder to two 50-ml centrifuge tubes. Record the time of venipuncture.

4. Move the subject to the metabolism testing area, and conduct the following test according to standard procedure:
   a. Biological time.
   b. Electroencephalogram.
   c. Resting metabolism.

TABLE II. 30 (Continued)

d. Voluntary maximal hyperventilation.

5. After completion of the resting metabolism test, the subject will void at the end of 120 minutes into the labelled one-pint cans, the exact time of voiding being recorded. If the subject cannot void at 120 minutes, he will be required to remain at the station until he can. This urine will be the basal urine for the water diuresis test.

6. The blood specimens and urinary specimens will be delivered to the clinical laboratory station promptly for further processing.

7. Prepare an oral water load for the subject: body weight (lb) x 9.1 = ml of water to be ingested. Include in this volume 40 gm of deuterium oxide. This volume of fluid must be ingested by the subject within 45 minutes after passing the two-hour urine.

8. At hourly intervals for four hours after passing the two-hour urine, the subject will void into separate cans.

9. The volume of each hourly urine will be measured. Pool these four urinary specimens, mix, and prepare two four-oz specimens in screw-capped brown bottles. Label "D_2O."

10. Allow no more food or water until the end of the 24-hour period and collect the urine in a fresh gallon can. Prepare two four-oz aliquots in screw-capped brown bottles. Label "POST-D_2O."

Disposition of Specimens:

1. Urinary specimens passed on this day will not be included in the 7-day pool.

2. The 7-day pool for this subject will be closed.

3. The two-hour test urine will be processed in the customary fashion.

4. The whole blood, smears, and sera will be processed in the customary fashion.

5. The D_2O specimens will be packed and readied for shipment.

Variations from Procedure:

Depending upon the clinical situation, special bloods and urinary analyses may be requested. Adequate samples of blood or urine should be obtained and should be labelled so as to designate their subsequent use.

O. THE EPIDEMIC AND ITS MANAGEMENT

The most unexpected development during the summer tests was the high incidence of respiratory disease among the subjects and the support personnel. In this section we shall summarize our experience and indicate how we

proceeded to bring the infectious processes under control. In a later section of the report we shall discuss in detail the types of respiratory infections which we encountered, and their impact on the primary physiological, biochemical and nutritional data collected during the course of this investigation.

Among the 100 volunteer subjects, 18% became seriously ill; that is, they suffered from a respiratory disease which requires isolation, bed rest, and antibiotic therapy. Of the 17h persons participating in the field test, 12% had to be hospitalized either locally or at Chanute. The local facilities for hospitalization were a Sick Bay at Camp Atterbury, the hospital at Fort Benjamin Harrison, Indianapolis, and Bartholomew County Hospital at Columbus, Indiana. The reasons for this remarkable incidence of infections especially in the summer, are not at all clear. At the present time, the responsible investigators are seeking to determine the etiology of this epidemic. They are working in collaboration with the Sub-Committee on Respiratory Diseases of the Army Epidemiological Board. The results of their work on this problem will be summarized in the section dealing with diagnosis of the various diseases observed at Camp Atterbury.

The Epidemic. During the pre-period (22 June - 5 July) there were seven cases of infection, four of which were diagnosed as pneumonia. Only one man (Subject 59) had to be evacuated because of the seriousness of his condition. The experimental period (6 July - 1h July) began with two more cases of pneumonia, a case of mastoiditis, and a fatal case of meningococcemia (Waterhouse-Friederichsen's Syndrome). Then the situation rapidly became worse, and in the four days of 12 - 15 July there were ten new cases of infection, many of whom were very sick. Four of the subjects (5, 13, 16 and 20) were from the same flight. With inadequate manpower and facilities to care for these patients and with the entire field test in jeopardy, it was decided to discontinue the experimental period and begin rehabilitation promptly.

Management of the Epidemic. At the time the fatal case developed, it was not clear that we faced an epidemic. When the diagnosis had been established, all personnel who had close contact with Subject 77 were given prophylactic sulfadiazine. When a few of the men in Flight h (limited water, light work) developed crystalluria, the water allowance of the entire flight was promptly raised to 2700 ml/day. The men went through the three days of prophylaxis without further complications.

The fatal case, however, prompted us to acquire more antibiotics and cortisone so that we might be prepared in the event of further trouble. Our only antibiotic at that point had been penicillin in oil for intramuscular administration.

It was our good fortune that Colonel Jack Bollerud was visiting Camp Atterbury at the height of the epidemic (July 13 - 1h); because of the serious nature of the situation, a conference was held with him. The decisions of the conference were (1) to air evacuate all men sick at the time and any new cases which might appear, (2) to terminate the experimental period as rapidly as possible, (3) to keep the four groups of subjects isolated one from another

as much as feasible until the epidemic subsided, and (4) to give all men in Flight 1 prophylactic penicillin.

The decisions were implemented with support from Chanute AFB for air evacuation and medicaments and from the Post Engineer, Captain Hartong, in arranging for more housing for the subjects. Each flight was housed in a separate barracks with half the men living upstairs and half downstairs. They slept head-to-foot in beds separated by about six feet. Each flight was fed at a separate mess. Measurement of respiratory metabolism was discontinued until the epidemic had subsided.

The epidemic rapidly subsided and only one additional case of bronchopneumonia developed in the recovery period (Subject 68). The only other seriously ill subject was No. 19 who had mastoiditis.

Because there were no new cases of respiratory disease within the three-day interval following 15 July, the subjects began to eat together at the evening meal on 18 July. They continued to live in separate barracks. On 19 July testing began again. Because the epidemic subsided so rapidly, it is difficult to attribute the break of incidence to the measures adopted.

P. STATISTICAL METHODS

Statistical procedures similar to those used in analyzing the data of the 1953 temperate study and the 1954 winter study were repeated during the analysis of observations and data collected in the 1955 summer tests. Because of the importance of the concepts of control used in these two studies, we shall reiterate the material published in the report of the first trial (Sargent et al., 1954).

1. The Concept of Own-Control

The design of the present investigation was that common to all clinical investigation; viz., repetition of critical observations on the subject in a pre-period with those of the experimental and recovery periods. By this device the measurements of the pre-period can arbitrarily be equated to 100 and the data of the experimental and recovery periods expressed as a percentage of the pre-period measurement. The results of the several critical observations are thus expressed in units independent of the original observations and the order of magnitude of deviations from the pre-period or control values becomes readily apparent.

It is a known fact that individuals differ one from another with respect to the exact value of a given physiological or biochemical measurement. This inter-individual variability--the so-called normal range--may prejudice statistical analyses when absolute values are used in the mathematical treatment. On the other hand, the concept of own-control allows this potential bias to be minimized. When the individual control data are set equal to 100, the changes in the experimental and recovery periods can be expressed as averages which are not prejudiced by the influence of one individual. This mathematical procedure was used in studying the effects of the several experimental regimens on a great

many of the functions of organs and systems and different biochemical levels in the several biological fluids.

2. The Concept of Positive and Negative Control

Reference standards had to be established for interpreting the data collected while the subjects subsisted on the several experimental nutrient mixtures. By definition, a fixed intake of 3000 Cal/man/day was identified as the "positive control." (In the winter of 1953 this regimen was made from components of the 5-in-1 ration; in the 1954 winter and 1955 summer trials the 15/52/33 regimen was fed at 3000 Cal/day.) This regimen was pictured as that most closely approaching the subjects' usual diet. The distribution of calories approximated those of the pre- and recovery periods and was very similar to that reported for voluntary food consumption by troops residing in temperate climates (Johnson and Kark, 1947). Subsequent analysis of the data on caloric expenditure indicated that the men in Flight 3 (light work, unlimited water) used up about 3000 Cal/day. These subjects of this flight who subsisted on this regimen lost relatively little body weight during the 14-day interval on this regimen. Most of the functional data showed little change. In general, then, this positive control fulfilled our idea of a reference standard. A negative standard was also needed. By definition, starvation was pictured as the "negative control." This regimen produced marked changes in body weight; the physiological reactions to the several experimental nutrient mixtures would fall somewhere within the range delimited by positive control and negative control. The more nearly the reactions approached those of positive control, the less presumably was the nutritional stress. The more nearly the reactions approached those of negative control, the greater presumably was the nutritional stress. Perhaps evaluation of the data within this conceptual frame would lead to practical information regarding the feasibility of an all-purpose or at least a multi-purpose survival ration.

From the statistical point of view, positive and negative control can be visualized as the upper and lower limits of variation in physiological processes and biochemical levels in this investigation. Generally speaking, positive control was the optimum nutrient mixture. It should follow, then, that a measurement expressed as a percentage of the pre-period average should remain, within the limits of experimental error, at 100% in the experimental and recovery periods. The maximum deviation, plus or minus, from 100% should occur in negative control---except when subsisting on a given mixture may be worse than eating nothing! The other nutrient mixtures should give values within the limits described by positive control and negative control. The differences between the measurements made during the 1000- and 2000-Calorie regimens and those made in the control regimens can be evaluated statistically and assist in drawing conclusions regarding the best possible nutrient mixture for survival. This attitude of mind has been adopted in this investigation in the analysis of the entire body of observational material.

3. The Concept of Paired-Feeding

The three investigations, and particularly the two field investigations, have taken advantage of the technique of paired-feeding. Each nutrient regimen has been tested under four different conditions; namely, hard work,

unlimited water; hard work, limited water; light work, unlimited water; light work, limited water. Groups of two to four subjects have subsisted on each nutrient regimen under each of these four conditions; therefore, it has been possible to compare the separate effects of work and water on the reactions of the subjects to a given regimen. Since every regimen studied has been tested under these conditions, we can, in the final analysis, arrive at specific conclusions regarding the nutrient regimens which provoke the least and the most deterioration in the function of the organs and systems of the body; i.e., the regimens can be ranked from the least to the most deleterious.

4. The Concept of Ration Control

Although a packaged ration, such as the 5-in-1 ration, may provide an adequate control ration, it is still not a "normal" diet. The usual diet of Americans does not consist entirely, or even largely, on packaged items. Thus, the 5-in-1 components do not provide an ideal control ration. Furthermore, the components of this ration are not merely packaged but processed to meet special military specifications regarding stability and utility under conditions not ordinarily encountered by ordinary commercially packaged items. To our knowledge there is no adequate proof that a diet of rations prepared to meet military characteristics has the same nutritional and physiological effects on man as a diet comprised of foods customarily eaten by Americans. A rigorous test has never been made in which subjects living on the 5-in-1 ration, for instance, have been compared with subjects living on standard garrison rations. Because a doubt was present, in our minds at least, regarding the 5-in-1 ration, we assigned 12 of the volunteer subjects to a FRA group. These men were ration controls in that they subsisted throughout the period of study on Field Ration A, and they took part in all the activities and tests as the members of their respective flight did. In the summer test we were in a better position to judge the meaning of differences with regard to physiological function and biochemical levels between the ration controls and the volunteer subjects. The ration controls of the summer tests were of a comparable age group and represented the same type of general background, both physical and cultural, as did the experimental subjects; consequently, the major difference between these two groups was one of diet.

The ration controls also served in two other useful capacities. In the first place, any trends due to the procession of the seasons would be reflected by the ration controls. In the second place, non-specific reactions to the several conditions of the trial would be reflected by the ration controls. Such information would provide a basis for deciding whether or not a given nutrient mixture rather than the work load or the non-specific factors of the trial was the cause of a significant alteration of a physiological process or a biochemical level.

5. Statistical Analyses

Throughout the report the statistical procedures and terms are the same as those described by Rider (1939) and Croxton (1953).

Average and mean are used interchangeably and in both cases refer to the arithmetical mean.

The variance of a set of data from the mean has been measured in two ways: (1) standard deviation and (2) coefficient of variation. The standard deviation has been calculated from the equation:

$$(s.d.)^2 = \frac{1}{N} \Sigma (X-\bar{X})^2$$

where s.d. = standard deviation.

The coefficient of variation was calculated from the equation: $C.V. = \frac{(s.d.)}{M}$ X 100 where C.V. = coefficient of variation and M arithmetical mean.

The "t" test was used to analyze the significance of the difference between means. The Chi Square test was employed to determine the statistical significance of changes in frequency distributions. At a later date it is planned to perform analysis of variance on these data. The University's digital computor, Illiac, will be utilized.

6. Validation of All Methods

Most of the procedures used in this investigation were validated in the hands of the individual responsible for the particular method. In some instances, validation was rather elaborate. In the case of all chemical methods, recovery studies were performed. In general, ten recovery experiments were done before results were accepted as satisfactory. In all such cases the material recovered was 95-105% of that added. For the routine chemical work, the analyses were done "in duplicate."

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A. INTRODUCTION

1. General Results

This report presents the results of metabolic investigations made upon 100 volunteer airmen, 12 of whom served as ration controls. During the 36 days of continuous observation, food and water intake were measured daily, all urine and feces were collected, blood was drawn weekly, functional tests were conducted weekly, and four complete physical examinations were made. Since the objective was to evaluate the effect of 40 different experimental regimens on the efficiency of the body as a whole and changes in the function of the organ systems, many kinds of data were recorded for each subject. Literally thousands of analyses, mostly in duplicate, were made of blood, urine, and feces. Various functional tests accounted for several thousand more observations. Daily entries were made for each of the 88 subjects for 17 quantitative aspects of the nutritive intake. From these nutritional figures several hundreds of thousands of intermediate calculations were made to arrive at the final entries. For the 100 subjects, then, over 100,000 individual accurate quantitative entries were required from which numerous averages, ratios, and statistical analyses and graphs were prepared for the present section.

In the main, results will be presented according to the organs and systems of the body which were studied. In each part of the text dealing with a particular system or organ, the material will be subdivided according to experimental nutrient mixture, and further subdivided according to work output, whether hard or light. Original data will be summarized in figures and tables similar to those presented in previous technical reports (Sargent et al., 1954, 1955) giving means and various measurements of variance. The actual original data will be found in various appendicies (Volume II of the present report). The integration of this large mass of data leading to conclusions regarding the experimental nutrient mixture for survival under temperate cold and hot conditions will be dealt with in Section IV: Discussion.

2. The Weather

An extensive battery of meteorological observations were made by the weather observer, S/Sgt. Hanley. An instrument shelter was improvised in the Headquarters Area. This shelter contained standard U. S. Weather Bureau maximum and minimum thermometers and a thermograph. Observations on dry bulb and wet bulb temperatures were made three times daily--0730, 1230, and 1630 hours--with a sling psychrometer. Additional observations were made at these times on wind velocity and direction, cloud cover, precipitation, and barometric pressure. Some of these records have been summarized in Table III. 1.

Study of this table and Figure III. 1 indicates that the weather was, indeed, hot throughout the field test. In the pre-period the mean maximum and minimum temperature were 90° and 60°, respectively. The relative humidity at 1630 hours averaged 49%. The weather was relatively cool in the first week, for on five days the maximum temperature did not exceed 90° and the minimum frequently fell to the low 50's. In the second week, it was hot and humid. On two of these days

the maximum temperature rose above 100°.

The experimental period was consistently hot. The mean maximum and minimum temperatures were 94° and 67°, respectively, and the relative humidity at 1630 hours averaged 57%. The maximum temperature exceeded 90° on each of the nine days and the minimum temperature was below 65° only twice. Never, however, did the maximum temperature exceed 100°.

The weather continued hot in the recovery period. The maximum and minimum temperatures averaged 94° and 68°, respectively, and the mean relative humidity at 1630 hours was 58%. On only two days did the maximum temperature fail to rise above 90°. On two days it rose above 100°.

During the entire 36-day period of the test, the maximum temperature ranged from 72° to 105°. The mean was 92°. The minimum temperature ranged from 52° to 75°. The mean was 65°. The relative humidity at 1630 hours averaged 54%. The fact that each of the three periods was consistently hot indicates that the weather will not be a major variable in inter-period comparisons.

3. Daily Work Load

In addition to the weather another major consideration controlled the daily planning of the study: daily work load. It was planned to study two kinds of survival situations. The first required the castaway to escape and evade by travel; the second required the castaway to remain in one spot surviving there until rescued. In the field phase of the present study, half the subjects simulated escape and evasion by marching 12 miles a day while the other half remained almost sedentary. The results of the study did emphasize many significant differences between these two kinds of survival.

FIGURE III. 1. DAILY MAXIMUM AND MINIMUM TEMPERATURE, CAMP ATTERBURY, INDIANA.

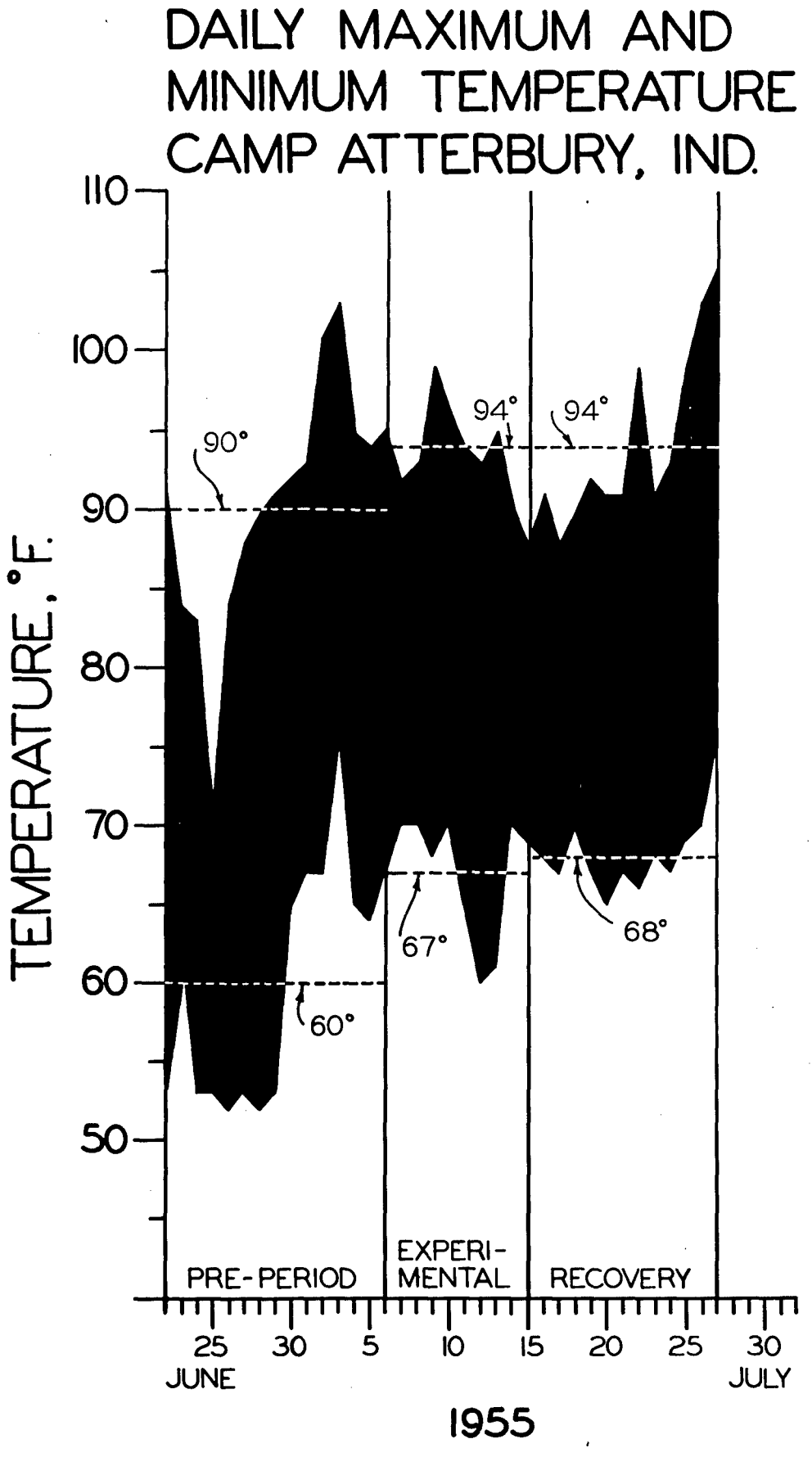

DAILY MAXIMUM AND MINIMUM TEMPERATURE CAMP ATTERBURY, IND.
TEMPERATURE, °F.
110
100
90
80
70
60
50
90°
94°
94°
67°
68°
60°
PRE-PERIOD
EXPERI-MENTAL
RECOVERY
25
30
5
10
15
20
25
30
JUNE
JULY
1955

TABLE III. 1

METEOROLOGICAL OBSERVATIONS
HEADQUARTERS AREA
22 June - 27 July 1955

Date	Temp. (°F) Max.	Min.	* 1630 Rel. Humidity (%)
June 22	91	58	43
23	84	60	44
24	83	53	67
25	72	53	75
26	84	52	38
27	88	53	40
28	90	52	40
29	91	53	44
30	92	65	38
July 1	93	67	42
2	101	67	56
3	103	75	51
4	95	65	51
5	94	64	56
Mean Pre	90	60	49
6	95	67	46
7	92	70	54
8	93	70	81
9	99	68	81
10	96	70	53
11	94	65	35
12	93	60	34
13	95	61	34
14	90	70	99
Mean Exp	94	67	57
15	88	69	65
16	91	68	64
17	88	67	63
18	90	70	78
19	92	67	67
20	91	65	50
21	91	67	57
22	99	66	36
23	91	68	57
24	93	67	83
25	99	69	49
26	103	70	40
27	105	75	41
Mean Rec	94	68	58
Mean	92	65	54

*The 1630 observation was closest in time to the daily maximum temperature.

B. BALANCES

1. Calorie Balance

Pre-Periods. In the first pre-week, the flights consumed an average of 3610 Cal/man/day; during the second pre-week food consumption dropped to an average of 3355 Cal/man/day (Table III.2 A). In these same weeks, average balances were +430 and +155 Cal/man/day respectively (Table III. 2 B). These slight positive balances would be expected in healthy young men of the age group of these subjects. The decreased balance of the second week was due entirely to a slight decrease in food intake, because the mean caloric expenditure was practically constant in the two weeks, averaging 3165 Cal/man/day in PRE I and 3195 in PRE II (Table III.3).

Experimental Periods. As compared with pre-periods, caloric expenditure increased in the hard work Flights 1 and 2, and decreased in the light work Flights 3 and 4 (Table III. 3). Because of an accelerated testing schedule, the hard work Flights 1 and 2 expended fewer calories daily in the second experimental period than in the first. There was no change in the expenditure of the light work Flights 3 and 4 during the second experimental week. There is an apparent discrepancy in the data for expenditure: The total caloric output for the hard work groups was only slightly greater than for the light work groups. This discrepancy is explained by the fact that the average body weights of the hard work groups were substantially less than that of the light work groups in the experimental periods. The apparent discrepancy disappears if we examine the caloric expenditure per kilogram body weight (Table III. 4). Flights 1 and 2 marched 12 miles per day and per kilogram body weight expended about 10% more energy than Flights 3 and 4.

Caloric intakes during the experimental period approximated closely those demanded by the experimental planning: 0, 1000, 2000, and 3000 Cal (Tables III. 5; Figures III. 2 and III. 3).

Caloric balances became negative in all groups, in inverse proportion to the caloric intake. Only the groups on 15/52/33 3000 approached positive balance (Table III. 6; Figures III. 2 and III. 3). The only two contributing factors to the balance were gross caloric intake and caloric expenditure. In the dehydrated groups, balances tended to be slightly more favorable than in the hydrated groups, because the former lost more weight.

Recovery Periods. Rehabilitation was accomplished by step-wise increases in food allowances. Hence, in the first recovery period, intakes and balances approximated those of the pre-periods. In the second recovery period, the subjects were permitted to eat as much as they wanted, and their food consumption rose on the average to about 5000 Cal per day. At the same time, their caloric balances became strongly positive as they repaired the deficits of the experimental periods. Previous caloric intakes, protein/fat/carbohydrate ratios, and water intake bore no apparent correlation with recovery intakes or balances.

TABLE III. 2

PRE-PERIOD DATA ON MEAN CALORIC INTAKE AND BALANCE
(Cal/day)

Flight	P I Mean	P I Range	P II Mean	P II Range
		A. Intake		
1	3520	2730 - 4490	3370	2410 - 4160
2	3490	2560 - 4470	3220	2660 - 4210
3	3790	2600 - 5760	3600	1480 - 5550
4	3630	2800 - 4450	3230	1950 - 3980
FRA	----	-------	4130	3580 - 4730
		B. Balance		
1	+375	-460 to +960	+160	-600 to +770
2	+400	-555 to +1390	+135	-845 to +1100
3	+470	-1080 to +2255	+230	-1735 to +1910
4	+480	-255 to +1270	+90	-1335 to +795
FRA	----	-------	+315	-1330 to +1415

TABLE III. 3

DAILY CALORIC EXPENDITURE
(Mean and Range)

Period	Flight 1	Flight 2	Calories/day Flight 3	Flight 4	FRA
PRE I	3140	3100	3260	3150	4070
	2690-4190	2530-3970	2630-3680	2680-4180	3540-4730
PRE II	3210	3070	3370	3140	4130
	2790-3950	2520-3930	2720-3760	2660-4190	3580-4730
EXP I	3350	3130	3120	2870	4180
	2840-4330	2510-3890	2560-3520	2470-3110	3660-4750
EXP II	3260	2910	3110	2880	4150
	2740-4180	2370-3410	2540-3540	2480-3150	3530-4810
REC I	2920	2710	2950	2660	4150
	2520-3690	2100-3180	2440-3340	2250-2910	3540-4800
REC II	3240	2980	3220	3120	4180
	2770-3970	2410-3500	2670-3570	2680-3470	3650-4800

TABLE III. 4

CALORIC EXPENDITURE PER KILOGRAM BODY WEIGHT, EXPERIMENTAL PERIODS

Period and Distribution of Expenditure	Flight 1	2	3	4
		Cal/kg/day		
EXP I				
Rest	9.1	9.1	8.7	8.8
Light Work	24.2	24.2	32.6	32.3
Hard Work	18.8	18.8	5.2	5.2
Total	52.1	52.1	46.5	46.3
EXP II				
Rest	10.1	10.1	7.9	8.1
Light Work	27.0	24.9	34.1	33.4
Hard Work	14.0	14.0	5.2	5.6
Total	51.1	49.0	47.2	47.1

TABLE III. 5

CALORIE INTAKE (Summer 1955)
(Calories/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	3310	3220	0	170	3010	4785	3705	3375	0	0	2685	5255
	L	3345	2945	0	0	2650	5315	3920	3410	0	0	2850	5310
0/100/0	U	3525	3020	1000	1000	2770	5135	3950	3575	995	830	2770	4905
1000	L	3795	3455	1000	1000	2685	5095	3610	3325	1000	1000	2640	5770
0/100/0	U	3720	3850	1845	2000	3140	4850	3745	3200	2005	2005	3145	4755
2000	L	3995	3255	2005	2005	3175	4710	3545	2465	2000	2005	3110	5390
2/20/78	U	3575	3680	1000	1000	2685	6005	3560	2640	1000	1000	2720	5285
1000	L	3605	3140	1000	1000	2700	4745	3775	3085	1000	1000	2760	4935
2/20/78	U	4000	3480	2005	2005	3235	N.D.	2600	2670	2005	2005	3115	4440
2000	L	3320	3250	2005	2005	2985	4670	3700	3170	1940	2005	3015	4580
15/52/33	U	3460	3060	1015	1015	2670	4830	3875	3990	1015	1015	2770	4595
1000	L	3140	2990	1015	----	----	----	3560	3315	1015	1015	2815	5105
15/52/33	U	3105	3060	2015	2015	3075	3550	4165	4130	2015	2015	3215	5740
2000	L	3650	3410	2015	2015	3245	5370	3420	3220	2015	2015	3215	4465
15/52/33	U	3160	3015	3015	3015	3030	4075	5285	5100	3015	3015	3230	5420
3000	L	3675	3750	3015	3015	3120	4625	3965	3785	3015	----	----	----
30/0/70	U	3665	3705	1000	1000	2745	5270	2860	3115	995	995	2690	3325
1000	L	3450	3305	1000	1000	2655	4245	3320	3020	995	995	2450	4800
30/0/70	U	3850	3555	1995	1995	3180	5275	3265	3870	1995	1995	3180	5240
2000	L	3360	2850	1995	1995	3115	4175	3155	3305	1995	1995	3200	5480
FRA		----	4480	----	3830	3920	4375	----	4480	----	3830	3920	4375

TABLE III. 6

CALORIE BALANCE (Summer 1955)
(Calories/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	+115	-25	-3235	-2800	+180	+1675	+405	-15	-3070	-3000	-145	+2060
	L	+320	-50	-3015	-2740	+120	+2335	+825	+315	-2855	-2735	+275	+2190
0/100/0 1000	U	+595	-30	-2115	-2220	-100	+1975	+1070	+580	-1750	-1885	+170	+2075
	L	+940	+635	-1885	-1705	+205	+2390	+475	+190	-1925	-1920	-15	+2635
0/100/0 2000	U	+555	+575	-1525	-1235	+240	+1720	+330	-320	-1225	-1280	-5	+1375
	L	+425	-70	-1455	-1280	+180	+1480	+410	-600	-690	-695	+250	+2080
2/20/78 1000	U	+485	+460	-2275	-2140	-105	+2875	-365	-1035	-2190	-2170	-270	+2005
	L	+585	+145	-2055	-1875	+35	+1835	+710	+35	-1850	-1800	+165	+1900
2/20/78 2000	U	+855	+200	-1420	-1595	+65	N.D.	-1080	-1090	-1260	-1305	-15	+1085
	L	+185	+150	-1220	-1050	+120	+1625	+665	+145	-910	-1095	+195	+1420
15/52/33 1000	U	-20	+180	-2710	-2500	-415	+1450	+625	+595	-2125	-2110	-175	+1625
	L	+70	-10	-1985	-----	----	-----	+510	+250	-1850	-1845	+200	+2025
15/52/33 2000	U	+365	+205	-995	-855	+535	+805	+650	+475	-1425	-1440	-35	+2200
	L	+630	+390	-1255	-1085	+355	+2200	+290	+110	-890	-960	+480	+1425
15/52/33 3000	U	+255	+25	-150	-90	+290	+1120	+1805	+1425	-435	-455	-35	+1940
	L	+775	+690	-205	-40	+305	+1605	+305	+115	+625	-----	----	-----
30/0/70 1000	U	+300	+210	-2575	-2435	-300	+1905	-150	+35	-1865	-1835	-20	+405
	L	-30	-160	-2460	-1835	+25	+1375	+305	+15	-1775	-1790	-85	+1785
30/0/70 2000	U	+425	+5	-1690	-1555	+40	+1845	+415	+890	-780	-765	+535	+2315
	L	+325	-150	-860	-875	+405	+1230	-45	+110	-1065	-1155	+240	+2010
FRA		----	+315	-----	-405	-360	+200	----	+315	-----	-405	-360	+200

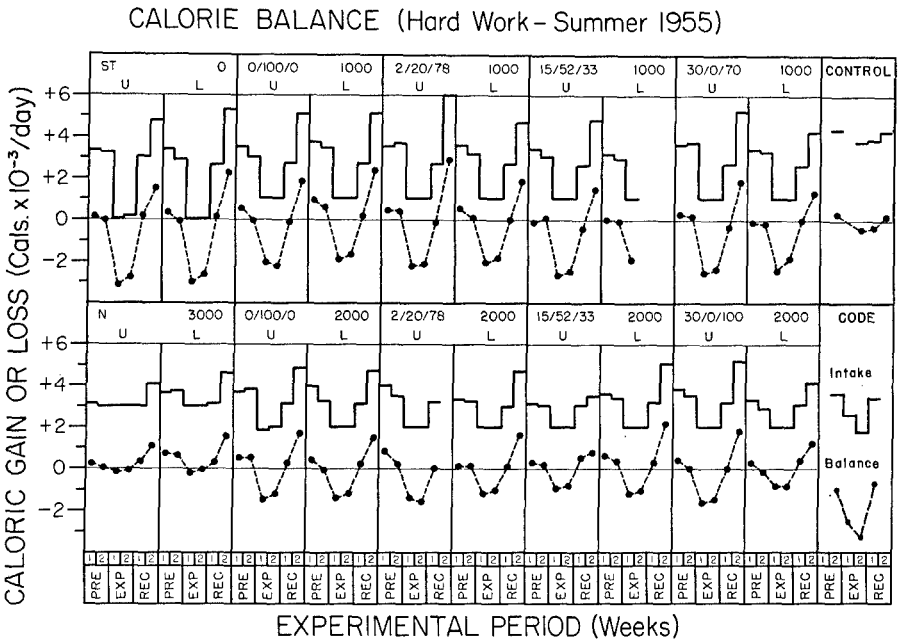


FIGURE III. 2. CALORIE BALANCE: HARD WORK.

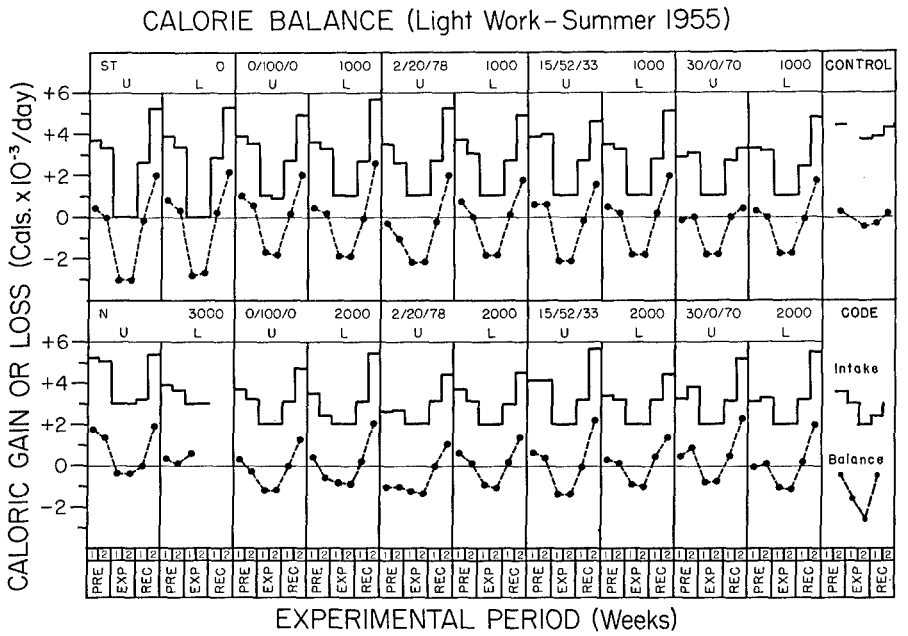


FIGURE III. 3. CALORIE BALANCE: LIGHT WORK.

2. Water Balance

Pre-Periods. Intake included fluid, water preformed in food, and metabolic water (Table III. 7 A). In the first week it averaged about 3.7 liters/day; it averaged over 4 liters/day in the second week, because the weather became hot. Balances (including corrections for dermal and pulmonary losses) were slightly positive in the first week and slightly negative in the second week (Table III. 7 B). The "ideal controls" were studied every other week, and remained in balance with an intake averaging about 5 liters/day.

Experimental Period: Water Intake. The original plans called for only 910 ml of water/day for subjects whose water intake was to be limited. After the first three days, cases of anhidrosis and hypohidrosis began to develop in Flights 2 and 4. Because of the gravity of this situation, it was decided that 910 ml per day was dangerously inadequate for these hot, moist conditions and on July 8 the water allowance of hard work Flight 2 was increased to 2730 ml/day and light work Flight 4 was permitted 1820 ml/day. No further change was made for Flight 2; but the situation deteriorated in Flight 4, and on July 10 a water diuresis test was given to all members of that flight. Starting on July 11 they received 2730 ml of water/day for the rest of the experimental period. The data in Table III. 8 and Figures III. 4 and III. 5 should be viewed with these changes of intake in mind. The clearest picture of the effects of enforced deprivation will be seen in EXP I (Table III. 8). The largest voluntary intakes in both flights were associated with the regimens of highest osmotic effect---2/20/78 2000, 15/52/33 2000 and 3000, 30/0/70 2000, and FRA. Regimens of smallest osmotic effect diminished thirst, as in 0/100/0 1000 and 2000 and STO. Even with an increased water allowance, the restricted groups never reached the intake of the unlimited groups.

Experimental Period: Urine Volume. Regardless of nutrient combination, urine volume tended to correlate with water intake (Table III. 9). With the single exception of ST 0 in EXP II, those on limited water excreted less urine than those on unlimited water. The smallest urine volumes were observed in the regimens of smallest osmotic effect, 0/100/0 1000 and 2000. Osmotically obligated water must be excreted, and this fact accounts for the small increases from regimen to regimen in water restriction in relation to the osmotic excretion.

In EXP II the urine volumes of the restricted subjects increased as the water allowance increased. Nevertheless, except in ST 0, the urine volumes of the restricted subjects remained below that of the unlimited paired subjects.

Experimental Period: Dermal and Pulmonary Water Loss. In EXP I these losses were very similar to those of PRE II (Table III. 10). In 17 of 19 paired comparisons, the limited subjects lost less than the unlimited subjects, presumably because of differences in body weight. The same tendency had been present in PRE II, when water intake was unlimited for all subjects. In EXP II, the hard work flights were not so active as they had been in EXP I and their losses were slightly smaller.

Experimental Period: Water Balance. With the single exception of

2/20/78 2000 L, all groups of subjects in all flights were in negative water balance in both experimental periods (Table III. 11; Figures III. 4 and III. 5). Part of this negativity is explained by the fact that all were losing weight and therefore there would be an "automatic negative water balance" as water accompanies the excretory products of the lost body tissue. A contribution to this negativity would also be made by enforced water deprivation, especially in EXP I in Flight 4. A further contribution would be made by the "involuntary dehydration" caused by loss of thirst in ST 0, and in the low osmotic diets 0/100/0 1000 and 2000.

When the water intake was increased in Flights 2 and 4, negativity tended to be less in EXP II than in EXP I among the restricted subjects. Among the unrestricted subjects, there was an amelioration in the hard work groups, because they worked less hard and sweated less. In the light work groups, the unrestricted subjects remained about the same. Under all conditions, ST 0 had the greatest negativity. Other correlations with the regimen are not very apparent.

Recovery Periods. During recovery, the water deficits of the experimental period were repaired, and positive water balances were obtained. Water intake increased to as much as 7 liters/day, and urine volumes increased sharply. Even by the end of REC II, however, the subjects had not yet fully restored the losses of EXP I and EXP II, and among the 37 individual regimens, balances were still negative in 32. As would be expected, those who had been doing hard work tended to have the largest negative balances in EXP II.

TABLE III. 7

PRE-PERIOD DATA ON
WATER INTAKE AND BALANCE
(l/day)

	P I		P II	
Flight	Mean	Range	Mean	Range
		A. Intake		
1	3.64	2.68-4.54	4.12	3.22-5.33
2	3.61	2.78-4.84	3.75	3.18-5.08
3	4.07	3.26-5.12	5.30	3.76-7.18
4	3.84	3.02-5.00	4.54	3.60-5.40
FRA	----	---------	4.96	3.93-5.75
		B. Balance		
1	+0.18	(-0.50)-(+1.21)	-0.18	(-0.60)-(+0.31)
2	+0.27	(-0.22)-(+0.83)	-0.42	(-1.69)-(+0.19)
3	+0.05	(-0.34)-(+0.37)	-0.06	(-0.87)-(+0.52)
4	-0.09	(-1.23)-(+1.32)	+0.06	(-1.20)-(+0.56)
FRA	-----		-0.01	(-0.03)-(+0.04)

TABLE III. 8

WATER INTAKE
(ml/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	3080	3620	2515	1370	2815	3890	3775	5025	2725	2325	4195	4670
	L	3340	3595	1730	1785	3480	4690	4025	4670	1390	2385	3910	5405
0/100/0	U	3380	3955	3450	2930	3155	4710	4220	5280	3020	2260	4615	4940
1000	L	4060	3900	2050	2290	3310	5190	3540	4710	1495	2635	3980	5270
0/100/0	U	4385	4620	4200	3520	4000	5090	4150	4960	3250	2980	4190	5045
2000	L	3940	3645	2140	2580	3930	4245	3340	4360	1730	2200	4840	5315
2/20/78	U	3790	4145	3250	5060	4460	5770	3605	4355	3195	3000	3675	4955
1000	L	3190	3630	2060	2605	3385	4180	4510	4100	1570	2825	5025	5390
2/20/78	U	4040	4110	3100	4250	4190	----	3505	4740	3330	3600	4610	4410
2000	L	3255	3445	2250	3890	3335	4460	4085	4560	1730	3000	4635	5660
15/52/33	U	3590	4470	3360	3365	3960	4870	4460	5365	3540	3265	4060	4770
1000	L	4320	4240	3180	----	----	----	4250	4600	1670	2930	4130	5450
15/52/33	U	3325	3615	3140	3305	4780	4290	5085	6870	6135	5475	6565	7400
2000	L	3675	3680	2360	3105	4220	4815	3455	4395	1900	3070	4070	5040
15/52/33	U	3620	4135	4575	4925	4690	4930	4805	6990	4515	3940	4825	5965
3000	L	3990	4225	2575	3280	4480	5330	3960	4930	----	----	----	----
30/0/70	U	3475	4175	3590	3130	3370	4790	3300	4240	3250	2970	3790	3440
1000	L	3350	3810	1970	2385	3100	3850	3615	4400	1550	2530	3570	4250
30/0/70	U	4265	4810	4750	4885	4940	5580	3570	4715	4850	4430	4300	5160
2000	L	3390	3545	2205	2625	4455	4860	3415	4560	1790	2945	3600	4670
FRA		----	4960	----	4835	4810	6930	----	4960	----	4835	4810	6930

TABLE III. 9

URINE VOLUME
(ml/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	1175	880	785	790	1315	1275	1410	1060	1520	1325	1025	1665
	L	1335	1080	635	1030	1180	1580	1790	1390	700	1605	1300	2465
0/100/0	U	1335	1060	1380	970	990	1680	1675	1255	1645	1285	1320	1870
1000	L	1530	1195	405	615	1065	1670	1465	1125	485	1150	1475	1930
0/100/0	U	1970	1395	1590	1205	1970	1885	1455	1090	1220	935	1185	1345
2000	L	1290	890	345	355	830	1305	1470	930	585	890	1440	1880
2/20/78	U	1200	1140	930	1950	1270	1980	1425	1250	1570	1770	900	1850
1000	L	1270	1085	450	875	1070	1320	2215	1745	680	1385	2175	2295
2/20/78	U	1965	1460	1225	1620	1645	----	1260	910	1180	1595	1200	1500
2000	L	1330	1025	615	465	1200	1720	1725	1240	690	860	2580	2420
15/52/33	U	1435	1485	835	890	985	1430	1775	1450	1590	1455	1235	2500
1000	L	1850	1750	590	----	----	----	1730	1415	645	920	2055	1930
15/52/33	U	1465	1320	1135	1030	1060	1280	2410	2460	3830	3715	3350	3805
2000	L	1275	1055	850	930	1110	1490	1280	1080	695	785	1395	1585
15/52/33	U	1885	1320	1455	2325	1440	1690	1960	1330	1570	1205	1260	1755
3000	L	1750	1435	820	1045	1850	2045	1465	1245	----	----	----	----
30/0/70	U	1585	1050	1165	1400	1040	1480	1320	850	1720	1150	920	1170
1000	L	1260	1160	870	940	1210	1340	1330	920	705	1025	1295	1575
30/0/70	U	2015	1665	2180	2255	1460	2280	1695	1230	3395	2960	1330	1770
2000	L	1280	965	975	1185	1535	1915	1015	925	1360	980	1120	1360
FRA		1345	1240	1415	1500	1500	1640	1345	1240	1415	1500	1500	1640

TABLE III. 10

ESTIMATED DERMAL AND PULMONARY WATER LOSS
(ml/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work PRE I	Light Work PRE II
ST 0	U	2125	2935	2815	2780	1835	2545	2210	3960	2325	2365	2460	2665
	L	1900	2825	2790	2485	1645	2015	1395	3300	2165	2055	2220	2385
0/100/0	U	1730	2860	3305	3055	2180	2760	2260	4165	2675	2735	2930	2915
1000	L	1920	3055	2805	2540	1910	1855	2425	3250	2530	2590	2280	3065
0/100/0	U	2140	3525	3360	3095	2050	2685	2450	3890	2800	2845	3020	3220
2000	L	2290	3035	3165	2825	2210	2450	2680	2975	2595	2460	2410	3110
2/20/78	U	1875	3120	3530	3355	2110	2490	2040	3445	2290	2320	2740	2720
1000	L	1705	2715	2555	2295	2000	2025	2000	2920	1975	2020	1775	3175
2/20/78	U	1840	2785	3395	2970		----	2140	3480	2955	3015	2800	2610
2000	L	1600	2745	2905	2610	1980	1965	2445	3235	1925	1850	2290	2890
15/52/33	U	1975	3290	3730	3445	2125	2715	2480	4075	2380	2425	2630	2350
1000	L	1990	3675	3970	----	----	----	2220	3250	2180	2235	2195	2940
15/52/33	U	1490	2515	3855	2655	1780	----	2600	4300	2655	2705	2955	3110
2000	L	1715	3195	3300	2950	2110	2680	2145	3135	2325	2390	3275	2540
15/52/33	U	1600	2835	3775	3490	1940	2275	2830	5385	3575	3665	3795	3960
3000	L	1815	3080	2680	2850	1925	2090	2580	3280	----	----	----	----
30/0/70	U	1210	3105	3525	3270	1900	2540	1930	3320	1990	2030	2070	2300
1000	L	1830	2855	3040	1640	1220	1310	3300	3190	2255	2290	2300	3215
30/0/70	U	2235	3035	3225	2995	2160	2505	2015	3275	2265	2305	2360	2515
2000	L	1910	2640	2850	2645	1840	2145	2470	3375	2140	2180	2120	2650
FRA		2240	3635	3210	3210	3175	2855	2240	3635	3210	3210	3175	2855

TABLE III. 11

WATER BALANCE
(l/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	-0.07	-0.24	-1.10	-2.22	-0.41	-0.04	+0.08	-0.06	-1.14	-1.30	+0.27	+0.23
	L	+0.02	-0.36	-1.71	-1.77	+0.47	+0.94	+0.75	-0.07	-1.50	-1.30	+0.27	+0.07
0/100/0	U	+0.23	-0.02	-1.25	-2.02	-0.08	+0.19	+0.21	-0.19	-1.31	-1.79	+0.27	+0.07
1000	L	+0.53	-0.40	-1.19	-0.90	+0.25	+1.55	-0.43	+0.29	-1.55	-1.13	+0.15	+0.17
0/100/0	U	+0.19	-0.37	-0.57	-0.86	-0.13	+0.40	+0.15	-0.07	-0.83	-0.85	-0.08	+0.37
2000	L	+0.27	-0.33	-1.41	-0.65	+0.84	+0.39	-0.87	+0.39	-1.49	-1.20	+0.93	+0.17
2/20/78	U	+0.35	-0.19	-1.23	-0.66	+1.03	+1.16	+0.09	-0.40	-0.68	-1.12	-0.02	+0.33
1000	L	+0.15	-0.23	-0.98	-0.61	+0.27	+0.44	+0.21	-0.61	-1.13	-0.63	+1.01	-0.17
2/20/78	U	+0.15	-0.20	-1.55	-0.62	+0.10	----	+0.04	-0.06	-0.85	-1.07	+0.55	+0.22
2000	L	+0.27	-0.35	-1.29	-0.23	+0.09	+0.57	-0.17	+0.04	-0.97	+0.24	-0.35	+0.25
15/52/33	U	+0.13	-0.43	-1.24	-1.01	+0.79	+0.63	+0.12	-0.22	-0.47	-0.67	+0.11	-0.18
1000	L	+0.52	-1.24	-1.43	----	----	----	+0.21	-0.12	-0.19	-0.29	-0.23	+0.47
15/52/33	U	+0.31	-0.28	-0.89	-0.38	+1.84	+1.42	+0.01	+0.05	-0.40	-0.99	+0.19	+0.37
2000	L	+0.59	-0.63	-1.84	-0.84	+0.93	+0.53	-0.09	+0.09	-0.19	-0.17	-0.70	+0.78
15/52/33	U	+0.07	-0.17	-0.71	-0.95	+1.13	+0.89	-0.08	+0.19	-0.69	-0.99	-0.33	+0.15
3000	L	+0.33	-0.35	-0.99	-0.67	+0.61	+1.08	-0.17	+0.32	----	----	----	----
30/0/70	U	+0.60	-0.04	-1.13	-1.59	+0.37	+0.65	-0.01	+0.01	-0.49	-0.25	+0.71	-0.11
1000	L	+0.19	-0.27	-1.98	-0.24	+0.59	+1.13	-1.07	+0.23	-1.45	-0.83	-0.08	-0.33
30/0/70	U	-0.08	+0.05	-0.69	-0.41	+1.26	+0.69	-0.18	+0.15	-0.91	-0.89	+0.53	+0.76
2000	L	+0.11	-0.14	-1.65	-1.01	+1.00	+0.68	-0.15	+0.19	-1.75	-0.26	+0.27	+0.48
FRA		----	0.00	----	+0.17	+0.12	-0.45	----	0.00	----	+0.17	+0.12	-0.45

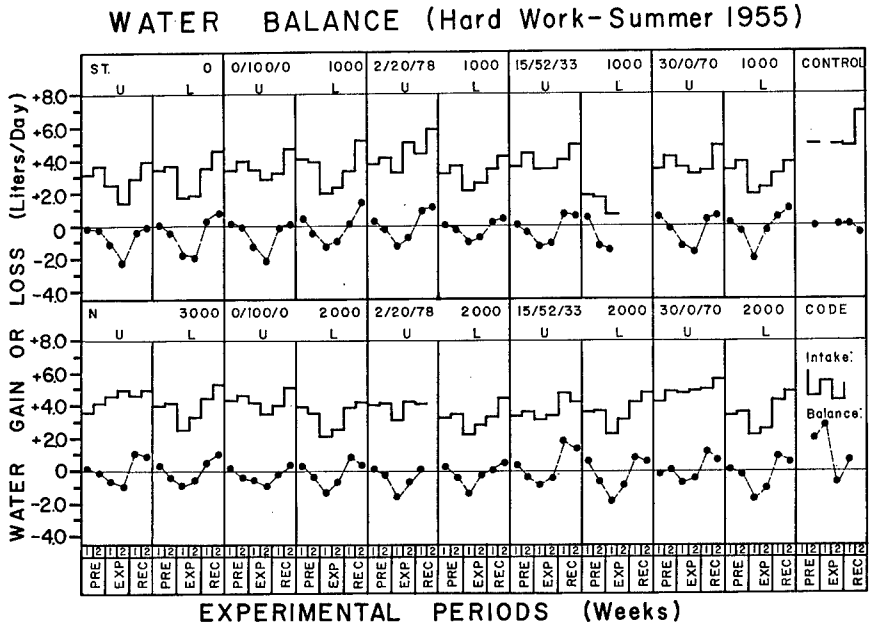


FIGURE III. 4. WATER BALANCE: HARD WORK.

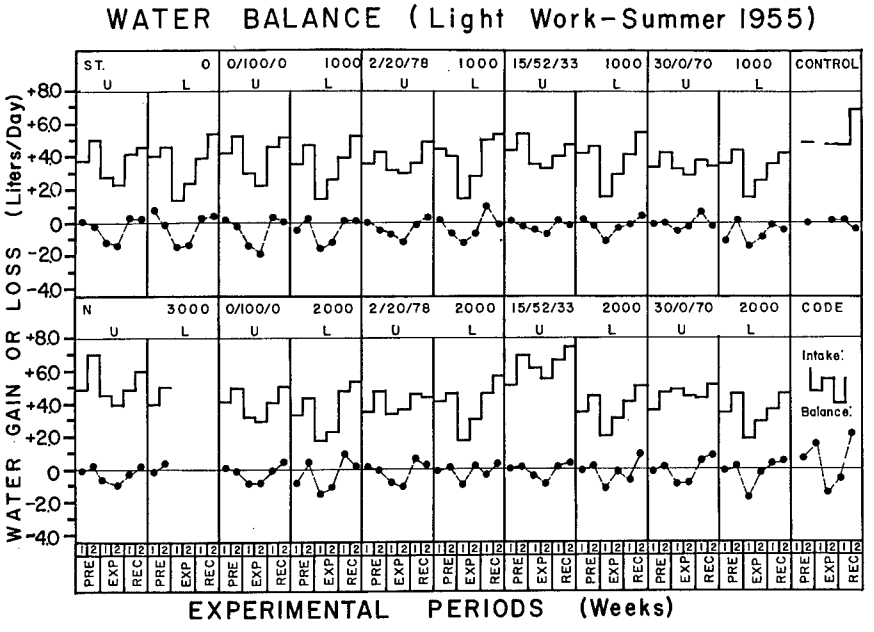


FIGURE III. 5. WATER BALANCE: LIGHT WORK.

3. Nitrogen Balance

Pre-Periods. Mean intake was over 20 gm N/day in PRE I (Table III. 12 A) and was accompanied by mean positive balance of about 2 gm N/day (Table III. 12 D). With the onset of hot weather in PRE II, appetites diminished somewhat. The average intake dropped to about 19 gm N/day, urinary and fecal excretions diminished somewhat, and balances were positive only by about 0.5 gm N/day (Tables III. 12 A, B, C, D). The "ideal controls" had an unrestricted intake, which was 27.3 gm N/day, and a positive balance of 8 gm N/day in PRE II. All these results would be expected in very young men, such as our subjects were.

Experimental Periods: Nitrogen Intake. The planned intakes were achieved in both experimental periods (Table III. 13) and in all flights. Among the various regimens intake of 0, 1, 2, 6, 11, 17, 12, and 24 gm N/day were recorded. The intake of the "ideal controls" dropped to 21.6 gm N/day.

Experimental Periods: Urinary Nitrogen. Excretion of nitrogen parallelled intake (Table III. 14), and it tended to decrease slightly in EXP II; this phenomenon could be accounted for by the "levelling off" whenever gross changes in nitrogen intake occur. Interpretation of the data probably is most satisfactory in EXP II for this reason. A consistent effect of dehydration is to be noted. In hard work, among 9 paired comparisons in EXP II, dehydration was accompanied by increased nitrogen excretion in 9; in hard work, among 9 paired comparisons, this effect was observed in 7. Our interpretation is that dehydration was provoking a catabolic reaction with an extra tendency to break down body tissue.

Experimental Periods: Fecal Nitrogen. No subject excreted excessive amounts of nitrogen through the gastrointestinal tract (Table III. 15). No convincing correlations appear among this excretion, and work load, water intake, or nitrogen intake. It would appear that nitrogen was well absorbed in all regimens, and that we were observing, in effect, endogenous fecal nitrogen.

Experimental Periods: Estimated Sweat Nitrogen. Nitrogen loss in sweat was significant, amounting to about 1 gm N/day. The value was independent of work load, nitrogen intake, and calorie intake. Dehydration did have a slight effect. Excretion was less in dehydrated subjects than in well hydrated. In hard work in EXP II, this was seen in 8 of 9 paired comparisons; in light work in EXP II, it was seen in 7 of 9 paired comparisons. The effect was of the order of 0.1 gm N/day.

Experimental Periods: Nitrogen Balance. Numerous interesting correlations were found between nitrogen balance and other variables. (Table III. 17; Figures III. 6 and III. 7). First, all subjects tended to be in negative balance in both EXP I and EXP II. Among the possible 77 instances, this was observed in 75 cases. The "ideal controls" remained positive. The situation possibly invoked a general catabolic reaction in all subjects. Second, work load affected somewhat the amount of negativity. In comparing hard work vs. light work, in EXP (allowing for stabilization after EXP I), negativity was greater in 12 of 18 comparisons. Third, nitrogen intake affected balance. If we look at individual regimens, in which calorie intake was the same, we can rearrange the data in Table III. 17 as follows:

Nitrogen Intake (gm N/day)	Nitrogen Balance (EXP II) Hard Work U	Hard Work L	Light Work U	Light Work L
1000-Cal Regimens				
0	-8.9	-9.9	-7.7	-8.6
1.3	-10.0	-8.7	-8.8	-8.3
5.6	-7.6	----	-7.1	-6.6
12.0	-7.5	-7.3	-5.5	-7.5
2000-Cal Regimens				
0	-8.2	-8.0	-7.3	-7.5
2.2	-6.5	-7.0	-6.5	-6.8
11.4	-3.7	-7.0	-5.1	-2.9
23.8	-4.5	-5.7	-2.6	-6.1

Although the results are not as regular as one would like to see, increased intake tended to decrease negativity of balance. Fourth, at a given nitrogen intake, calories had an effect. Increased calorie intake decreased the negativity. Notice especially the pure carbohydrate diet (0 gm N), and the comparison between 12.0 gm N at 1000 Cal/day and 11.4 gm N at 2000 Cal.

A graphic presentation assists in examining the relations among the several important variables (Figure III. 7). The four points made above are brought out: a general negativity; an effect of work load; an effect of nitrogen intake at a given calorie intake; an effect of calories at a given nitrogen intake. In addition, there is an irregular effect of dehydration in 11 of 17 comparisons.

An important metabolic defect of the meat bar (30/0/70) appears in this graph. Even with a much larger nitrogen intake, when compared with 15/52/33 at the same calorie intake, 30/0/70 induces the same negative nitrogen balance as 15/52/33. This is seen most clearly at 2000 Cal. Increasing the nitrogen intake by 11.8 gm N/day does not at all alleviate the negative balance in hard work U or light work L and only slightly in hard work L and light work U. We can only speculate on the reason for this interesting effect, for we have no conclusive evidence one way or the other. It could be a simple calorie effect, because positive balance is achieved by the subjects at 20 gm N/day and 3000-4000 Cal. It could not be inadequate absorption, because the fecal loss and urinary loss are consistent with good absorption. Furthermore, the Pepsin Digest Residue (PDR) Amino Acid Index was 84.3 on the average, a high value (Spector, 1956; Sheffner et al., 1956). It could be an amino acid deficiency, perhaps lysine which is easily destroyed by heat. This is an unlikely explanation in view of amino acid analysis of the meat bar (courtesy of the Quartermaster Food and Container Institute, Doctor Harry Spector) which can be interpreted as showing that the processing of the meat bar does not in fact cause individual amino acids, especially lysine, to be destroyed. The data are listed in Table III. 18, which shows that the intake of all eight essential amino acids at 1000 Cal of meat bar is far above the recommended allowance of Rose (1952).

We are left with a mystery which could only be explained by further research, including (a) balance studies on the meat bar at 3000 Cal/day; and (b) supplementation of meat bar with individual amino acids on the unlikely assumption that we are dealing with an amino acid deficiency of a subtle kind not revealed by microbiological assay.

In W. C. Rose's classic studies on the individual amino acid requirements of man, it was found necessary to provide as many as 5000 Cal/day to achieve balance with complete amino acid mixtures. In contrast, with native protein, 3000 Cal/day would permit balance to be achieved (L. Henderson, personal communication) at low levels of nitrogen intake. Perhaps we are dealing with a similar phenomenon here.

TABLE III. 12

PRE-PERIOD DATA ON
NITROGEN INTAKE, OUTPUT, AND BALANCE
(gm/day)

Flight	P I		P II	
	Mean	Range	Mean	Range
		A. Intake		
1	21.6	16.2-25.4	18.7	14.6-24.0
2	20.8	16.2-26.1	18.7	14.1-23.5
3	23.0	16.0-29.6	19.2	6.6-26.4
4	22.6	18.4-25.1	19.4	11.5-22.1
FRA	----	---------	27.3	21.3-33.4
		B. Urinary Nitrogen		
1	15.5	9.9-19.3	14.2	10.0-17.9
2	14.8	10.8-19.7	14.7	9.8-18.3
3	16.9	12.6-21.6	15.0	9.3-19.1
4	15.5	9.4-19.2	14.9	8.6-17.7
FRA	13.0	8.5-17.4	15.1	11.8-20.2
		C. Fecal Nitrogen		
1	2.4	0.9-5.8	2.1	0.9-3.7
2	2.6	1.3-4.7	2.0	1.1-3.4
3	3.0	1.0-6.2	2.3	1.1-5.8
4	2.7	1.7-4.6	1.6	0.5-2.7
FRA	2.3	1.2-4.4	2.2	1.3-3.4
		D. Balance		
1	+2.3	(-3.3)-(+9.7)	+1.1	(-1.7)-(+4.0)
2	+2.1	(-0.9)-(+9.1)	+0.2	(-3.0)-(+2.5)
3	+1.7	(-4.7)-(+4.7)	+0.2	(-4.2)-(+5.1)
4	+2.8	(-2.9)-(+7.4)	+1.1	(-5.6)-(+3.8)
FRA	----	----------	+8.0	(+3.5)-(+15.2)

TABLE III. 13

NITROGEN INTAKE
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	19.3	16.6	0.0	1.0	20.2	25.7	22.7	19.1	0.0	0.0	18.8	30.2
	L	19.0	16.3	0.0	0.0	18.2	28.2	24.1	20.8	0.0	0.0	19.0	33.5
0/100/0	U	22.7	19.9	0.0	0.0	18.9	30.2	25.5	21.1	0.0	0.0	18.8	29.9
1000	L	23.7	21.1	0.0	0.0	18.6	31.8	21.6	19.5	0.0	0.0	17.6	34.6
0/100/0	U	21.6	21.5	0.0	0.0	21.0	28.7	23.8	16.8	0.0	0.0	20.5	27.5
2000	L	24.3	19.4	0.0	0.0	20.9	27.3	23.1	15.5	0.0	0.0	20.0	34.7
2/20/78	U	22.7	21.9	1.3	1.3	17.9	38.6	21.7	13.8	1.3	1.3	18.4	31.2
1000	L	20.5	19.1	1.3	1.3	18.7	28.9	23.1	18.3	1.3	1.3	18.9	30.3
2/20/78	U	24.1	17.4	2.2	2.2	21.3	----	16.0	14.9	2.2	2.2	20.8	23.2
2000	L	19.9	19.5	2.2	2.2	19.7	30.3	23.1	17.6	2.2	2.2	19.5	32.3
15/52/33	U	21.3	16.8	5.5	5.5	17.8	27.6	23.7	22.1	5.6	5.6	18.9	27.1
1000	L	19.5	17.1	5.6	5.6	----	----	22.6	21.2	5.6	5.6	18.9	32.5
15/52/33	U	20.5	19.3	11.4	11.4	20.6	20.5	23.3	19.7	11.4	11.4	21.2	32.1
2000	L	22.1	19.7	11.4	11.4	21.3	32.2	22.5	20.8	11.4	11.4	21.3	29.5
15/52/33	U	21.3	19.4	16.8	16.8	20.7	24.6	28.4	25.3	16.8	16.8	21.3	32.6
3000	L	21.7	21.3	16.8	16.8	20.5	26.8	23.1	21.5	----	----	----	----
30/0/70	U	20.5	22.3	12.0	12.0	18.8	29.2	18.9	15.2	10.7	9.9	18.6	21.8
1000	L	19.7	19.1	12.0	12.0	16.8	21.0	20.6	18.0	12.1	12.1	16.3	31.0
30/0/70	U	24.3	21.7	23.8	23.8	21.3	31.4	21.6	20.1	23.8	23.8	21.0	33.7
2000	L	20.8	17.1	23.8	23.8	20.6	23.3	20.4	20.5	23.8	23.8	21.0	33.3
FRA		----	27.3	----	21.6	23.8	25.3	----	27.3	----	21.6	23.8	25.3

TABLE III. 14

URINARY NITROGEN
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	13.9	12.6	10.1	7.5	13.5	13.3	16.7	15.8	9.6	9.3	11.6	14.8
	L	13.9	13.2	10.4	12.5	11.9	13.5	17.5	16.0	7.8	10.2	14.1	19.9
0/100/0	U	16.5	14.9	6.8	5.4	12.0	16.5	18.8	17.7	7.1	4.9	11.9	15.3
1000	L	14.0	17.1	7.2	6.3	11.4	17.1	15.1	15.7	6.3	6.1	12.1	18.3
0/100/0	U	17.1	15.3	7.3	4.5	13.1	16.2	16.1	12.9	4.2	3.7	11.8	13.1
2000	L	19.7	15.5	6.7	4.7	11.3	13.0	17.7	15.1	5.1	4.0	11.6	16.6
2/20/78	U	18.3	15.5	8.9	5.9	13.3	20.9	15.9	13.7	10.4	7.1	10.2	14.5
1000	L	12.5	14.3	8.8	7.0	11.2	12.1	16.1	14.5	8.7	6.9	12.2	15.6
2/20/78	U	15.5	12.5	8.1	5.4	11.3	----	17.0	14.1	8.1	4.9	10.3	12.3
2000	L	17.1	15.3	8.3	5.8	11.3	18.8	14.1	12.5	7.3	6.2	13.0	16.3
15/52/33	U	15.3	13.3	8.9	8.9	11.9	15.3	12.7	15.5	11.8	8.9	12.7	16.9
1000	L	15.9	13.7	10.5	----	----	----	14.7	15.4	5.8	9.1	12.9	17.6
15/52/33	U	14.9	14.5	8.5	11.1	12.7	14.7	17.5	16.1	15.2	13.0	16.4	18.2
2000	L	12.5	13.3	14.2	13.6	12.1	14.0	15.5	15.9	9.5	10.9	13.5	16.7
15/52/33	U	16.6	16.1	13.1	14.3	13.5	16.4	18.1	16.9	16.8	15.7	16.9	19.3
3000	L	16.3	15.9	13.7	15.4	13.5	14.3	16.4	16.5	----	----	----	----
30/0/70	U	14.3	12.3	17.9	15.7	14.6	14.7	12.6	11.5	11.4	12.1	11.6	13.1
1000	L	13.9	15.7	15.3	16.6	4.4	11.4	9.5	12.4	13.9	16.5	11.8	16.0
30/0/70	U	13.7	17.7	25.3	24.2	15.5	22.5	17.1	12.6	27.1	22.7	16.7	17.0
2000	L	15.1	14.7	21.3	25.8	12.3	10.3	13.5	13.8	15.5	25.5	15.1	14.3
FRA		13.0	15.1	15.8	14.6	14.3	14.7	13.0	15.1	15.8	14.6	14.3	14.7

TABLE III. 15

FECAL NITROGEN
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	1.8	1.6	0.4	0.0	2.4	3.0	3.2	2.1	0.7	0.7	2.7	2.4
	L	2.9	1.6	0.4	0.6	2.6	2.1	3.0	3.1	0.9	0.4	2.7	2.2
0/100/0	U	2.6	2.2	0.2	0.4	2.1	2.3	2.7	2.1	0.3	0.3	3.4	2.1
1000	L	3.3	1.8	1.2	1.2	2.7	2.4	1.9	1.3	0.3	0.3	3.5	2.6
0/100/0	U	3.7	2.7	0.8	1.0	2.3	2.5	3.3	4.4	1.0	1.0	2.7	2.1
2000	L	3.7	2.1	0.7	0.7	2.3	1.5	3.8	1.9	0.7	0.7	2.1	2.5
2/20/78	U	3.7	2.5	1.5	2.4	2.5	3.2	2.8	1.5	0.5	0.5	0.9	1.7
1000	L	1.9	1.9	0.6	0.6	1.7	2.5	2.1	1.3	0.8	0.8	5.0	2.3
2/20/78	U	3.1	2.9	0.6	0.5	2.3	---	2.3	1.4	0.9	1.1	2.1	1.5
2000	L	1.7	1.1	0.9	0.9	2.1	2.0	2.4	1.2	0.7	0.9	3.3	1.8
15/52/33	U	1.4	2.9	1.3	1.3	2.9	2.0	3.2	2.3	1.1	1.3	3.1	1.9
1000	L	1.5	1.7	0.7	---	---	---	2.3	1.2	0.9	1.0	2.5	1.9
15/52/33	U	2.3	2.0	1.6	1.5	4.4	2.0	2.7	2.5	0.5	0.9	4.1	2.3
2000	L	3.5	3.3	2.1	2.1	2.9	1.5	3.3	2.4	1.7	1.3	2.9	2.0
15/52/33	U	2.1	1.8	1.5	1.9	4.5	1.7	5.7	2.5	1.9	1.3	3.2	2.2
3000	L	2.4	2.1	3.1	1.7	4.5	2.2	3.6	2.0	---	---	---	---
30/0/70	U	2.2	2.0	0.8	1.1	2.5	2.1	2.2	2.2	0.4	1.0	4.1	2.2
1000	L	2.3	1.9	1.0	0.5	2.1	1.4	2.3	1.4	1.1	1.1	1.9	2.3
30/0/70	U	1.7	1.7	1.4	1.4	2.5	2.9	1.1	1.9	1.2	1.2	3.3	1.7
2000	L	2.9	2.5	1.1	1.1	2.2	2.3	2.1	1.7	1.0	2.4	2.7	4.3
FRA		2.3	2.3	1.9	2.3	2.3	1.9	2.3	2.3	1.9	2.3	2.3	1.9

TABLE III. 16

SWEAT NITROGEN
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.87	1.17	1.13	1.08	0.73	1.03	0.90	1.58	0.92	0.96	0.98	1.06
	L	0.75	1.13	1.13	1.00	0.67	0.90	0.55	1.33	0.85	0.67	0.87	1.03
0/100/0	U	0.70	1.15	1.30	1.60	0.90	1.10	0.95	1.65	1.10	1.10	1.15	1.20
1000	L	0.75	1.20	1.15	1.00	0.75	0.75	1.00	1.30	1.00	1.05	0.95	1.20
0/100/0	U	0.90	1.40	1.35	1.25	0.80	1.05	1.00	1.55	1.15	1.15	1.20	1.30
2000	L	0.90	1.20	1.25	1.15	0.90	1.00	1.05	1.20	1.05	0.95	0.95	1.20
2/20/78	U	0.75	1.25	1.40	1.50	0.80	1.00	0.80	1.40	0.90	1.00	1.10	1.10
1000	L	0.70	1.10	0.60	0.95	0.80	0.80	0.80	1.25	0.80	0.85	0.70	1.30
2/20/78	U	0.75	1.10	1.35	1.30	0.90	----	0.80	1.50	1.15	1.25	1.15	1.10
2000	L	0.65	1.10	1.15	1.05	0.80	0.80	1.00	1.35	0.85	0.80	0.90	1.20
15/52/33	U	0.80	1.10	1.50	1.40	0.85	1.10	1.00	1.65	0.95	0.95	1.05	0.95
1000	L	0.80	1.50	1.60	----	----	----	0.90	1.30	0.90	0.95	0.90	1.20
15/52/33	U	0.60	1.05	1.15	1.00	0.70	0.60	1.05	1.75	1.05	1.10	1.20	1.25
2000	L	0.70	1.25	1.30	1.20	0.80	1.10	0.85	1.25	0.95	0.95	1.35	1.25
15/52/33	U	0.70	1.15	1.50	1.40	0.80	1.75	1.05	2.05	1.35	1.45	1.45	1.50
3000	L	0.70	1.20	1.10	1.15	0.75	0.85	1.00	1.30	----	----	----	----
30/0/70	U	0.45	1.25	1.40	1.30	0.75	1.00	0.80	1.30	0.80	0.80	0.80	0.90
1000	L	0.70	1.15	1.20	0.70	0.50	1.40	1.35	1.30	0.95	0.95	0.90	1.30
30/0/70	U	0.90	1.25	1.30	1.20	0.85	1.00	0.85	1.35	0.95	0.95	0.95	1.05
2000	L	0.80	1.05	1.15	1.15	0.75	0.90	1.00	1.40	0.90	0.90	0.80	1.00
FRA		0.90	1.45	1.28	1.28	1.26	1.14	0.90	1.45	1.28	1.28	1.26	1.14

TABLE III. 17

NITROGEN BALANCE
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	+1.5	+0.6	-12.1	- 9.3	+3.4	+ 7.8	+1.4	-0.9	-11.8	-12.4	+3.2	+11.3
	L	+0.9	-0.3	-12.5	-15.8	+2.7	+11.2	+2.5	+0.7	-10.3	-12.5	+1.1	+ 9.8
0/100/0	U	+2.3	+0.9	- 8.9	- 8.9	+3.7	+ 9.7	+2.5	-1.1	- 9.0	- 7.7	+2.2	+10.7
1000	L	+5.0	+0.3	-10.1	- 9.9	+3.6	+11.0	+3.0	+0.5	- 8.3	- 8.6	+0.9	+11.9
0/100/0	U	-0.7	+1.5	- 9.9	- 8.2	+4.6	+ 8.3	+2.8	-2.6	- 6.9	- 7.3	+4.5	+10.5
2000	L	-0.6	+0.1	- 9.8	- 8.0	+6.3	+11.3	-0.9	-5.6	- 8.1	- 7.5	+3.9	+12.1
2/20/78	U	-0.7	+2.0	-11.1	-10.0	+1.1	+12.9	+1.7	+4.3	-11.1	- 8.8	+6.0	+13.3
1000	L	+4.7	+1.1	- 9.7	- 8.7	+4.8	+12.9	+3.5	+0.7	-10.1	- 8.3	+0.7	+10.5
2/20/78	U	+4.2	+0.3	- 8.5	- 6.5	+7.7	———	-4.7	-2.7	- 8.5	- 6.5	+7.1	+ 7.7
2000	L	-0.1	+1.3	- 8.7	- 7.0	+5.2	+ 8.1	+4.9	+1.9	- 7.3	- 6.8	+2.1	+12.4
15/52/33	U	+3.3	+2.7	- 6.9	- 7.6	+2.0	+ 8.6	+1.6	+2.1	- 8.3	- 7.1	+1.9	+ 6.8
1000	L	+0.7	-0.5	- 7.8	———	———	———	+4.1	+2.7	- 2.5	- 6.6	+2.4	+11.3
15/52/33	U	+2.1	+1.1	- 0.5	- 3.7	+2.6	+ 2.6	+1.5	-1.3	- 6.0	- 5.1	-0.7	+ 9.7
2000	L	+4.8	+1.1	- 6.8	- 7.0	+5.3	+15.0	+2.6	+0.6	- 1.3	- 2.9	+3.3	+ 8.9
15/52/33	U	+1.5	-0.3	+ 0.1	- 2.3	+1.7	+ 4.9	+2.9	+3.3	- 3.8	- 3.1	-0.4	+ 8.7
3000	L	+1.7	+1.5	- 1.7	- 2.9	+1.4	+ 8.9	+1.5	+1.1	———	———	———	———
30/0/70	U	+3.0	+2.5	- 8.7	- 7.5	+0.7	+10.9	+2.7	-0.4	- 2.5	- 5.5	+1.9	+ 5.0
1000	L	+2.1	-0.3	- 6.1	- 7.3	+9.6	+ 7.1	+4.5	+2.3	- 7.3	- 7.5	+1.5	+10.9
30/0/70	U	+7.5	+0.5	- 4.8	- 4.5	+2.1	+ 4.3	+1.9	+3.7	- 6.0	- 2.6	-0.1	+13.3
2000	L	+1.4	-1.7	- 0.3	- 5.7	+5.1	+ 9.3	+3.3	+3.0	+ 5.8	- 6.1	+2.7	+13.1
FRA		———	+8.0	———	+ 1.8	+5.9	+ 6.2	———	+8.0	———	+ 1.8	+5.9	+ 6.2

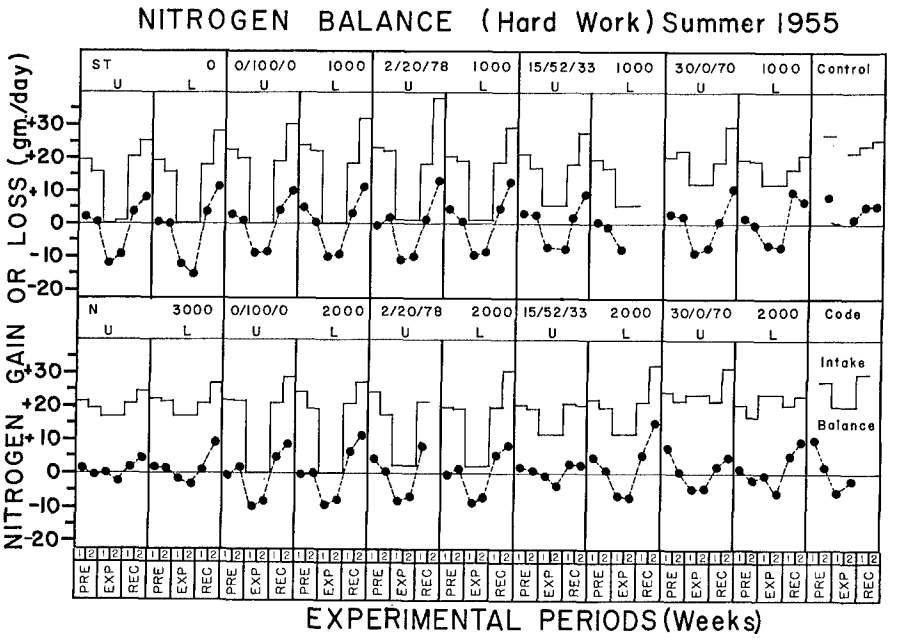


FIGURE III. 6. NITROGEN BALANCE: HARD WORK

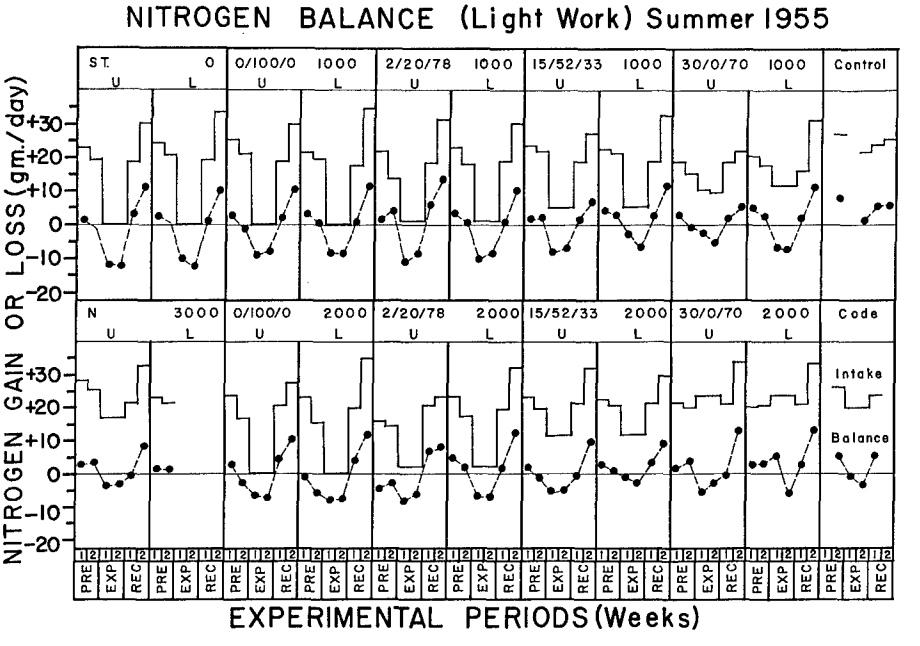


FIGURE III. 7. NITROGEN BALANCE: LIGHT WORK

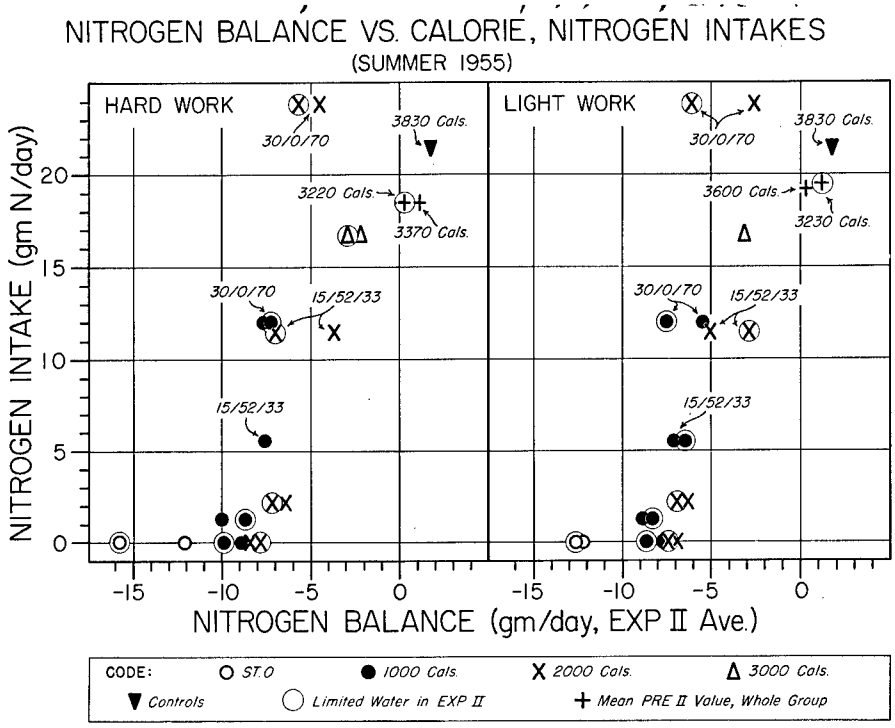


FIGURE III. 8. NITROGEN BALANCE VS. CALORIE, NITROGEN INTAKES (SUMMER 1955)

TABLE III. 18

AMINO ACID CONTENT OF MEAT BAR

Amino Acid	Amount Provided By Meat Bar* 1000 Cal	2000 Cal	Requirement** Minimum	Recommended
	gm/day	gm/day	gm/day	gm/day
Isoleucine	3.79	7.58	0.70	1.4
Leucine	6.08	12.16	1.10	2.2
Lysine	0.88	1.76	0.80	1.6
Methionine	1.86	3.71	1.10	2.2
Phenylalanine	3.29	6.58	1.10	2.2
Threonine	3.63	7.26	0.50	1.0
Tryptophan	0.91	1.82	0.25	0.5
Valine	4.71	9.43	0.80	1.6
Histidine	3.40	6.80	Not essential	
Cystine	0.83	1.66	Not essential	
Tyrosine	2.23	4.46	Not essential	
Arginine	5.94	11.89	Not essential	
Total	37.55	75.11		
Total Protein	72.60	145.20		

*Meat bar provides 1000 Cal for every 165 gm. Amino acid analyses were conducted at the QM Food and Container Institute and reported by Spector (1956). **W. C. Rose (1952).

4. Chloride Balance

Introduction. Among all the balances, those of chloride and sodium are most likely to be inaccurate in this study, and, for the same reason, we cannot be sure that the estimate of dermal loss is correct. Urinary excretions and fecal excretions are accurate for all subjects. Intakes were reliable for all subjects except FRA, who were permitted to use salt shakers; FRA intakes are not even listed. Dermal losses may be inaccurate because any of three major calculations may be erroneous: (a) total daily sweat loss was calculated from intermittent measurement of hard work sweat rate in the heat acclimatization test, and this latter value was used for extrapolation; (b) samples of sweat collected in gloves were analyzed for chloride and sodium, and these values were applied to total body sweat; (c) reasonable assumptions had to be made on changes of sweat chloride and sweat sodium with rate of sweating. We have relied heavily on the work of Ladell and of Robinson in arriving at our method of calculation, taken together with our own special observations at Camp Atterbury.

Pre-Period. PRE I was relatively cool; PRE II was hot and humid. Salt intake diminished in PRE II (Table III. 19 A), but still remained high by usual American standards. Urinary loss diminished somewhat in PRE II (Table III. 19 B) because of the diminution of intake. Dermal losses doubled in PRE II (Table III. 19 C) because of the increased heat, with concomitant increases in total sweat losses. Balance changed from positive in all flight to slightly negative in Flights 2, 3, and 4.

Experimental Periods: Intake. Five regimens provided virtually no chloride (Table III. 20): STO; 0/100/0 1000 and 2000; 30/0/70 1000 and 2000. Two regimens might be considered high: 2/20/78 2000 and 15/52/33 3000. The other three were intermediate: 2/20/78 1000; 15/52/33 1000 and 2000. It should be remembered that the primary control of the regimens was with respect to water, total calories, and protein-carbohydrate-fat ratios. Minerals were not specifically controlled by plan, but were controlled in the sense that the subjects ate a constant diet.

Experimental Periods: Urinary Chloride. In hard work, all subjects excreted less chloride in EXP II than in EXP I (Table III. 21); in light work, this occurred in only 13 of the 19 regimens. Presumably, the relatively greater sweating in hard work depleted the body faster than in light work. There was a fair correlation in EXP II between urinary excretion and intake, except in the case of 30/0/70 1000 and 2000. In those regimens, urinary excretion remained quite high in the face of an intake that was practically nil. Other zero intake regimens caused very low urinary excretions in EXP II. Also in 30/0/70, doubling the protein intake virtually doubled the urinary chloride excretion.

Experimental Periods: Dermal Chloride Loss. These data are tabulated in Table III. 22. As compared with PRE II, there were general decreases of dermal loss in EXP I, EXP II, or both. In hard work this occurred in 15 of 20 comparisons; in light work, it occurred in 19 of 19 comparisons. Furthermore, as would be anticipated from the differences in total sweat, dermal chloride losses were usually greater in hard work than in light. If we look at both EXP I and EXP II,

the paired comparisons in 39 cases showed greater losses in hard work in 29.

Dermal losses in sweat are a highly individual characteristic. Not only may different subjects sweat at greatly different rates under the same conditions, but also the sweat chloride concentration may be very different. In the extreme, a man who sweats profusely and at high chloride concentration will lose far more chloride under identical conditions than will a man who sweats moderately at low chloride concentrations. These individual differences will affect strongly the relative depletion of the two subjects, and may render the chloride balances seemingly erratic. Exactly the same comments hold for sodium balance as affected by individual idiosyncrasy.

In EXP II, the dermal losses in the hard work groups diminished because an accelerated testing schedule diminished the number of hours daily in hard work.

Experimental Period: Chloride Balance. Regardless of intake, practically all regimens went into negative balance in EXP I (Table III. 23; Figures III. 9 and III. 10). In EXP II, negativity was reduced in 32 of 38 comparisons, but only in 2/20/78 2000 did it become positive (hard work) or near positive (light work); 2/20/78 2000 provided the greatest salt intake of any experimental regimen. This "adaptation" to a low salt intake is a well known phenomenon. Effects of work load or dehydration are not striking.

One point that was clear in the cold weather study was the increased nitrogen intake tends to increase the negativity of chloride balance. If we rearrange the data for the summer study, the same point is again evident. Regimens of similar chloride intakes are listed below, together with nitrogen intake and chloride balance. For this purpose, work load and dehydration have been disregarded, and EXP II data have been used.

EFFECT OF NITROGEN INTAKE ON CHLORIDE BALANCE

Regimen	Chloride Intake (mEq/day)	Chloride Balance (mEq/day)	Nitrogen Intake (gm/day)
0/100/0 1000	0	-44	0
30/0/70 1000	1	-50	12
0/100/0 2000	0	-45	0
30/0/70 2000	2	-95	24
2/20/78 1000	78	-35	1
15/52/33 1000	53	-56	6
15/52/33 2000	89	-53	11
2/20/78 2000	156	- 2	2
15/52/33 3000	126	-50	17

The table supports the conclusion that other factors being equal, increasing the nitrogen intake also increases the negativity of chloride balance. This is particularly true at low chloride intakes. Also, even under conditions of profuse sweating, chloride balance is more closely reached at high chloride intakes when the nitrogen intake is small.

The magnitude of our negative balances is not surprising when it is re-

called that the subjects were losing weight (Section C. 1), were in negative water balance (Section B. 2) and had lost a considerable amount of body water as measured by D_2O (Section C. 2). Therefore, they were certainly losing tissue fluid continuously, and with it sodium and chloride. An "automatic" deficit would therefore be expected in all subjects, especially at low chloride intakes.

Recovery Period. Even in REC I there was a return to approximately PRE I intake. Stepwise rehabilitation permitted a further increase in EXP II. Urinary chloride excretion increased in similar fashion. Dermal losses became lower in the hard work groups, and higher in the light work groups than they had been in EXP II. Balances became positive as the deficits of EXP I and EXP II were repaired. There is no clear correlation between the amount of positivity in REC I and REC II, and previous work load, state of hydration, calorie intake or nutrient mixture.

TABLE III. 19

PRE-PERIOD DATA ON
CHLORIDE INTAKE, OUTPUT, AND BALANCE
(mEq/day)

	P I		P II	
Flight	Mean	Range	Mean	Range
		A. Intake		
1	333	257-409	310	216-371
2	326	263-408	292	224-380
3	368	235-526	340	190-490
4	353	273-416	312	166-369
FRA	---	-------	---	-------
		B. Urinary Chloride		
1	279	168-342	222	127-308
2	242	167-313	224	155-294
3	270	148-387	239	59-331
4	260	150-329	246	100-333
FRA	159	109-208	170	62-257
		C. Dermal Loss		
1	30	15-61	76	33-113
2	34	14-92	73	26-159
3	43	23-77	116	68-194
4	40	9-101	76	30-122
FRA	43	21-81	86	31-174
		D. Balance		
1	+24	(-52)-(+111)	+12	(-15)-(+56)
2	+50	(-18)-(+139)	- 5	(-56)-(+42)
3	+55	(-43)-(+162)	-15	(-70)-(+87)
4	+54	(-32)-(+124)	-10	(-57)-(+32)
FRA	---	----------	---	----------

TABLE III. 20

CHLORIDE INTAKE
(mEq Cl/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	293	278	0	9	305	337	363	319	0	0	280	417
	L	305	257	0	0	273	354	380	331	0	0	285	429
0/100/0	U	345	296	0	0	285	415	406	346	0	0	285	405
1000	L	365	323	0	0	280	432	348	311	0	0	244	467
0/100/0	U	349	343	0	0	317	387	361	287	0	0	308	424
2000	L	382	295	0	0	313	360	348	231	0	0	298	445
2/20/78	U	347	350	78	78	272	503	343	350	78	78	280	392
1000	L	324	280	78	78	281	365	369	297	78	78	283	374
2/20/78	U	379	311	156	156	319	---	235	230	156	156	305	313
2000	L	318	307	156	156	297	413	350	353	156	156	276	360
15/52/33	U	342	293	45	45	269	338	366	371	53	53	285	375
1000	L	305	254	53	---	---	---	357	323	53	53	285	431
15/52/33	U	309	298	89	89	308	257	388	376	89	89	318	476
2000	L	329	303	89	89	319	444	337	311	89	89	311	384
15/52/33	U	281	289	126	126	313	334	487	458	126	126	317	449
3000	L	337	338	126	126	308	348	383	356	---	---	---	---
30/0/70	U	348	327	1	1	285	387	307	263	1	1	278	298
1000	L	317	305	1	1	247	264	316	283	1	1	248	435
30/0/70	U	375	340	2	2	319	416	340	341	2	2	318	461
2000	L	327	265	2	2	311	307	316	315	2	2	317	448
FRA		---	---	---	---	---	---	---	---	---	---	---	---

TABLE III. 21

URINARY CHLORIDE
(mEq Cl/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	254	182	43	2	285	221	294	223	36	4	136	313
	L	223	209	56	0	149	299	292	265	76	5	172	351
0/100/0	U	291	221	29	0	152	328	335	272	33	0	171	288
1000	L	245	271	30	0	179	337	237	257	41	1	173	345
0/100/0	U	304	266	29	0	320	327	225	219	14	7	226	267
2000	L	271	190	30	0	142	245	280	178	34	1	169	241
2/20/78	U	253	241	66	17	239	347	287	218	35	42	177	270
1000	L	219	192	68	21	207	232	243	230	95	66	191	267
2/20/78	U	304	235	113	83	229	---	166	151	117	91	227	217
2000	L	262	245	121	63	227	351	241	210	102	105	248	216
15/52/33	U	274	193	39	8	192	221	209	294	104	62	201	246
1000	L	248	226	98	---	---	---	252	291	66	52	213	363
15/52/33	U	253	219	86	79	254	222	231	265	58	112	224	295
2000	L	289	243	142	98	200	243	263	265	63	69	235	243
15/52/33	U	279	226	120	113	253	263	370	299	115	143	225	317
3000	L	256	252	102	79	201	271	298	311	---	---	---	---
30/0/70	U	292	215	53	13	208	276	202	177	21	29	210	233
1000	L	214	231	62	15	76	214	261	209	40	15	184	323
30/0/70	U	323	254	86	56	245	325	264	212	101	54	256	327
2000	L	237	209	73	30	228	229	205	229	109	37	206	276
FRA		159	170	194	177	190	192	159	170	194	177	190	192

TABLE III. 22

ESTIMATED DERMAL CHLORIDE LOSS
(mEq Cl/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	31	78	42	31	26	44	45	107	39	40	67	60
	L	31	72	57	43	31	38	24	89	47	68	43	65
0/100/0	U	39	90	54	52	39	44	29	93	37	37	67	43
1000	L	25	45	50	41	29	22	33	75	44	46	54	49
0/100/0	U	19	53	31	27	23	25	39	105	35	37	57	48
2000	L	61	113	94	77	71	74	55	47	23	23	43	58
2/20/78	U	35	89	144	123	43	67	45	109	54	55	77	46
1000	L	41	85	85	70	61	79	37	102	57	59	24	60
2/20/78	U	21	47	102	62	30	---	41	114	80	83	75	47
2000	L	22	51	95	79	67	29	37	71	60	62	64	81
15/52/33	U	49	97	120	101	45	60	37	108	53	55	63	42
1000	L	27	36	53	---	---	---	21	42	39	41	23	31
15/52/33	U	17	54	51	43	21	---	71	172	56	58	111	77
2000	L	23	73	80	67	36	72	50	82	47	49	69	56
15/52/33	U	27	70	81	68	30	50	43	146	53	55	83	45
3000	L	32	105	85	69	41	38	35	59	---	---	---	---
30/0/70	U	17	98	53	40	31	43	23	92	26	27	31	23
1000	L	31	73	47	21	16	13	48	60	35	37	38	45
30/0/70	U	42	85	71	60	37	51	47	109	43	57	59	49
2000	L	35	56	50	55	31	44	69	103	34	37	52	77
FRA		43	86	72	71	70	57	43	86	72	71	70	57

TABLE III. 23

CHLORIDE BALANCE
(mEq Cl/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	+ 8	+ 20	- 85	- 24	- 14	+ 71	+ 24	+ 12	- 74	- 42	+ 77	+ 44
	L	+ 51	- 23	-113	- 43	+ 93	+ 51	+ 69	- 22	-123	- 73	+ 70	+ 20
0/100/0	U	+ 30	- 15	- 83	- 52	+ 94	+ 43	+ 43	- 19	- 69	- 37	+ 47	+ 75
1000	L	+ 96	+ 7	- 80	- 41	+ 73	+ 62	+ 79	- 20	- 85	- 47	+ 17	+ 73
0/100/0	U	+ 26	+ 24	- 60	- 27	- 26	+ 36	+ 98	- 36	- 47	- 41	+ 26	+107
2000	L	+ 19	- 6	-123	- 77	+100	+ 41	+ 14	+ 5	- 65	- 33	+ 86	+146
2/20/78	U	+ 59	+ 20	-131	- 62	- 10	+ 89	+ 11	+ 23	- 11	- 19	+ 26	+ 76
1000	L	+ 63	+ 3	- 75	- 13	+ 13	+ 55	+ 89	- 35	- 75	- 47	+ 63	+ 97
2/20/78	U	+ 53	+ 29	- 59	+ 11	+ 60	----	+ 28	- 35	- 41	- 19	+ 3	+ 49
2000	L	+ 34	+ 11	- 59	+ 13	+ 2	+ 33	+ 71	+ 11	- 6	- 11	- 36	+ 63
15/52/33	U	+ 20	+ 3	-113	- 64	+ 33	+ 57	+119	- 31	-103	- 64	+ 19	+ 88
1000	L	+ 29	+ 16	- 98	----	----	----	+ 84	- 10	- 52	- 40	+ 49	+ 38
15/52/33	U	+ 39	+ 25	- 47	- 33	+ 33	----	+ 87	- 60	- 25	- 81	- 19	+103
2000	L	+ 17	- 13	-133	- 76	+ 83	+ 49	+ 24	- 33	- 21	- 23	+ 7	+ 59
15/52/33	U	- 24	- 7	- 75	- 55	+ 31	+ 16	+ 76	+ 13	- 43	- 72	+ 9	+ 86
3000	L	+ 49	- 19	- 60	- 22	+ 67	+ 39	+ 50	- 15	----	----	----	----
30/0/70	U	+ 39	+ 13	-105	- 57	+ 47	+ 76	+ 82	- 6	- 46	- 55	+ 37	+ 42
1000	L	+ 73	+ 1	-108	- 35	+155	+ 37	+ 7	+ 14	- 75	- 51	+ 26	+ 67
30/0/70	U	+ 15	+ 1	-155	-114	+ 29	+ 41	+ 29	+ 20	-141	-109	+ 3	+ 89
2000	L	+ 51	+ 1	-121	- 83	+ 52	+ 34	+ 42	- 11	-141	- 72	+ 59	+ 95
FRA		----	----	----	----	----	----	----	----	----	----	----	----

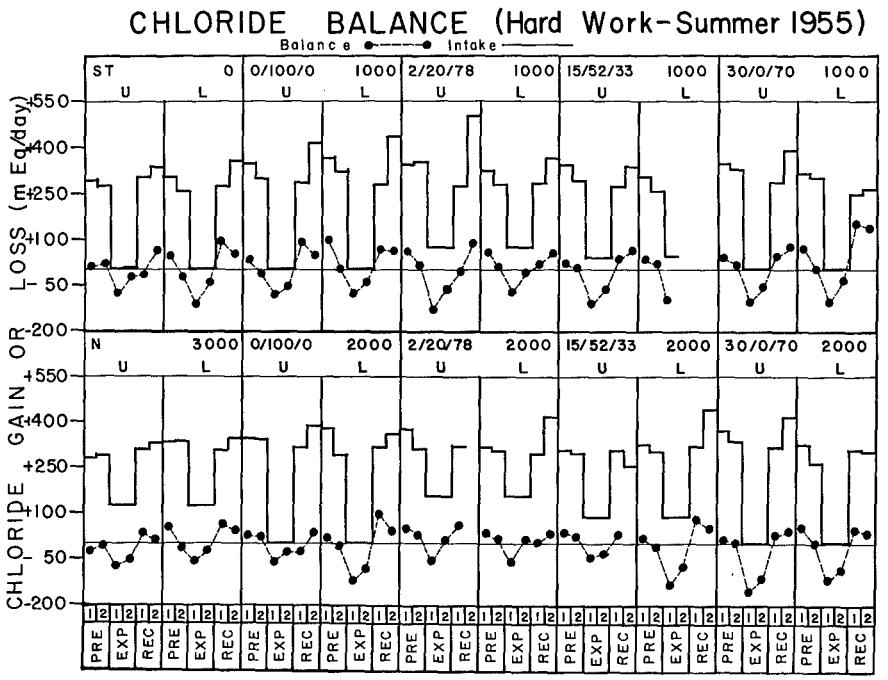


FIGURE III. 9. CHLORIDE BALANCE: HARD WORK

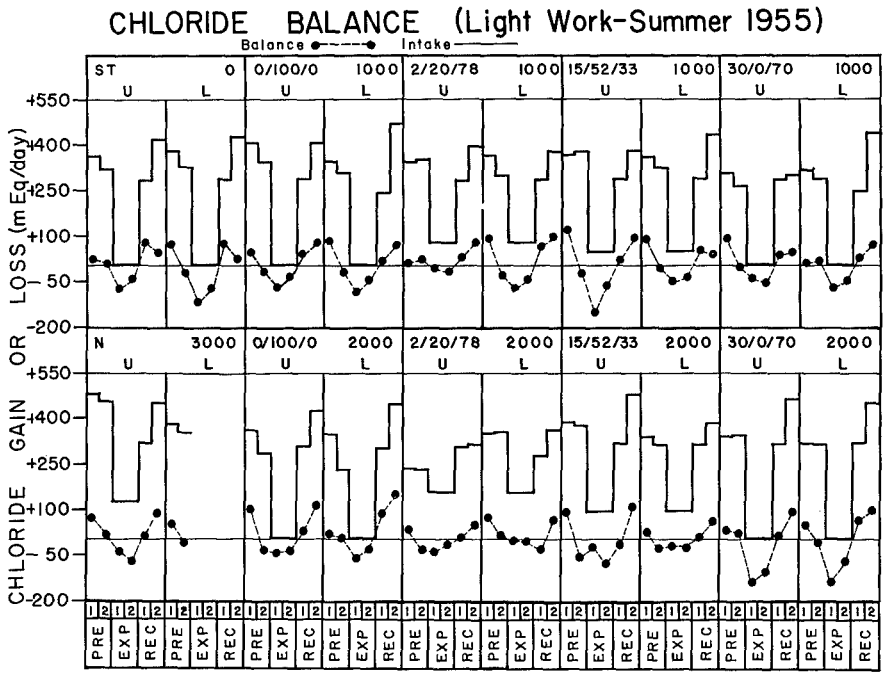


FIGURE III. 10. CHLORIDE BALANCE: LIGHT WORK

5. Sodium Balance

Introduction. In Section B. 4 it was explained that the estimates of chloride balance may be erroneous because of large sweat losses, correction for which had to be calculated; the exact accuracy of our estimates cannot be guaranteed.

Pre-Periods. During PRE II, the weather became hot and humid. Appetites were dulled, and sodium intake diminished. Urinary sodium excretion decreased in three of four flights. Fecal sodium, small in amount in any case, was unaffected, or increased very slightly. Sweating increased sharply, and with it the dermal loss of sodium. Balances were positive in PRE I, but the effect of the changes noted above caused the balance to become slightly negative in PRE II in three of the four flights. These data are presented in Table III. 24 A, B, C, D, and E. It should be emphasized that a usual American sodium intake is 150-250 mEq/day, and that our subjects were ingesting substantially more than this; they were on a high salt diet in the pre-periods.

Experimental Periods: Intake. Sodium intake varied widely from regimen to regimen (Table III. 25). It was negligible in ST 0, 0/100/0 1000 and 0/100/0 2000. It was moderate in 2/20/78 1000, 15/52/33 2000, 30/0/70 1000, and 30/0/70 2000. It was quite high in 2/20/78 2000 and 15/52/33 2000 and 3000. In none of the experimental regimens did it approach the intake of PRE II.

Experimental Periods: Urinary Sodium. Work load had some effect on urinary excretion, presumably because the hard work Flights 1 and 2 sweated more than the light work Flights 3 and 4. In EXP II, after equilibration was possible, hard work regimens showed a lower urinary sodium in 12 of 18 comparisons (Table III. 26). Intake also affected urinary excretion, the lowest excretions being recorded in those regimens of lowest intake. Limitation of water had no consistent effect, nor did nutrient ratio.

Experimental Periods: Dermal Sodium Loss. Dermal loss is a very individual matter, depending on two major factors which are quite characteristic of the individual, regardless of regimen: total sweat volume, and sweat sodium concentration. In the hard work subjects, dermal loss diminished in EXP II as compared with EXP I, because the accelerated testing program cut down somewhat on their daily work. Dermal loss did not change among the light work flights.

No consistent correlation could be detected between dermal sodium loss and the variables water intake, sodium intake, or nutrient regimen.

Experimental Periods: Sodium Balance. Scrutiny of the data in Table III. 28 and Figures III. 11 and III. 12 will be facilitated by a rearrangement of data for EXP II according to calorie and sodium intakes; all subjects were averaged, because work load had only a negligible effect, and water intake and nutrient ratios had none so far as can be seen. Nitrogen intake is also included because of the striking correlation it had with chloride balance. EXP II has been chosen because of the known phenomenon of "levelling off" on a low sodium intake, which requires about one week.

SODIUM BALANCE VS. INTAKE

Regimen	Sodium Intake (mEq/day)	Sodium Balance (mEq/day)	Nitrogen Intake (gm/day)
0 Cal			
ST 0	0	-64	0
1000 Cal			
0/100/0	2	-61	0
30/0/70	54	-28	12
2/20/78	77	-86	1
15/52/33	91	-39	6
2000 Cal			
0/100/0	5	-51	0
30/0/70	107	-22	24
15/52/33	147	-20	11
2/20/78	154	-43	2
3000 Cal			
15/52/33	179	-16	17

Even a large sodium intake did not permit balance to be achieved. However, there was a tendency for higher intakes to promote less negativity within the same nutrient ratio. In contrast to chloride balance (Section B. 4) where increased protein intake accentuated the chloride negativity, sodium balance negativity at any given calorie level was if anything ameliorated by increased protein intake. Perhaps we are not dealing with an effect of protein per se on chloride balance, but with the acidoses produced by meat bar. Accumulation of organic acid would tend to drive out other anions such as chloride, leaving sodium relatively untouched.

The chief generalization to be made on our subjects was that they were almost all in negative sodium balance throughout the experimental period. It is remarkable that there were no cases of heat cramp, which is usually attributed to sodium and chloride depletion. Perhaps such cases would have appeared had the experimental period lasted longer. We interpret the universal negativity to mean much the same for both chloride and sodium. The subjects were losing weight, and with it, tissue and tissue fluid. Therefore one would expect them to be in negative balance with respect to sodium and chloride almost regardless of intake. Increased calories would spare tissue, and would tend to be correlated with diminished negativity.

TABLE III. 24

PRE-PERIOD DATA ON
SODIUM INTAKE, OUTPUT, AND BALANCE
(mEq/day)

Flight	P I Mean	P I Range	P II Mean	P II Range
		A. Intake		
1	352	279-419	317	221-383
2	341	262-422	305	247-362
3	370	236-531	348	198-499
4	353	273-413	312	179-376
FRA	---	-------	---	
		B. Urinary Sodium		
1	262	154-335	227	164-320
2	227	159-320	227	153-286
3	274	153-386	234	67-342
4	270	143-343	234	85-329
FRA	157	95-237	151	59-240
		C. Fecal Sodium		
1	1.6	0.8-3.7	3.0	0.8-8.1
2	1.8	0.8-3.8	2.2	0.7-5.3
3	1.6	0.8-2.8	1.6	0.9-4.2
4	1.4	1.0-3.1	1.3	0.6-3.9
FRA	1.6	0.8-6.2	1.9	0.9-5.2
		D. Dermal Sodium		
1	33	15-62	90	33-157
2	38	16-98	87	32-175
3	53	33-92	136	65-236
4	45	11-126	84	37-157
FRA	55	25-98	86	51-182
		E. Balance		
1	+55	(-39)-(+106)	+ 2	(-63)-(+64)
2	+69	(-58)-(+150)	-16	(-84)-(+58)
3	+36	(-33)-(+149)	-19	(-102)-(+86)
4	+35	(-50)-(+107)	- 8	(-63)-(+36)
FRA	---	----------	---	----------

TABLE III. 25

SODIUM INTAKE
(mEq Na/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	325	287	0	0	317	385	363	325	0	0	287	440
	L	318	268	0	0	280	433	380	332	0	0	292	473
0/100/0	U	359	305	2	2	290	440	417	355	2	2	290	447
1000	L	384	337	2	2	286	482	350	324	2	2	270	517
0/100/0	U	329	357	5	5	331	436	364	289	5	5	320	409
2000	L	400	304	5	5	327	396	350	240	5	5	305	487
2/20/78	U	375	360	77	78	279	577	342	372	77	77	284	442
1000	L	341	286	77	77	287	401	366	304	77	77	289	406
2/20/78	U	393	320	154	154	333	---	236	243	154	154	327	356
2000	L	339	319	154	154	313	449	349	280	154	154	283	398
15/52/33	U	321	312	74	74	272	383	368	380	91	91	289	416
1000	L	313	273	91	---	---	---	356	330	90	91	290	466
15/52/33	U	317	301	147	147	323	---	388	383	148	147	333	535
2000	L	344	313	147	147	333	506	334	318	147	147	333	421
15/52/33	U	329	278	179	179	326	386	487	466	179	179	332	496
3000	L	351	334	178	178	322	397	384	361	178	---	---	---
30/0/70	U	359	332	54	54	289	434	311	272	54	54	283	323
1000	L	334	313	54	54	267	293	321	294	53	53	250	486
30/0/70	U	390	348	107	107	333	465	342	350	107	107	332	510
2000	L	341	270	107	107	325	337	315	321	106	106	331	476
FRA		---	173	---	217	185	229	---	173	---	217	185	229

TABLE III. 26

URINARY SODIUM
(mEq Na/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	212	197	57	10	297	246	282	227	57	16	156	307
	L	209	205	54	9	134	267	297	251	61	22	178	335
0/100/0	U	264	222	37	5	216	313	331	294	39	5	209	268
1000	L	230	266	32	10	207	339	253	237	29	20	213	358
0/100/0	U	279	276	41	14	335	313	246	224	22	8	259	256
2000	L	249	188	23	4	157	241	283	167	26	8	181	298
2/20/78	U	281	247	72	50	243	331	296	210	53	74	181	276
1000	L	202	199	75	40	221	222	250	218	97	98	195	287
2/20/78	U	278	225	142	123	249	---	170	132	136	142	213	214
2000	L	247	250	128	95	264	345	261	190	112	137	210	243
15/52/33	U	246	181	43	17	190	243	213	262	116	91	192	248
1000	L	236	235	106	---	---	---	269	282	63	79	213	351
15/52/33	U	224	213	102	103	252	230	265	247	64	137	221	325
2000	L	219	241	153	126	182	237	266	246	57	72	234	257
15/52/33	U	244	230	140	143	254	269	366	270	141	143	225	355
3000	L	269	262	132	102	197	284	313	303	131	---	---	---
30/0/70	U	265	220	79	34	211	277	210	180	34	64	213	237
1000	L	212	237	85	51	69	199	271	203	42	39	194	317
30/0/70	U	324	269	129	93	246	336	276	212	121	93	246	345
2000	L	224	212	91	54	201	223	214	223	108	59	193	298
FRA		157	151	158	190	178	196	157	151	158	190	178	196

TABLE III. 27

ESTIMATED DERMAL SODIUM LOSS
(mEq Na/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	36	92	54	39	25	48	56	122	36	37	69	66
	L	38	85	68	53	30	42	23	91	37	51	42	72
O/100/O	U	47	52	70	68	33	47	41	110	42	42	67	50
1000	L	30	58	62	51	28	37	43	82	43	45	57	52
O/100/O	U	20	73	41	35	20	27	51	131	41	43	58	48
2000	L	98	130	88	72	69	90	73	61	25	25	44	56
2/20/78	U	41	109	149	134	49	89	54	125	54	55	73	41
1000	L	52	102	93	77	63	81	37	123	56	57	27	61
2/20/78	U	22	58	96	46	25	---	42	123	81	83	85	43
2000	L	27	69	112	93	74	33	35	84	65	62	67	81
15/52/33	U	53	127	96	81	45	78	45	128	56	58	49	41
1000	L	31	45	48	---	---	---	30	53	41	43	25	26
15/52/33	U	18	62	35	28	18	---	79	203	66	68	122	81
2000	L	26	97	90	75	35	65	59	87	51	53	72	61
15/52/33	U	28	88	69	58	30	53	58	185	62	64	92	52
3000	L	31	120	83	68	39	36	43	60	---	---	---	---
30/0/70	U	21	114	62	52	31	46	33	104	32	33	32	23
1000	L	34	81	57	19	10	17	49	69	24	25	42	45
30/0/70	U	47	98	54	46	34	53	56	124	59	75	59	51
2000	L	40	65	52	56	30	50	86	128	30	32	57	77
FRA		55	86	72	70	73	55	55	86	72	70	73	55

TABLE III. 28

SODIUM BALANCE
(mEq Na/day)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC I	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	+ 75	- 4	-113	- 51	- 7	+ 89	+ 7	- 5	- 94	- 65	+ 59	+ 64
	L	+ 69	- 25	-126	- 64	+114	+119	+ 56	- 13	-100	- 75	+ 70	+ 68
0/100/0	U	+ 46	- 19	-106	- 73	+ 39	+ 78	+ 44	- 51	- 81	- 47	+ 13	+128
1000	L	+122	+ 12	- 93	- 62	+ 50	+104	+ 52	+ 3	- 72	- 64	- 2	+105
0/100/0	U	+ 28	+ 7	- 79	- 46	- 26	+ 95	+ 66	- 68	- 63	- 50	+ 2	+ 58
2000	L	+ 51	- 15	-103	- 73	+ 99	+ 68	- 9	+ 11	- 56	- 37	+ 78	+131
2/20/78	U	+ 52	+ 2	-145	-108	- 15	+155	- 10	+ 35	- 32	- 54	+ 28	+123
1000	L	+ 85	- 23	- 93	- 42	+ 2	+ 96	+ 78	- 39	- 77	- 80	+ 66	+ 56
2/20/78	U	+ 91	+ 41	- 85	- 17	+ 57	----	+ 22	- 14	- 65	- 73	+ 33	+103
2000	L	+ 63	- 2	- 88	- 36	- 27	+ 69	+ 47	+ 4	- 24	- 47	+ 4	+ 72
15/52/33	U	+ 21	+ 2	- 67	- 26	+ 36	+ 55	+109	- 12	- 83	- 59	+ 42	+126
1000	L	+ 44	+ 4	- 65	----	----	----	+ 55	- 7	- 16	- 32	+ 45	+ 82
15/52/33	U	+ 74	+ 25	+ 9	+ 14	+ 51	----	+ 43	- 68	+ 17	- 60	- 12	+128
2000	L	+ 97	- 27	- 98	- 56	+114	+202	+ 8	- 17	+ 38	+ 21	+ 25	+102
15/52/33	U	+ 55	- 42	- 32	- 24	+ 41	+ 63	+ 61	+ 9	- 26	- 30	+ 14	+ 88
3000	L	- 10	- 50	- 39	+ 7	+ 85	+ 70	+ 26	- 4	----	----	----	----
30/0/70	U	+ 71	- 4	- 89	- 34	+ 46	+110	+ 66	- 14	- 14	- 45	+ 36	+ 61
1000	L	+ 58	- 7	- 90	- 18	+186	+ 75	- 1	+ 18	- 15	- 14	+ 13	+122
30/0/70	U	+ 17	- 21	- 78	- 33	+ 52	+ 73	+ 8	+ 13	- 75	- 62	+ 25	+113
2000	L	+ 75	- 9	- 38	- 5	+ 93	+ 63	+ 13	- 32	- 34	+ 13	+ 79	+ 99
FRA		----	- 62	----	- 36	- 59	- 5	----	- 62	----	- 36	- 59	- 5

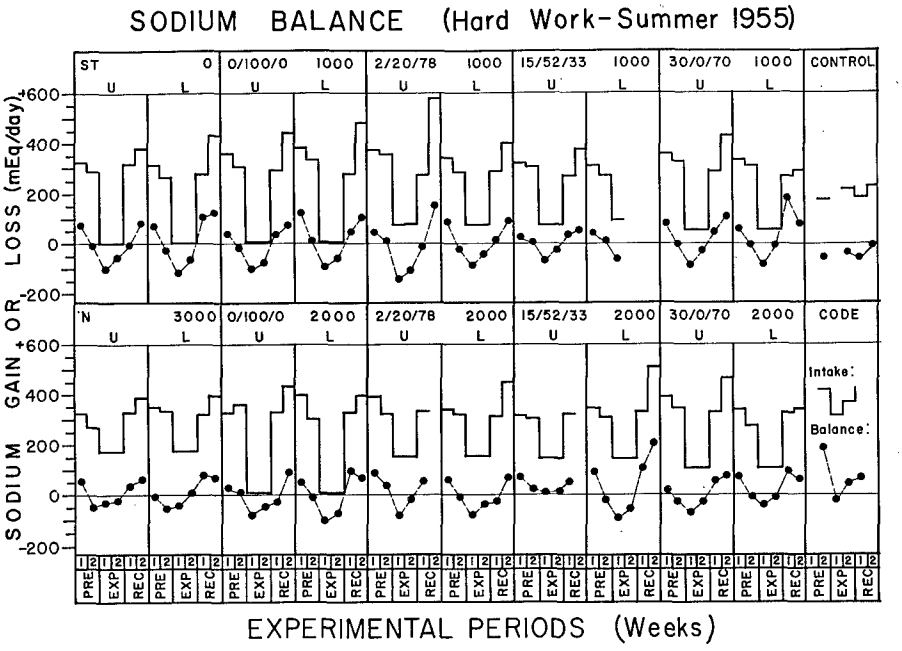


FIGURE III. 11. SODIUM BALANCE: HARD WORK.

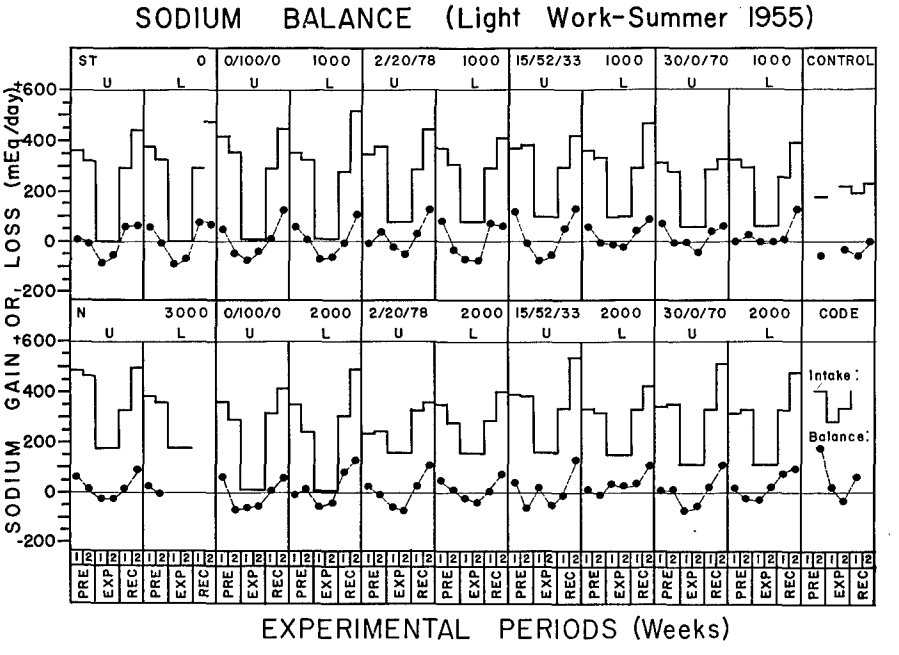


FIGURE III. 12. SODIUM BALANCE: LIGHT WORK.

6. Potassium Balance

Pre-Periods. There was about a 40% decrease of intake between PRE I and PRE II, because the weather turned hot and appetites diminished (Table III. 29 A). Concomitantly, urinary excretion of potassium decreased by about 15% in EXP II, and fecal excretion decreased very slightly (Table III. 29 B, C). The onset of hot weather caused an increase of sweating, with a corresponding increase of dermal loss (Table III. 29 D). Balances were positive in PRE I, as would be expected among very young men, many still growing; in PRE II, balances became negative except among the controls (Table III. 29 E).

Experimental Periods: Potassium Intake. No experimental regimen provided much over half as much as was ingested in PRE II (Table III. 30). Very small intakes were recorded for ST 0, 0/100/0 1000 and 2000, 2/20/78 1000, and 30/0/70 1000. Low intakes were recorded for 15/52/33 1000 and 30/0/70 1000. Moderately low intakes were recorded for 15/52/33 2000, 15/52/33 3000, and 30/0/70 2000.

Experimental Periods: Urinary Potassium. As compared with EXP II there was a decreased urinary excretion of potassium in EXP I (Table III. 31). This occurred in 16 of 20 comparisons in hard work, and in 17 of 19 comparisons in light work. In EXP II there was a further decrease in hard work; it occurred in 19 of 19 comparisons. By contrast, there was an increase in light work in EXP II; it occurred in 14 of 19 comparisons. The net result of these differences was that in EXP II urinary excretion in hard work was less than in light work; this occurred in 13 of 18 comparisons, regardless of intake. There was a rough positive correlation between urinary excretion and intake, but excretion never approached zero with zero intake. Limitation of water had no consistent effect.

Experimental Periods: Fecal Excretion. There was a tendency for fecal excretion to diminish in EXP I and EXP II as compared with PRE II (Table III. 32). There was no apparent correlation with work load, water intake, potassium intake, or nutrient ratios.

Experimental Periods: Estimated Dermal Loss. In EXP I as compared with PRE II, dermal loss was correlated with work load (Table III. 33). In hard work, it increased in 15 of 20 comparisons; in light work it decreased in 15 of 19 comparisons. There were no other clear correlations.

Experimental Periods: Potassium Balance. Scrutiny of the balance data will be facilitated by a rearrangement of the data in Table III. 34 and Figures III. 13 and III. 14. Only EXP II has been tabulated. The major conclusion that can be drawn from this table is that, regardless of potassium, calorie, protein, or water intakes, all subjects tended to be in rather strong negative balance. Furthermore, no convincing evidence exists for correlation among potassium balance and any other major variable.

POTASSIUM BALANCE VS. INTAKE

Regimen	Potassium Intake (mEq/day)	Potassium Balance (mEq/day)				Nitrogen Intake (mg/day)
		Hard Work		Light Work		
		U	L	U	L	
0 Cal						
ST 0	0	-43	-69	-72	-86	0
1000 Cal						
0/100/0	0	-54	-67	-52	-59	0
2/20/78	3	-69	-35	-33	-69	1
15/52/33	21	-43	---	-83	-68	6
30/0/70	27	-43	-25	-34	-75	12
2000 Cal						
0/100/0	0	-51	-48	-47	-42	0
2/20/78	6	-36	-39	-99	-42	2
15/52/33	49	-18	-77	-79	-41	11
30/0/70	54	-42-	-38	-27	-67	24
3000 Cal						
15/52/33	62	-41	-16	-80	---	17

We can only conclude that a common environmental or situational factor existed which led to a "catabolic reaction" among all subjects, regardless of nutritional conditions. It is true that there was a general weight loss, but the negative potassium balance did not correlate convincingly with the decrement in body weight, and this fact would indicate that the source of potassium could not be merely tissue potassium.

It is appropriate at this point to quote from the report of the winter study, in which a similar conclusion with respect to potassium was reached: "We are left with the conclusion that these experimental conditions led uniformly to negative potassium balance in all groups of subjects. ... The explanation of this nonspecific effect is not clear, but the most attractive hypothesis is that there was a true catabolic phase in our subjects." The mean negative balance for all groups in the winter study was 22 mEq/day; negativity was more severe in the hot weather study, averaging for all groups 53 mEq/day.

Recovery Period. In spite of the controlled rehabilitation, intakes in REC I approximated those of PRE I, and in EXP II, when intakes were free, potassium intakes exceeded those of PRE I on the average, but only by about 15 mEq/day. Urinary potassium in REC II was actually less than in PRE I in half the previously hard work subjects, and in 15 of 19 previously light work groups. Fecal excretion increased sharply to or above pre-period values. Dermal losses diminished with the cessation of the field phase for hard work Flight 1 and 2 (16 of 19 comparisons) and also for the light work Flights 3 and 4 (15 of 19 comparisons). New tissue was laid down, and balances became strongly positive, especially in REC II. No convincing correlations could be found between the amount of positivity in REC II, and previous work load, water intake, potassium intake, caloric intake, or nutrient ratios.

TABLE III. 29

PRE-PERIOD DATA ON POTASSIUM INTAKE, OUTPUT, AND BALANCE
(mEq/day)

Flight	Mean	Range	Mean	Range
		A. Intake		
1	142	53-186	94	49-109
2	127	71-170	90	70-113
3	149	87-194	96	39-122
4	132	88-163	95	46-112
FRA	---	------	142	93-189
		B. Urinary Output		
1	83	41-112	60	35- 85
2	75	50-112	66	46- 85
3	79	41-109	64	35- 81
4	71	41- 96	66	42- 85
FRA	72	53- 96	94	60-131
		C. Fecal Output		
1	11	4-33	12	4-38
2	11	6-18	8	3-12
3	12	5-21	10	5-32
4	11	4-25	8	4-13
FRA	14	6-35	15	9-30
		D. Estimated Dermal Loss		
1	19	6-41	29	12-57
2	18	12-31	34	18-70
3	26	7-60	39	14-73
4	25	7-46	38	21-87
FRA	18	10-25	29	18-39
		E. Balance		
1	+29	(- 7)-(+53)	- 7	(-46)-(+12)
2	+23	(-24)-(+60)	-18	(-64)-(+15)
3	+32	(- 1)-(+85)	-17	(-57)-(+23)
4	+25	(-21)-(+61)	-17	(-56)-(+43)
FRA	---	----------	+ 6	(-50)-(+43)

TABLE III. 30

POTASSIUM INTAKE
(mEq K/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	132	87	0	0	130	192	138	93	0	0	111	156
	L	130	93	0	0	111	161	151	106	0	0	112	174
0/100/0	U	163	94	0	0	113	163	168	102	0	0	113	158
1000	L	154	106	0	0	111	166	142	107	0	0	109	184
0/100/0	U	141	105	0	0	117	154	158	96	0	0	117	153
2000	L	157	98	0	0	117	157	131	69	0	0	115	156
2/20/78	U	135	99	3	3	111	175	115	83	3	3	107	144
1000	L	121	87	3	3	110	150	137	98	3	3	113	154
2/20/78	U	166	97	6	6	119	----	108	88	6	6	117	124
2000	L	99	82	6	6	93	131	140	78	6	6	116	158
15/52/33	U	143	86	21	21	110	144	171	111	22	22	113	147
1000	L	115	79	22	----	----	----	132	105	22	22	113	172
15/52/33	U	126	94	49	49	117	124	182	107	49	49	119	183
2000	L	138	101	49	49	119	160	131	102	49	49	119	155
15/52/33	U	144	97	62	62	100	136	192	121	62	62	119	169
3000	L	146	98	62	62	103	146	116	99	----	----	----	----
30/0/70	U	117	78	27	27	113	154	114	74	27	27	111	137
1000	L	109	91	27	27	109	141	114	82	27	27	80	105
30/0/70	U	165	107	54	54	119	164	129	96	55	55	117	198
2000	L	118	79	54	54	112	115	112	102	55	55	116	174
FRA		----	142	----	100	109	108	----	142	----	100	109	108

TABLE III. 31

URINARY POTASSIUM
(mEq K/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	77	58	31	15	57	55	84	63	26	36	33	64
	L	74	69	33	31	43	85	76	75	32	55	52	67
0/100/0	U	91	63	30	20	25	64	98	79	25	15	33	55
1000	L	71	76	28	20	43	91	71	76	22	23	46	67
0/100/0	U	86	64	30	13	38	50	68	72	14	8	32	51
2000	L	104	69	23	13	30	91	76	61	17	13	25	60
2/20/78	U	70	63	22	15	60	55	70	45	9	15	41	55
1000	L	68	66	30	15	45	91	63	64	27	33	51	63
2/20/78	U	84	48	20	5	25	--	71	66	29	40	42	56
2000	L	70	55	32	8	33	77	71	56	27	25	35	50
15/52/33	U	86	46	33	22	47	54	75	71	44	50	66	38
1000	L	84	66	54	--	--	--	63	69	22	50	47	63
15/52/33	U	74	55	38	34	50	46	76	79	23	75	63	70
2000	L	76	71	76	45	55	76	70	67	26	55	55	54
15/52/33	U	88	76	58	49	61	62	97	61	51	83	65	79
3000	L	84	69	62	30	46	96	78	68	--	--	--	--
30/0/70	U	77	51	56	32	69	44	55	36	15	30	46	66
1000	L	68	63	43	35	33	76	78	62	33	60	52	53
30/0/70	U	109	71	76	54	74	71	76	56	60	56	85	80
2000	L	63	54	61	43	53	63	62	61	49	80	50	60
FRA		72	94	95	116	73	83	72	94	95	116	73	83

TABLE III. 32

FECAL POTASSIUM
(mEq K/day)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC I	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	7	6	3	0	14	12	14	10	4	4	18	10
	L	11	6	2	3	19	11	14	8	5	2	20	12
0/100/0	U	11	12	1	3	14	15	14	8	1	1	27	11
1000	L	13	8	8	8	16	15	7	6	3	3	19	9
0/100/0	U	16	33	4	6	18	20	13	21	3	3	11	13
2000	L	7	7	4	4	12	8	12	8	5	5	7	11
2/20/78	U	19	13	13	20	16	17	9	7	2	2	3	5
1000	L	8	6	4	4	9	12	11	7	7	7	16	9
2/20/78	U	14	18	3	3	16	--	9	8	6	6	10	6
2000	L	8	4	4	4	10	9	11	7	6	4	13	6
15/52/33	U	7	10	7	7	19	9	11	7	5	6	17	10
1000	L	9	9	6	--	--	--	8	6	6	6	13	7
15/52/33	U	8	8	7	7	21	7	10	9	2	4	8	8
2000	L	13	12	10	10	14	9	8	12	11	9	18	9
15/52/33	U	10	8	8	10	24	9	19	14	13	8	20	11
3000	L	12	10	16	8	22	9	16	8	--	--	--	--
30/0/70	U	8	8	6	9	15	13	10	10	4	5	20	13
1000	L	12	11	8	4	16	11	8	8	4	4	10	9
30/0/70	U	11	5	5	5	12	12	6	6	6	6	13	8
2000	L	12	12	6	7	15	13	10	8	6	7	29	17
FRA		14	15	12	16	16	11	14	15	12	16	16	11

TABLE III. 33

ESTIMATED SWEAT POTASSIUM
(mEq K/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	15	25	26	30	15	18	21	37	31	32	21	21
	L	25	32	39	34	20	21	16	41	29	29	20	31
0/100/0	U	16	17	25	31	17	22	24	40	35	36	23	20
1000	L	23	39	44	39	29	22	18	34	32	34	18	29
0/100/0	U	21	36	35	32	16	20	36	46	36	37	24	23
2000	L	17	25	37	32	22	23	27	28	20	21	19	27
2/20/78	U	30	45	48	37	21	47	21	31	19	19	17	20
1000	L	18	24	22	19	19	24	27	69	31	32	20	39
2/20/78	U	24	33	45	34	30	---	14	27	57	58	42	33
2000	L	19	42	43	38	18	25	34	55	23	19	25	39
15/52/33	U	22	33	46	40	23	27	31	54	47	48	22	34
1000	L	26	50	47	---	---	---	27	61	32	34	26	32
15/52/33	U	14	21	29	26	12	12	46	63	48	49	34	48
2000	L	23	63	80	71	28	37	21	26	25	26	25	21
15/52/33	U	16	28	48	43	21	21	29	47	49	50	31	45
3000	L	19	64	46	40	22	24	28	37	---	---	---	---
30/0/70	U	8	21	32	29	18	25	18	22	26	26	14	15
1000	L	16	25	24	13	9	13	30	36	36	38	21	28
30/0/70	U	23	31	37	37	17	22	16	21	20	21	14	14
2000	L	14	22	43	42	17	23	33	43	34	35	16	26
FRA		18	29	24	24	24	26	18	29	24	24	24	26

TABLE III. 34

POTASSIUM BALANCE
(mEq K/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	+31	- 3	- 60	-43	+41	+107	+19	-14	-61	-72	+39	+61
	L	+22	- 4	- 73	-69	+29	+ 44	+46	-18	-66	-86	+20	+65
0/100/0	U	+45	+ 2	- 54	-54	+57	+ 62	+32	-25	-61	-52	+30	+73
1000	L	+48	-21	- 78	-67	+23	+ 39	+46	- 9	-57	-59	+27	+80
0/100/0	U	+19	-27	- 69	-51	+45	+ 65	+41	-43	-53	-47	+20	+68
2000	L	+29	- 1	- 63	-48	+54	+ 36	+14	-27	-42	-42	+64	+58
2/20/78	U	+16	-32	- 80	-69	+14	+ 56	+15	-22	-27	-33	+46	+64
1000	L	+27	- 9	- 53	-35	+37	+ 23	+36	+ 2	-71	-69	- 8	+ 4
2/20/78	U	+46	-12	- 63	-36	+48	--	+14	-12	-85	-99	+21	+30
2000	L	+ 3	-17	- 73	-39	+32	+ 20	+25	-39	-47	-42	+43	+63
15/52/33	U	+29	- 2	- 65	-43	+23	+ 54	+53	-22	-74	-83	+12	+40
1000	L	- 3	-15	- 72	--	--	--	+34	-31	-38	-68	+28	+70
15/52/33	U	+30	+10	- 25	-18	+34	+ 59	+51	-44	-23	-79	+ 3	+58
2000	L	+27	-46	-117	-77	+22	+ 38	+32	- 4	-13	-41	+20	+72
15/52/33	U	+30	-15	- 52	-41	- 6	+ 44	+48	- 1	-51	-80	+ 3	+35
3000	L	+32	-45	- 63	-16	+13	+ 18	- 6	-14	--	--	--	--
30/0/70	U	+25	- 2	- 67	-43	+12	+ 73	+31	+ 6	-17	-34	+31	+43
1000	L	+14	- 9	- 47	-25	+52	+ 41	- 3	-24	-46	-75	- 2	+16
30/0/70	U	+23	- 0	- 65	-42	+18	+ 60	+33	+13	-31	-27	+ 5	+97
2000	L	+29	-10	- 56	-38	+28	+ 16	+ 8	-10	-34	-67	+21	+71
FRA		--	+ 6	--	-59	- 3	- 12	--	+ 6	--	-59	- 3	-12

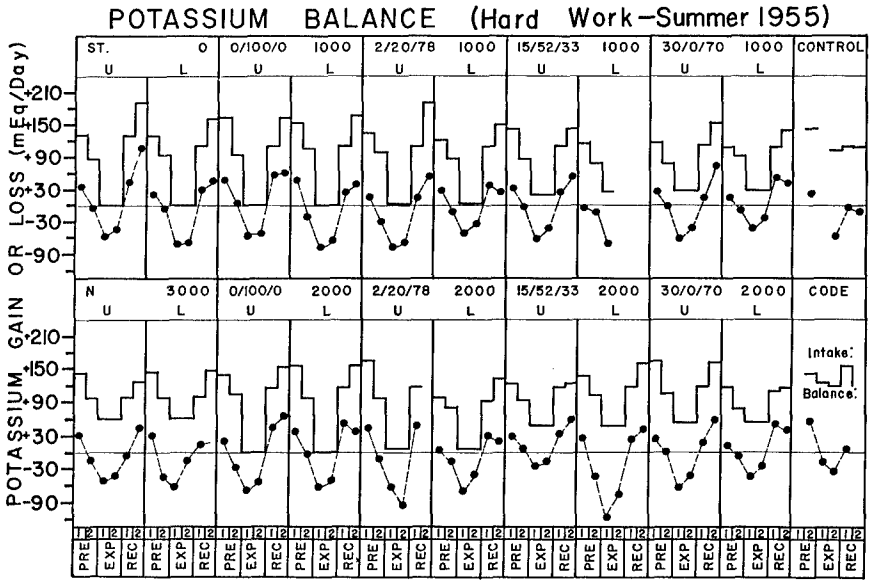


FIGURE III. 13. POTASSIUM BALANCE: HARD WORK.

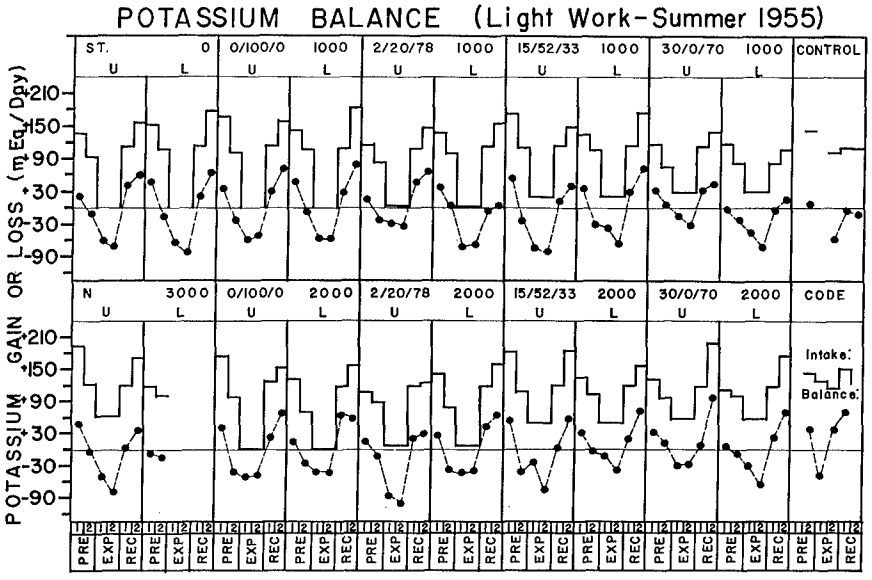


FIGURE III. 14. POTASSIUM BALANCE: LIGHT WORK.

7. Calcium and Phosphorus Balances (Winter 1954)

At the time the final report was submitted on the cold weather experiments of 1954, analyses had not yet been completed on fecal calcium and phosphorus. Therefore, a detailed discussion of calcium and phosphorus balances could not be presented in the report of Sargent et al. (1954). What could be reported at that time were intakes and urinary excretions. Having completed all the analyses and computations, we wish to report at this time on the metabolic balances of calcium and phosphorus for the 1954 study.

a. Calcium Balance (Winter 1954)

Pre-Period. Means and ranges for calcium intake, urinary calcium, fecal calcium, and balances are given in Table III. 35. Owing to the omission of certain calcium-rich dairy products, the dietary intake of calcium in P I and P II was somewhat low by National Research Council standards, averaging about 0.8 gm of Ca in each period. Urinary excretion of calcium remained almost the same in P I and P II for all four flights. On the other hand, the fecal excretion diminished between P I and P II in all flights. As a result, the balances, which had been slightly negative in P I in all flights, in P II approached positivity and reached it in Flights 1, 2, and 4. Therefore, by the end of P II all flights were substantially in calcium balance in spite of the intake of only about 0.8 gm of Ca per day. The wide ranges displayed in the tables for calcium intake, urinary excretion, fecal excretion and balance are quite usual among healthy young men.

Experimental Period. In all regimens in EXP I and EXP II the calcium intake was very low, a situation that was dictated by dietary considerations in planning the regimens (Table III. 36). Between P II and EXP I there was a decreased urinary calcium excretion in 19 of 20 of the hard work regimens, and in all 20 of the light work regimens (Table III. 37). In EXP II there was a further decrease in 17 of the 20 hard work regimens and in 14 of the light work regimens. There was a tendency for pure carbohydrate to depress the urinary excretion. In all 40 regimens, values of less than 60 mg of Ca per day were obtained in six regimens; four of these were 0/100/0. This interesting phenomenon needs further investigation.

Fecal excretion of calcium tended to parallel the dietary intake (Table III. 38). Between PRE II and EXP I, it decreased in all 40 regimens; between EXP II and EXP I, there was a further decrease in only 8 of the 40 regimens, and an increase in 14. There was no convincing evidence of a systematic effect of work load or water consumption.

All calcium balances were negative in all regimens in both EXP I and EXP II, even in 15/52/33 3000 U and L (Table III. 39; Figures III 15 and III. 16). There was little, if any, tendency to adapt to these low calcium regimens. The balances among the 20 hard work regimens were more negative in EXP II than in EXP I in 11, less negative in 8. Among the 20 light work regimens, there was greater negativity in 6, and less in 12. Perhaps here there was a suggestion that hard work tended to increase the negativity, but the evidence is not strong.

We conclude that calcium balance was negative because all regimens were very low in calcium.

Recovery Period. In REC I average intakes approached 1 gm of Ca/day, and with the addition of milk products, calcium intake exceeded 1 gm of Ca/day in all but one of the 40 regimens. Concomitant with these progressive increases in intake, there were corresponding changes in urinary and fecal excretion, especially in REC II. Balances tended to become positive in REC I. In the hard work groups, 12 of 20 became positive in that period, and among the light work groups 13 of 20 became positive. In REC II all groups became positive, some very strikingly so. There was little evidence that previous hard work, limitation of water, protein/carbohydrate/fat ratio, or calorie intake had any effect. The only clear correlation was with previous negativity.

In summary, we conclude that the calcium balance correlated mainly with calcium intake in these studies. Water level, water intake, calorie intake, and protein/carbohydrate/fat ratios had no apparent influence.

TABLE III. 35W

PRE-PERIOD DATA ON CALCIUM INTAKE, URINARY CALCIUM, FECAL CALCIUM, AND BALANCE (WINTER 1954)
(gm Ca/day)

	P I		P II	
Flight	Mean	Range	Mean	Range
		A. Intake		
1	0.81	0.41-1.29	0.74	0.42-1.21
2	0.87	0.34-1.84	0.96	0.37-1.81
3	0.77	0.41-1.47	0.76	0.36-1.38
4	0.70	0.34-1.19	0.76	0.41-1.18
		B. Urinary Excretion		
1	0.21	0.12-0.35	0.21	0.09-0.33
2	0.16	0.06-0.28	0.17	0.06-0.29
3	0.22	0.09-0.36	0.23	0.09-0.38
4	0.17	0.09-0.32	0.18	0.09-0.29
		C. Fecal Excretion		
1	0.69	0.42-1.38	0.52	0.28-1.02
2	0.86	0.30-1.53	0.69	0.08-1.18
3	0.69	0.22-1.07	0.54	0.15-1.04
4	0.64	0.27-1.12	0.57	0.19-1.00
		D. Balance		
1.	-0.08	-0.83 to +0.28	+0.01	-0.38 to +0.37
2	-0.10	-0.94 to +0.44	+0.07	-0.25 to +0.61
3	-0.23	-0.42 to +0.18	-0.04	-0.72 to +0.31
4	-0.14	-0.62 to +0.56	+0.03	-0.56 to +0.68

TABLE III. 36W

CALCIUM INTAKE--WINTER 1954
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	0.73	0.62	0.02	0.02	1.22	2.50	0.42	0.42	0.02	0.03	1.00	2.46
	L	1.03	1.13	0.01	0.02	1.21	2.47	0.56	0.67	0.01	0.01	1.08	2.22
0/100/0	U	0.83	0.63	0.03	0.03	1.60	2.55	0.46	0.42	0.02	0.02	0.85	2.27
1000	L	1.29	1.32	0.01	0.01	1.47	2.23	0.40	0.49	0.02	0.02	0.66	2.31
0/100/0	U	0.82	0.71	0.01	0.02	1.47	2.66	1.31	1.18	0.02	0.02	1.38	2.46
2000	L	1.11	0.88	0.02	0.02	1.03	2.00	0.82	1.09	0.01	0.02	1.06	2.32
2/20/78	U	1.15	0.98	0.07	0.06	1.37	2.47	0.66	0.88	0.06	0.07	1.29	2.45
1000	L	0.70	0.60	0.05	0.05	0.98	2.47	0.68	0.78	0.05	0.05	1.07	2.30
2/20/78	U	1.18	0.97	0.11	0.11	1.57	2.37	0.65	1.11	0.10	0.12	1.45	2.37
2000	L	0.68	0.69	0.09	0.09	1.20	2.38	0.79	0.84	0.09	0.09	1.34	2.38
15/52/33	U	0.74	0.67	0.23	0.14	1.45	2.65	0.62	0.59	0.13	0.13	1.01	2.66
1000	L	1.00	1.02	0.12	0.12	1.46	2.39	0.71	0.72	0.12	0.12	1.24	2.14
15/52/33	U	0.61	0.63	0.18	0.18	1.33	2.34	0.54	0.76	0.18	0.18	1.02	2.20
2000	L	0.49	0.68	0.17	0.17	1.32	2.54	0.69	0.74	0.17	0.17	0.94	2.20
15/52/33	U	0.90	0.82	0.26	0.26	0.91	2.01	0.74	0.88	0.25	0.26	1.66	2.56
3000	L	1.03	1.19	0.24	0.23	1.00	2.18	0.81	0.95	0.24	0.24	1.10	2.13
30/0/70	U	0.55	0.96	0.06	0.07	1.49	2.81	1.20	0.90	0.06	0.06	1.53	2.67
1000	L	1.18	1.28	0.05	0.05	1.38	2.37	0.78	0.74	0.05	0.05	1.22	2.35
30/0/70	U	0.62	0.65	0.09	0.10	1.15	2.20	0.56	0.63	0.10	0.10	1.21	2.28
2000	L	0.47	0.48	0.06	0.08	1.47	2.20	0.80	0.68	0.08	0.07	1.41	2.25

TABLE III. 37 W

URINARY CALCIUM--WINTER 1954
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	0.15	0.16	0.08	0.06	0.23	0.26	0.19	0.23	0.12	0.09	0.25	0.30
	L	0.13	0.15	0.09	0.07	0.15	0.19	0.20	0.19	0.13	0.13	0.24	0.22
0/100/0	U	0.27	0.28	0.13	0.10	0.33	0.35	0.24	0.27	0.07	0.05	0.27	0.40
1000	L	0.21	0.27	0.09	0.04	0.20	0.28	0.22	0.25	0.10	0.08	0.24	0.25
0/100/0	U	0.29	0.22	0.12	0.09	0.26	0.30	0.21	0.20	0.07	0.05	0.19	0.22
2000	L	0.19	0.19	0.07	0.06	0.18	0.20	0.22	0.24	0.09	0.06	0.26	0.23
2/20/78	U	0.15	0.17	0.09	0.09	0.15	0.20	0.15	0.14	0.13	0.13	0.24	0.22
1000	L	0.17	0.21	0.13	0.13	0.28	0.34	0.20	0.20	0.12	0.12	0.23	0.26
2/20/78	U	0.30	0.28	0.09	0.12	0.24	0.22	0.21	0.17	0.15	0.21	0.26	0.25
2000	L	0.15	0.15	0.10	0.07	0.22	0.18	0.17	0.17	0.10	0.13	0.18	0.19
15/52/33	U	0.28	0.22	0.13	0.12	0.35	0.38	0.28	0.27	0.12	0.09	0.30	0.38
1000	L	0.15	0.12	0.06	0.06	0.12	0.12	0.16	0.16	0.09	0.07	0.15	0.16
15/52/33	U	0.22	0.25	0.14	0.13	0.24	0.29	0.27	0.35	0.17	0.13	0.28	0.34
2000	L	0.21	0.21	0.09	0.08	0.24	0.32	0.10	0.14	0.07	0.07	0.12	0.12
15/52/33	U	0.17	0.24	0.10	0.08	0.16	0.16	0.21	0.21	0.14	0.12	0.23	0.22
3000	L	0.13	0.13	0.06	0.06	0.16	0.13	0.17	0.18	0.09	0.08	0.18	0.19
30/0/70	U	0.16	0.19	0.13	0.13	0.31	0.31	0.24	0.26	0.15	0.13	0.28	0.34
1000	L	0.18	0.16	0.14	0.13	0.25	3.30	0.17	0.17	0.08	0.09	0.21	0.18
30/0/70	U	0.13	0.13	0.14	0.16	0.16	0.17	0.19	0.22	0.15	0.17	0.31	0.38
2000	L	0.15	0.14	0.11	0.11	0.29	0.29	0.11	0.10	0.07	0.07	0.19	0.14

TABLE III. 38w

FECAL CALCIUM--WINTER 1954
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.53	0.46	0.11	0.13	0.74	0.99	0.42	0.16	0.03	0.11	0.72	1.67
	L	0.85	0.81	0.09	0.09	1.06	1.26	0.49	0.72	0.11	0.11	1.00	1.33
0/100/0	U	0.60	0.47	0.15	0.50	0.91	1.48	0.57	0.44	0.10	0.11	0.69	1.12
1000	L	1.20	0.80	0.08	0.08	1.21	1.33	0.37	0.50	0.10	0.10	0.55	1.13
0/100/0	U	0.75	0.28	0.18	0.35	1.26	1.61	1.05	0.97	0.11	0.11	0.96	1.95
2000	L	0.97	0.78	0.21	0.21	1.00	1.61	0.94	0.79	0.20	0.19	0.50	1.44
2/20/78	U	0.74	0.62	0.24	0.25	0.98	1.09	0.85	0.68	0.25	0.22	1.05	1.52
1000	L	0.71	0.22	0.17	0.13	0.82	1.08	0.86	0.53	0.23	0.23	0.71	0.89
2/20/78	U	1.05	1.02	0.23	0.27	1.23	1.55	0.80	0.84	0.29	0.21	1.14	1.36
2000	L	0.68	0.72	0.13	0.13	1.47	1.63	0.67	0.41	0.13	0.13	0.44	1.02
15/52/33	U	0.92	0.42	0.15	0.17	1.08	1.75	0.51	0.30	0.11	0.22	0.94	1.66
1000	L	1.10	0.68	0.11	0.11	0.65	1.21	0.68	0.68	0.17	0.17	0.64	1.31
15/52/33	U	0.50	0.36	0.21	0.19	1.30	1.80	0.62	0.44	0.23	0.11	0.53	1.23
2000	L	1.33	0.54	0.10	0.16	1.03	1.72	0.61	0.66	0.21	0.21	0.69	1.45
15/52/33	U	0.95	0.67	0.25	0.30	0.77	1.33	0.56	0.72	0.34	0.29	1.58	1.47
3000	L	0.74	0.84	0.24	0.43	0.67	1.94	0.37	0.47	0.35	0.35	0.71	1.00
30/0/70	U	0.53	0.64	0.18	0.32	0.95	1.91	1.03	0.50	0.18	0.33	0.85	1.43
1000	L	0.80	0.87	0.16	0.16	1.22	1.41	0.82	0.54	0.15	0.15	0.51	1.55
30/0/70	U	0.50	0.45	0.19	0.11	0.80	1.31	0.61	0.37	0.13	0.31	1.13	1.42
2000	L	0.46	0.43	0.17	0.41	1.00	1.51	0.54	0.30	0.26	0.26	0.40	1.53

TABLE III. 39 W

CALCIUM BALANCE--WINTER 1954
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	+0.52	-0.12	-0.17	-0.18	+0.26	+1.25	-0.19	-0.09	-0.28	-0.22	+0.04	+0.02
	L	+0.52	+0.17	-0.31	-0.14	+0.58	+1.05	-0.28	-0.24	-0.22	-0.22	-0.16	+0.58
0/100/0	U	-0.40	-0.11	-0.25	-0.59	+0.77	+0.73	-0.34	-0.29	-0.15	-0.14	-0.10	+0.80
1000	L	-0.12	+0.24	-0.16	-0.11	+0.08	+0.63	-0.20	-0.26	-0.19	-0.17	-0.12	+0.94
0/100/0	U	-0.22	+0.14	-0.28	-0.41	-0.05	+0.76	+0.09	+0.01	-0.20	-0.18	+0.23	+0.28
2000	L	-0.06	-0.08	-0.28	-0.36	-0.16	+0.18	-0.34	+0.06	-0.28	-0.23	+0.30	+0.64
2/20/78	U	+0.26	+0.19	-0.26	-0.27	-0.23	+1.19	-0.34	-0.27	-0.32	-0.22	0.00	+0.71
1000	L	-0.18	+0.18	-0.26	-0.21	-0.18	+1.09	-0.38	+0.04	-0.30	-0.31	+0.13	+1.16
2/20/78	U	-0.17	-0.38	-0.23	-0.29	+0.09	+0.60	-0.20	+0.12	-0.33	-0.30	+0.06	+0.76
2000	L	-0.16	-0.18	-0.14	-0.12	-0.48	+0.58	-0.04	+0.26	-0.14	-0.18	+0.72	+1.16
15/52/33	U	-0.46	-0.04	-0.14	-0.15	+0.02	+0.51	-0.18	+0.02	-0.11	-0.18	-0.23	+0.62
1000	L	-0.25	-0.03	-0.04	-0.04	+0.68	+1.06	-0.14	-0.12	-0.14	-0.12	+0.45	+0.67
15/52/33	U	-0.11	+0.02	-0.16	-0.13	-0.20	+0.25	-0.35	-0.02	-0.21	-0.07	+0.22	+0.64
2000	L	-0.65	-0.12	-0.07	-0.06	+0.05	+0.48	-0.16	-0.06	-0.12	-0.10	+0.12	+0.62
15/52/33	U	-0.12	-0.10	-0.08	-0.15	-0.02	+0.52	-0.32	-0.07	-0.22	-0.16	-0.14	+0.88
3000	L	+0.17	+0.22	-0.05	-0.25	+0.18	+0.12	+0.28	+0.29	-0.20	-0.19	+0.20	+0.93
30/0/70	U	-0.18	+0.13	-0.26	-0.38	+0.22	+0.60	-0.07	+0.14	-0.26	-0.40	+0.40	+0.90
1000	L	+0.20	+0.25	-0.25	-0.24	-0.08	+0.66	-0.19	+0.04	-0.19	-0.20	-0.09	+0.62
30/0/70	U	-0.01	+0.06	-0.25	-0.18	+0.19	+0.72	-0.25	+0.04	-0.18	-0.37	-0.43	+0.48
2000	L	-0.14	-0.12	-0.22	-0.44	+0.18	+0.72	+0.15	+0.28	-0.25	-0.24	+0.82	+0.58

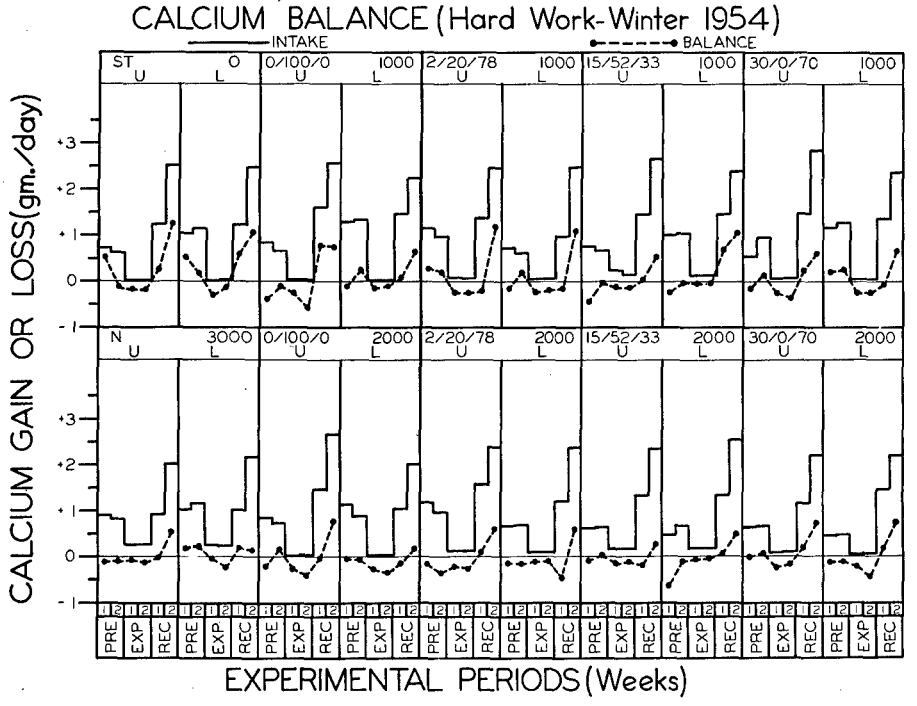


FIGURE III. 15. CALCIUM BALANCE: HARD WORK (WINTER, 1954).

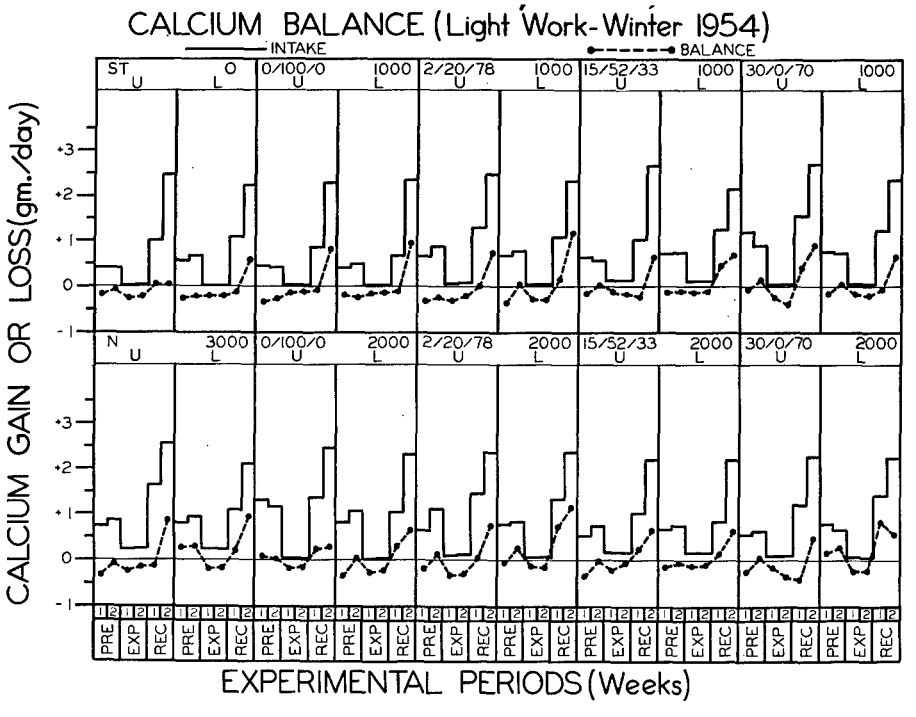


FIGURE III. 16. CALCIUM BALANCE: LIGHT WORK (WINTER, 1954)

b. Phosphorus Balance (Winter 1954)

Because of its central position in current schemes of intermediary metabolism in cellular activity, and particularly its contribution of high energy bonds, phosphorus was of particular interest in the present study.

Pre-Period. Intake was substantial in both pre-periods (Table III. 40), approximating the recommended dietary allowances of the Food and Nutrition Board. As a result all flights were at the balance point in PRE II. Urinary excretion was about the same during both weeks in all flights, and remained substantially unchanged in PRE II as compared with PRE I. On the other hand, fecal excretion decreased in all flights after PRE I; it averaged 0.48 gm of P/day in PRE I and 0.36 gm of P/day in PRE II.

There is nothing unusual about the pre-period data. All subjects received adequate amounts of phosphorus, and were substantially in balance.

Experimental Period. Intakes were widely different during the experimental periods (Table III. 41). In 16 regimens, intakes were extremely low: STO U and L, 0/100/0 1000 U and L, 0/100/0 2000 U and L, and 2/20/78 1000 U and L. In 16 regimens intakes were moderately low, averaging 0.53 gm of P/day; 2/20/78 1000 U and L, 15/52/33 1000 U and L, 15/52/33 2000 U and L, and 30/0/70 1000 U and L. In 8 regimens, intakes approximated those of pre-period, averaging 1.09 gm of P/day: 15/52/33 3000 U and L, and 30/0/70 2000 U and L.

Urinary excretion of phosphorus exhibited some interesting changes (Table III. 42). In EXP I there was a decrease in only 21 of the 40 regimens, a finding that would not have been expected in view of the fact that intake was very low or low in 32 regimens. Of special interest was a substantial increase in all 30/0/70 regimens. In EXP II, values were lower than for PRE II in 29 of the 40 regimens, and lower than for EXP I, in 31 of the 40 regimens. These findings suggest an adaptive renal response to low phosphorus intakes. There was an effect of limitation of water. If we take EXP I and EXP II together, 40 comparisons of U and L are possible. In 26 of these 40, urinary phosphorus was greater in L than in U. Work load had some effect also. In EXP II, comparing hard and light work regimens, excretion was greater among the hard work groups in 13 of 20 comparisons, being especially pronounced in the low intake regimens. Calories also had an effect. If we compare regimens in which the intake was the same at two different calorie levels, excretion was less at the higher calorie level in EXP II in:

STO vs. 0/100/0 1000	3 of 4 comparisons
0/100/0 1000 vs. 0/100/0 2000	4 of 4 comparisons
15/52/33 1000 vs. 2/20/78 2000	3 of 4 comparisons
30/0/70 1000 vs. 15/52/33 2000	4 of 4 comparisons
30/0/70 2000 vs. 15/52/33 3000	4 of 4 comparisons

Fecal excretion of phosphorus diminished in the experimental period (Table III. 43). PRE II was greater than EXP II in 38 of the 40 regimens. Dehydration tended to cause a decreased excretion of phosphorus in 16 of 20 comparisons in EXP II. Hard work and calorie intake had no special effect on fecal excretion,

nor did phosphorus intake in EXP I and EXP II.

Mostly as a result of relative changes in phosphorus intake and urinary excretion, phosphorus balance showed some striking changes in EXP I and EXP II. (Table III. 44; Figures III. 17 and III. 18); fecal excretion had a subordinate position in these effects. In EXP I there was a strong negative balance in all 40 regimens. The same results were found in EXP II, except that in one regimen balance was attained: 15/52/33 3000 L light work. During EXP II there was a tendency toward some decrease in negativity; i.e., a less negative balance than in EXP I, in 30 of the 40 regimens. Of the overall factors limitation of water and physical work made no difference in the phosphorus balance. Furthermore, phosphorus intake per se had surprisingly little effect. To be sure, STO groups displayed the greatest negativity of balance; however, starvation was accompanied by calorie deficit of strong degree. The lack of correspondence between phosphorus intake and phosphorus balance is well brought out by averaging intakes and balances for all regimens (excluding STO) within the groups of low phosphorus intake, intermediate phosphorus intake and high phosphorus intake, as in the following table.

PHOSPHORUS BALANCES AND INTAKES
(EXP II, WINTER 1954)
(gm P/day)

Mean Intake	Regimens Included	Phosphorus Balance
0.05	0/100/0 1000, 0/100/0 2000, 2/20/78 1000	-0.54
0.47	2/20/78 2000, 15/52/33 1000, 30/0/70 1000	-0.46
0.97	15/52/33 2000, 15/52/33 3000, 30/0/70 2000	-0.36

It is clear that an increase of intake of as much as 0.5 gm of P/day alleviated the negative balance only to the extent of 0.1 gm of P/day.

Calorie intake did have some effect upon phosphorus balance. If we compare regimens whose phosphorus intakes were substantially the same, but whose calorie levels were different, the higher calorie intake had the least negative balance as follows:

STO vs. 0/100/0 1000	3 of 4 comparisons
0/100/0 1000 vs. 0/100/0 2000	3 of 4 comparisons
15/52/33 1000 vs. 2/20/78 2000	3 of 4 comparisons
30/0/70 2000 vs. 15/52/33 3000	4 of 4 comparisons

In general, we must conclude that there was operative a factor common to all regimens and all subjects during EXP I and EXP II which forced them into negative phosphorus balance; phosphorus intake and calorie intake acted only to a minor degree in alleviating the negative phosphorus balance. It is tempt-

ing to postulate a catabolic reaction, caused by exposure to environment and field conditions.

Recovery Phosphorus intake during REC I became some 0.5 to 1.0 gm of P greater than it had been in PRE II. During REC II, addition of dairy products to the diet raised the phosphorus intake to very high values, exceeding 3.0 gm of P/day in many subjects.

Urinary excretion in REC I remained surprisingly low; in spite of the higher intake in REC I, urinary excretion in PRE II was higher in 37 of the 40 regimens. In REC II, urinary excretion increased again, but the increase by no means corresponded with the dietary increase in REC II.

Fecal phosphorus on the average was excreted in larger amounts in REC I than in PRE II in 37 of 40 regimens. This difference apparently was due to some inability of the subjects to absorb phosphorus as well in REC I as in PRE II, because in REC II, in spite of a substantial further increase of phosphorus intake, the fecal excretion did not rise correspondingly, in fact, it actually declined in 11 of 40 regimens.

Balances became positive in REC I in all 40 groups, and in REC II became more positive in all groups, corresponding to an increased intake. If we examine not merely the relationship of balance to intake, but compute a "utilization index", the results are quite informative when PRE II is compared with REC I and REC II (Table III. 45). The utilization index is defined as (Intake / Excretion) x 100. It changes in relationship to balance. If the subject is just in balance, intake equals excretion, and the index is 100. In negative balance, intake is less than excretion, and the index is less than 100. In positive balance, intake is greater than excretion and the index becomes greater than 100.

In PRE I, the subjects' "phosphorus utilization indices" were very close to 100, which corresponds with their known approach to true balance. In REC I, all indices were well above 100, ranging from 136 to 226. In REC II, indices were even higher, ranging from 141 to 243. These data are entirely consistent with the hypothesis that there was an anabolic phase during both REC I and REC II, during which phosphorus was being extracted from the ingested food, and being laid down in the tissues at a phenomenal rate. Apparently previous status of work, hydration, calorie intake, or phosphorus intake had but little direct controlling relation to this anabolic phase, for all subjects showed it to a marked degree. By the end of REC II all subjects had made up, or more than made up, the phosphorus deficits which they had incurred in EXP I and EXP II.

TABLE III. 40 W

PRE-PERIOD DATA ON PHOSPHORUS INTAKE, URINARY PHOSPHORUS, FECAL PHOSPHORUS, AND PHOSPHORUS BALANCE (WINTER 1954)
(gm P/day)

Flight	P I Mean	P I Range	P II Mean	P II Range
		A. Phosphorus Intake		
1	1.37	0.55 - 2.08	1.21	0.68 - 1.89
2	1.49	0.78 - 2.33	1.47	0.81 - 2.24
3	1.29	0.79 - 2.20	1.34	0.99 - 1.59
4	1.34	0.98 - 1.59	1.26	0.96 - 1.56
		B. Urinary Phosphorus		
1	0.97	0.61 - 1.32	0.90	0.62 - 1.28
2	0.91	0.65 - 1.21	0.96	0.67 - 1.40
3	0.98	0.73 - 1.21	0.92	0.66 - 1.18
4	0.88	0.72 - 1.05	0.90	0.69 - 1.10
		C. Fecal Phosphorus		
1	0.48	0.24 - 0.74	0.33	0.14 - 0.64
2	0.58	0.24 - 1.19	0.40	0.09 - 0.70
3	0.44	0.20 - 0.08	0.36	0.11 - 0.59
4	0.42	0.14 - 0.84	0.34	0.11 - 0.67
		D. Phosphorus Balance		
1	-0.08	-0.38 to + 0.51	-0.02	-0.70 to + 0.23
2	-0.02	-0.41 to + 0.51	+0.10	-0.23 to + 0.65
3	-0.13	-0.60 to + 0.21	+0.06	-0.23 to + 0.38
4	+0.02	-0.38 to + 0.47	+0.03	-0.39 to + 0.32

TABLE III. 41 W

PHOSPHORUS INTAKE (WINTER 1954)
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	1.32	1.21	0.00	0.00	2.06	3.57	1.22	1.18	0.00	0.00	1.93	3.42
	L	1.64	1.63	0.00	0.00	2.04	3.45	1.29	1.19	0.00	0.00	2.04	3.00
0/100/0	U	1.36	0.96	0.00	0.00	2.36	3.62	1.27	1.21	0.00	0.00	1.76	3.19
1000	L	1.79	1.76	0.00	0.00	2.29	2.95	1.31	1.03	0.00	0.00	1.65	2.99
0/100/0	U	1.36	1.19	0.00	0.00	2.43	3.66	1.69	1.51	0.00	0.00	2.09	3.15
2000	L	1.69	1.34	0.00	0.00	1.78	2.71	1.37	1.41	0.00	0.00	1.89	3.04
2/20/78	U	1.93	1.57	0.16	0.16	2.37	3.62	0.81	1.29	0.15	0.16	2.11	3.42
1000	L	1.09	1.01	0.16	0.16	1.70	3.62	1.38	1.33	0.16	0.16	1.93	3.14
2/20/78	U	1.84	1.59	0.41	0.41	2.35	3.02	1.14	1.67	0.36	0.41	2.46	3.59
2000	L	1.40	1.37	0.41	0.41	2.02	3.48	1.42	1.45	0.41	0.41	2.14	3.27
15/52/33	U	1.39	1.09	0.41	0.41	2.40	3.60	1.37	1.30	0.41	0.41	2.04	3.78
1000	L	1.42	1.40	0.41	0.41	2.17	3.32	1.26	1.22	0.41	0.41	1.96	2.81
15/52/33	U	1.02	1.10	0.71	0.71	2.09	3.26	1.18	1.38	0.71	0.71	1.78	2.66
2000	L	1.21	1.46	0.71	0.71	1.93	3.39	1.23	1.14	0.71	0.71	1.46	2.83
15/52/33	U	1.52	1.24	1.07	1.07	1.43	2.78	1.34	1.39	1.08	1.07	2.47	3.56
3000	L	1.61	1.67	1.07	1.04	1.68	2.81	1.47	1.44	1.07	1.07	1.82	2.79
30/0/70	U	0.88	1.26	0.58	0.59	2.36	3.80	1.79	1.47	0.57	0.61	2.44	3.52
1000	L	1.69	1.58	0.59	0.59	2.20	3.32	1.26	1.20	0.59	0.62	1.90	3.16
30/0/70	U	1.15	1.02	1.09	1.19	1.83	3.09	1.12	1.04	1.15	1.16	2.02	2.99
2000	L	1.24	1.27	0.92	1.12	2.25	3.83	1.40	1.25	1.19	1.12	2.11	2.94

TABLE III. 42 W

URINARY PHOSPHORUS (WINTER 1954)
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	0.98	0.90	0.96	0.63	0.66	1.24	0.88	0.85	0.88	0.72	0.78	0.95
	L	0.89	0.97	1.03	0.89	0.34	1.09	0.85	0.94	1.00	0.73	0.53	1.09
0/100/0	U	1.02	1.01	0.64	0.63	0.79	1.38	0.96	0.88	0.55	0.37	0.35	1.34
1000	L	0.89	1.01	0.69	0.58	0.48	1.13	0.76	0.76	0.64	0.55	0.49	0.96
0/100/0	U	1.18	0.89	0.68	0.47	0.76	1.60	1.03	0.92	0.58	0.32	0.78	1.20
2000	L	0.87	0.92	0.46	0.47	0.49	1.15	0.86	0.94	0.57	0.36	0.58	1.08
2/20/78	U	0.96	0.96	0.84	0.79	0.70	1.34	0.86	0.84	0.72	0.55	0.34	1.10
1000	L	0.86	0.87	0.94	0.85	0.81	1.01	0.86	0.84	0.78	0.63	0.52	1.04
2/20/78	U	1.03	1.14	0.84	0.61	1.00	1.41	0.97	0.98	0.75	0.60	0.63	1.08
2000	L	0.82	0.94	0.69	0.63	0.49	1.14	0.99	1.02	0.72	0.70	0.82	1.12
15/52/33	U	1.04	0.88	0.85	0.86	0.98	1.57	0.98	0.87	0.78	0.67	0.54	1.41
1000	L	0.93	0.98	0.75	0.86	0.36	1.08	0.90	0.81	0.72	0.65	0.52	1.09
15/52/33	U	0.82	0.74	0.90	0.85	0.78	1.36	1.06	1.04	0.82	0.81	0.80	1.05
2000	L	0.89	1.04	0.95	0.87	0.34	0.68	0.90	0.81	0.94	1.02	0.56	0.86
15/52/33	U	1.00	0.94	1.04	0.92	0.86	1.30	1.13	1.08	1.20	1.06	1.02	1.34
3000	L	0.95	0.94	1.15	1.20	0.57	0.88	0.97	1.10	1.13	0.78	0.66	0.94
30/0/70	U	0.80	0.76	0.94	0.95	0.56	1.50	1.15	1.04	1.27	1.12	0.57	1.20
1000	L	1.00	0.96	1.31	1.19	0.43	0.94	0.90	0.89	1.11	1.26	0.67	1.00
30/0/70	U	0.82	0.77	1.44	1.34	0.61	1.20	0.82	0.70	1.42	1.42	0.65	1.09
2000	L	1.04	0.98	1.37	1.70	0.60	1.50	0.87	0.84	1.51	1.44	0.88	1.06

TABLE III. 43w

FECAL PHOSPHORUS (WINTER 1954)
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.48	0.30	0.09	0.09	0.89	0.58	0.35	0.15	0.03	0.13	0.62	1.03
	L	0.61	0.43	0.05	0.05	0.91	0.93	0.32	0.44	0.07	0.08	0.78	0.77
0/100/0	U	0.42	0.31	0.11	0.28	0.74	0.82	0.38	0.36	0.11	0.12	0.45	0.57
1000	L	0.87	0.57	0.06	0.06	0.87	0.70	0.30	0.40	0.14	0.14	0.48	0.55
0/100/0	U	0.50	0.14	0.09	0.19	0.92	0.69	0.52	0.51	0.10	0.10	0.55	0.95
2000	L	0.54	0.32	0.11	0.16	0.75	0.81	0.49	0.38	0.13	0.13	0.38	0.63
2/20/78	U	0.61	0.43	0.18	0.14	0.82	0.56	0.46	0.41	0.19	0.16	0.69	0.80
1000	L	0.44	0.13	0.10	0.11	0.65	0.75	0.69	0.31	0.13	0.13	0.54	0.38
2/20/78	U	0.69	0.46	0.20	0.19	0.73	0.69	0.50	0.53	0.19	0.16	0.93	0.75
2000	L	0.54	0.52	0.11	0.11	1.13	0.81	0.40	0.25	0.07	0.07	0.28	0.43
15/52/33	U	0.52	0.25	0.15	0.17	0.73	0.94	0.36	0.27	0.17	0.22	0.76	1.01
1000	L	0.58	0.36	0.08	0.08	0.52	0.60	0.49	0.42	0.12	0.12	0.48	0.61
15/52/33	U	0.38	0.28	0.19	0.18	0.94	0.97	0.46	0.30	0.25	0.17	0.35	0.59
2000	L	0.85	0.34	0.16	0.15	0.95	0.94	0.39	0.41	0.14	0.14	0.45	0.66
15/52/33	U	0.48	0.38	0.27	0.26	0.43	0.65	0.35	0.45	0.29	0.24	1.10	0.74
3000	L	0.58	0.58	0.29	0.46	0.55	1.08	0.21	0.31	0.29	0.29	0.40	0.40
30/0/70	U	0.33	0.37	0.09	0.20	0.81	1.18	0.70	0.33	0.13	0.25	0.57	0.80
1000	L	0.54	0.46	0.11	0.11	1.08	0.72	0.55	0.30	0.08	0.08	0.30	0.74
30/0/70	U	0.40	0.34	0.14	0.11	0.56	0.70	0.42	0.30	0.11	0.32	0.71	0.63
2000	L	0.34	0.25	0.16	0.13	0.70	0.83	0.54	0.16	0.12	0.12	0.19	0.63

TABLE III. 44 W

PHOSPHORUS BALANCE (WINTER 1954)
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	-0.14	+0.02	-1.05	-0.76	+0.53	+1.28	-0.01	+0.13	-1.01	-0.92	+0.54	+1.43
	L	+0.13	+0.23	-1.08	-0.94	+0.78	+1.68	-0.02	-0.18	-1.07	-0.81	+0.73	+1.20
0/100/0	U	-0.08	-0.36	-0.75	-0.90	+0.83	+1.41	-0.07	-0.02	-0.66	-0.48	+0.96	+1.29
1000	L	+0.03	+0.18	-0.75	-0.64	+0.94	+1.12	+0.26	-0.12	-0.77	-0.68	+0.68	+1.49
0/100/0	U	-0.32	+0.09	-0.76	-0.66	+0.76	+1.38	+0.14	+0.09	-0.68	-0.43	+0.76	+1.29
2000	L	+0.28	+0.10	-0.63	-0.64	+0.54	+0.88	+0.02	+0.10	-0.70	-0.50	+0.93	+1.34
2/20/78	U	+0.36	+0.17	-0.85	-0.76	+0.84	+1.74	-0.51	+0.04	-0.78	-0.54	+1.08	+1.52
1000	L	-0.21	+0.02	-0.88	-0.80	+0.24	+1.86	-0.16	+0.18	-0.75	-0.60	+0.86	+1.72
2/20/78	U	+0.12	-0.15	-0.70	-0.40	+0.60	+0.92	-0.27	+0.15	-0.58	-0.34	+0.90	+1.76
2000	L	+0.04	-0.10	-0.39	-0.33	+0.40	+1.53	+0.03	+0.19	-0.38	-0.36	+0.94	+1.72
15/52/33	U	-0.17	-0.04	-0.59	-0.62	+0.70	+1.08	+0.04	+0.17	-0.54	-0.45	+0.72	+1.36
1000	L	-0.10	+0.05	-0.40	-0.52	+1.28	+1.64	-0.13	0.00	-0.44	-0.36	+0.95	+1.12
15/52/33	U	-0.19	-0.09	-0.37	-0.32	+0.36	+0.94	-0.35	+0.04	-0.35	-0.26	+0.68	+1.01
2000	L	-0.38	+0.09	-0.40	-0.32	+0.64	+1.72	-0.04	-0.08	-0.37	-0.46	+0.44	+1.30
15/52/33	U	+0.04	-0.07	-0.23	-0.10	+0.15	+0.82	-0.14	-0.13	-0.40	-0.23	+0.34	+1.98
3000	L	+0.08	+0.14	-0.37	-0.62	+0.56	+0.86	+0.28	+0.03	-0.35	0.00	+0.75	+1.45
30/0/70	U	-0.26	+0.08	-0.48	-0.36	+0.94	+1.12	-0.06	+0.10	-0.79	-0.78	+1.30	+1.54
1000	L	+0.14	+0.10	-0.84	-0.72	+0.74	+1.66	-0.20	+0.01	-0.60	-0.72	+0.65	+1.41
30/0/70	U	-0.07	-0.09	-0.49	-0.21	+0.64	+1.18	-0.12	+0.04	-0.40	-0.60	+0.64	+1.26
2000	L	-0.14	-0.04	-0.61	-0.70	+0.96	+1.50	+0.18	+0.24	-0.44	-0.44	+1.04	+1.24

TABLE III. 45w

"UTILIZATION INDEX", PHOSPHORUS, (WINTER 1954)

Experimental Regimen		Hard Work			Light Work		
		Pre	Rec		Pre	Rec	
		I	I	II	I	I	II
ST O	U	101	136	200	109	139	174
	L	115	167	196	88	174	161
0/100/0	U	79	154	165	99	221	169
1000	L	111	170	161	89	171	199
0/100/0	U	107	146	161	109	157	171
2000	L	107	149	141	109	201	179
2/20/78	U	115	162	200	107	206	181
1000	L	103	117	213	115	190	225
2/20/78	U	92	135	146	109	156	196
2000	L	93	125	179	115	183	211
15/52/33	U	95	141	145	118	156	157
1000	L	104	248	202	101	203	165
15/52/33	U	109	121	140	103	159	159
2000	L	106	149	205	97	143	186
15/52/33	U	95	112	143	92	117	243
3000	L	109	150	147	104	170	207
30/0/70	U	107	167	142	107	226	177
1000	L	110	156	211	101	155	213
30/0/70	U	93	157	163	105	147	173
2000	L	104	219	165	123	200	233

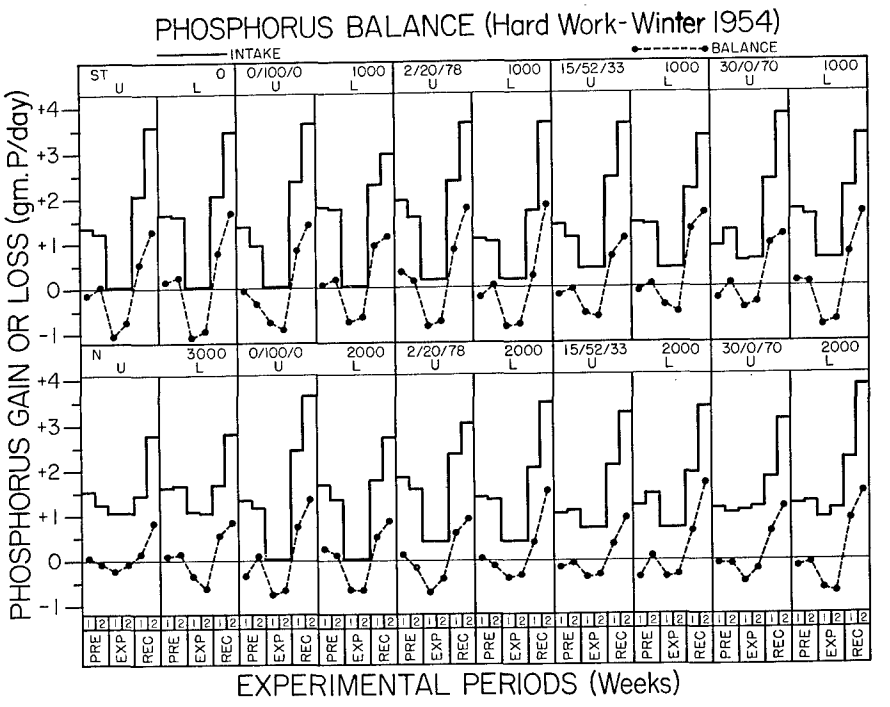


FIGURE III. 17. PHOSPHORUS BALANCE: HARD WORK (WINTER, 1954).

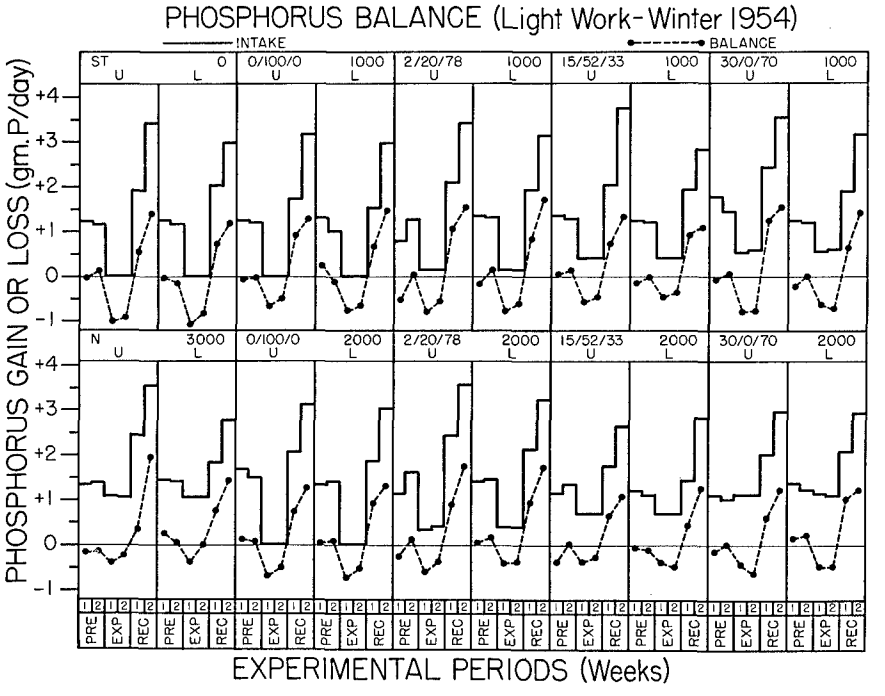


FIGURE III. 18. PHOSPHORUS INTAKE: LIGHT WORK (WINTER, 1954).

8. Calcium Balance (Summer 1955).

Introduction. The sweat calcium is relatively small in concentration as compared with sweat sodium, chloride, and nitrogen. Furthermore, sweat calcium concentration does not vary with rate of sweating to nearly the same extent as do sweat sodium and sweat chloride. Therefore, we can trust our estimate of dermal calcium loss, and therefore the balance figures.

Pre-Period. In PRE I intake approximated 1 gm of Ca/day (Table III. 35 A); in PRE II, intake diminished to 0.7 gm of Ca/day. Urinary calcium excretion diminished slightly between PRE I and PRE II, except in the controls, whose intake was large (Table III. 35 B). Fecal calcium diminished between PRE I and PRE II in Flights 2, 3, and 4, but increased in Flight 1 and the controls (Table III. 35 C). Balances diminished in Flights 1, 2, and 3 between PRE I and PRE II, and increased slightly in Flight 1; and the controls were in balance (Table III. 35 D). We interpret these balance results to be directly correlated with the different calcium intakes in PRE I and PRE II, and not to a direct effect of hot weather.

Experimental Period: Intake. Dietary planning necessitated the omission of dairy products from all experimental regimens. Therefore the calcium intakes were very low in all regimens (Table III. 36). Tap water accounted for up to 0.02 gm of Ca/day. In the regimen of largest intake, 15/52/33 3000, the intake was still only 0.26 gm of Ca/day. In short, we could consider the calcium intake of all regimens to be very low.

Experimental Period: Urinary Calcium. There tended to be a diminution of urinary calcium excretion in both experimental weeks. In EXP I or EXP II, or both, the excretion was lower than in PRE II as follows: hard work, 18 of 20 comparisons; light work, 18 of 19 comparisons (Table III. 37). Controls did not vary. Hard work tended to diminish the urinary calcium excretion. In EXP II, hard work subjects were lower than the paired light work subjects in 11 of 18 comparisons. Very low excretions were measured for the pure carbohydrate diets, but there was no other consistent correlation with intake. Neither did limitation of water, calorie intake, or nutrient ratio have any apparent effect.

Experimental Period: Fecal Calcium. From subject to subject, fecal calcium excretion is widely different; it is almost an individual characteristic. It tended to decrease in EXP I and EXP II among those regimens which cause a marked diminution of fecal bulk: ST 0, 0/100/0 1000 and 0/100/0 2000 (Table III. 38). Otherwise there were no convincing correlations with work load, water intake, nutrient ratios, or calorie intake.

Experimental Period: Dermal Loss. The sweat contributed about as much calcium loss as did the urine and feces (Table III. 39). It tended to be only slightly higher in hard work than in light work. It did not diminish significantly between PRE II and EXP II, and it did not correlate with any of the major variables.

Experimental Period: Calcium Balance. We interpret all of the calcium balances to mean that negativity was invoked in all subjects by a low calcium intake (Table III. 40; Figures III. 19, III. 20). Amount of negativity was not convincingly correlated with calcium intake, work load, nutrient ratios, or calorie intake. In hard work there was only one suggestive correlation: comparing water limited and unlimited, balance was less negative in limited groups in seven of nine comparisons. This correlation did not hold in light work. The controls remained in positive balance at all times, their consumption of milk being substantial.

Recovery Period. Intakes increased to 0.9 gm of Ca/day in REC I and to about 1.3 gm of Ca/day in REC II. Urinary excretion increased in REC I, as did fecal excretion. In REC II, urinary excretion tended to increase slightly further, but fecal excretion did not. Estimated dermal loss changed relatively little. Calcium balances still tended to be negative in REC I, although the severity of the negativity diminished as compared with EXP II. In REC II all subjects approached balance and the great majority of them became positive.

TABLE III. 35S

PRE-PERIOD DATA ON
CALCIUM INTAKE, OUTPUT, AND BALANCE
(gm/day)

Flight	P I Mean	P I Range	P II Mean	P II Range
		A. Intake		
1	1.09	0.33-1.50	0.68	0.32-0.82
2	0.97	0.53-1.41	0.67	0.44-0.84
3	1.21	0.67-1.72	0.70	0.35-1.02
4	1.04	0.64-1.32	0.71	0.38-0.84
FRA	----	---------	1.93	1.29-3.61
		B. Urinary Calcium		
1	0.20	0.07-0.31	0.17	0.05-0.32
2	0.16	0.03-0.28	0.15	0.03-0.26
3	0.25	0.09-0.42	0.22	0.08-0.40
4	0.21	0.08-0.34	0.18	0.06-0.32
FRA	0.20	0.06-0.35	0.22	0.04-0.31
		C. Fecal Calcium		
1	0.92	0.24-2.42	0.97	0.24-2.22
2	0.72	0.20-1.36	0.43	0.09-0.74
3	0.88	0.32-1.47	0.62	0.33-1.42
4	0.92	0.31-1.36	0.44	0.20-1.00
FRA	1.40	0.66-3.03	1.56	0.61-3.32
		D. Balance		
1	-0.10	(-1.54)-(+0.76)	-0.60	(-1.89)-(+0.32)
2	+0.01	(-0.47)-(+0.67)	-0.05	(-0.37)-(+0.23)
3	-0.04	(-0.53)-(+0.80)	-0.32	(-1.12)-(+0.02)
4	-0.20	(-0.69)-(+0.07)	-0.06	(-0.50)-(+0.28)
FRA	-----	----------	-0.02	(-0.47)-(+0.27)

TABLE III. 36S

CALCIUM INTAKE
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.99	0.63	0.01	0.02	0.90	1.17	1.05	0.65	0.02	0.01	0.90	1.28
	L	0.98	0.69	0.01	0.01	0.90	1.33	1.20	0.78	0.01	0.01	0.89	1.49
0/100/0	U	1.21	0.67	0.02	0.02	0.91	1.35	1.34	0.75	0.02	0.02	0.92	1.32
1000	L	1.14	0.76	0.01	0.01	0.89	1.35	1.12	0.83	0.01	0.02	0.86	1.45
0/100/0	U	1.12	0.77	0.02	0.02	0.96	1.29	1.43	0.74	0.02	0.02	0.95	1.34
2000	L	1.20	0.73	0.01	0.01	0.96	1.29	1.04	0.58	0.01	0.01	0.96	1.21
2/20/78	U	1.00	0.69	0.06	0.06	0.90	1.45	0.91	0.57	0.05	0.05	0.87	1.12
1000	L	0.81	0.64	0.05	0.05	0.90	1.20	1.05	0.71	0.04	0.05	0.92	1.23
2/20/78	U	1.33	0.72	0.09	0.10	0.97	----	0.82	0.62	0.09	0.09	0.96	1.04
2000	L	0.77	0.57	0.08	0.09	0.76	1.06	1.18	0.59	0.08	0.09	0.96	1.27
15/52/33	U	1.05	0.62	0.09	0.09	0.90	1.21	1.47	0.81	0.09	0.08	0.92	1.18
1000	L	0.93	0.63	0.08	----	----	----	0.99	0.81	0.07	0.08	0.92	1.46
15/52/33	U	1.00	0.72	0.17	0.17	0.96	1.11	1.56	0.83	0.19	0.19	0.98	1.55
2000	L	1.13	0.74	0.17	0.17	0.97	1.34	1.01	0.74	0.17	0.17	0.95	1.25
15/52/33	U	1.15	0.75	0.26	0.27	0.96	1.20	1.60	0.95	0.26	0.26	0.91	1.29
3000	L	1.24	0.71	0.26	0.26	0.84	1.28	0.87	0.74	----	----	----	----
30/0/70	U	0.92	0.56	0.05	0.05	0.90	1.29	0.80	0.45	0.05	0.05	0.89	1.10
1000	L	0.87	0.70	0.04	0.04	0.90	1.31	0.93	0.52	0.04	0.05	0.70	1.23
30/0/70	U	1.25	0.73	0.09	0.09	0.97	1.31	0.97	0.63	0.09	0.09	0.96	1.36
2000	L	0.78	0.50	0.07	0.08	0.87	0.88	0.89	0.76	0.07	0.08	0.90	1.39
FRA		----	1.93	----	1.76	1.85	1.19	----	1.93	----	1.76	1.85	1.19

TABLE III. 37S

URINARY CALCIUM
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC I	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	0.19	0.19	0.14	0.10	0.25	0.30	0.28	0.22	0.16	0.16	0.28	0.37
	L	0.17	0.15	0.10	0.12	0.16	0.33	0.25	0.22	0.12	0.21	0.27	0.36
0/100/0	U	0.19	0.14	0.07	0.02	0.15	0.32	0.37	0.29	0.09	0.06	0.24	0.36
1000	L	0.16	0.18	0.05	0.05	0.17	0.22	0.19	0.16	0.06	0.09	0.18	0.24
0/100/0	U	0.29	0.26	0.10	0.08	0.34	0.35	0.26	0.28	0.11	0.12	0.33	0.32
2000	L	0.19	0.18	0.06	0.07	0.25	0.32	0.26	0.20	0.10	0.11	0.35	0.32
2/20/78	U	0.10	0.12	0.10	0.03	0.06	0.13	0.27	0.19	0.06	0.12	0.22	0.24
1000	L	0.21	0.18	0.11	0.15	0.21	0.28	0.12	0.10	0.06	0.10	0.16	0.13
2/20/78	U	0.17	0.11	0.12	0.19	0.22	----	0.20	0.17	0.20	0.18	0.31	0.26
2000	L	0.21	0.18	0.11	0.15	0.21	0.28	0.14	0.12	0.08	0.13	0.25	0.15
15/52/33	U	0.24	0.23	0.13	0.11	0.23	0.34	0.26	0.27	0.14	0.09	0.19	0.37
1000	L	0.19	0.14	0.05	----	----	----	0.20	0.21	0.07	0.10	0.23	0.31
15/52/33	U	0.14	0.12	0.07	0.09	0.19	0.20	0.17	0.16	0.06	0.11	0.19	0.21
2000	L	0.13	0.11	0.06	0.07	0.15	0.19	0.26	0.25	0.06	0.15	0.31	0.28
15/52/33	U	0.25	0.19	0.11	0.14	0.26	0.25	0.32	0.23	0.08	0.10	0.23	0.32
3000	L	0.13	0.13	0.07	0.10	0.17	0.18	0.14	0.15	----	----	----	----
30/0/70	U	0.23	0.18	0.15	0.13	0.26	0.34	0.16	0.15	0.09	0.14	0.20	0.19
1000	L	0.23	0.25	0.14	0.18	0.16	0.36	0.21	0.18	0.09	0.12	0.24	0.29
30/0/70	U	0.22	0.20	0.22	0.17	0.31	0.38	0.16	0.14	0.12	0.11	0.25	0.27
2000	L	0.11	0.08	0.10	0.13	0.24	0.13	0.20	0.18	0.11	0.19	0.31	0.28
FRA		0.20	0.22	0.20	0.22	0.23	0.24	0.20	0.22	0.20	0.22	0.23	0.24

TABLE III. 38S

FECAL CALCIUM
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.94	1.14	0.08	0.00	0.74	0.90	0.91	0.53	0.17	0.17	0.72	0.55
	L	1.02	0.43	0.20	0.21	0.77	0.56	1.04	0.57	0.27	0.08	0.71	0.96
0/100/0	U	1.22	1.62	0.08	0.15	0.75	0.89	0.87	0.47	0.12	0.12	1.42	0.50
1000	L	1.10	0.46	0.29	0.29	0.77	0.64	0.77	0.44	0.08	0.08	0.96	1.02
0/100/0	U	1.26	1.87	0.08	0.27	0.79	0.90	1.18	1.14	0.15	0.15	0.70	0.46
2000	L	0.90	0.43	0.05	0.05	0.68	0.37	1.16	0.49	0.16	0.16	0.59	0.60
2/20/78	U	1.36	1.20	0.60	1.14	0.85	0.98	0.67	0.60	0.08	0.08	0.19	0.41
1000	L	0.51	0.43	0.08	0.08	0.43	0.75	0.94	0.39	0.37	0.37	0.71	0.61
2/20/78	U	0.81	1.01	0.34	0.32	0.71	----	0.79	0.59	0.39	0.44	0.79	0.58
2000	L	0.30	0.24	0.14	0.23	0.53	0.58	1.17	0.46	0.34	0.33	1.18	0.62
15/52/33	U	0.62	0.57	0.42	0.42	0.82	0.44	0.97	0.38	0.07	0.16	0.69	0.74
1000	L	0.42	0.48	0.12	----	----	----	0.81	0.35	0.15	0.20	0.63	0.60
15/52/33	U	0.44	0.50	0.55	0.40	1.21	0.66	0.68	0.68	0.03	0.21	1.34	1.14
2000	L	0.64	0.67	0.31	0.31	0.75	0.61	1.03	0.48	0.23	0.22	0.62	0.57
15/52/33	U	0.97	0.52	0.29	0.32	0.78	0.54	1.67	0.75	0.23	0.37	0.92	0.91
3000	L	1.07	0.39	0.32	0.32	0.86	0.40	0.84	0.47	----	----	----	----
30/0/70	U	0.76	0.51	0.40	0.51	0.65	0.59	0.36	0.46	0.08	0.25	1.05	0.44
1000	L	0.72	0.42	0.26	0.15	0.64	0.55	0.80	0.39	0.20	0.20	0.33	0.55
30/0/70	U	0.80	0.44	0.30	0.30	0.93	0.89	0.34	0.68	0.34	0.34	0.85	0.64
2000	L	0.29	0.40	0.06	0.21	0.40	0.51	0.61	0.27	0.20	0.41	1.62	0.93
FRA		1.40	1.56	1.13	1.38	1.38	1.17	1.40	1.56	1.13	1.38	1.38	1.17

TABLE III. 39 S

ESTIMATED SWEAT CALCIUM
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.09	0.13	0.12	0.12	0.08	0.11	0.09	0.18	0.10	0.10	0.10	0.12
	L	0.08	0.13	0.12	0.11	0.07	0.08	0.06	0.15	0.09	0.09	0.09	0.13
0/100/0	U	0.07	0.13	0.15	0.19	0.10	0.12	0.10	0.20	0.12	0.13	0.13	0.13
1000	L	0.08	0.14	0.13	0.11	0.08	0.08	0.11	0.15	0.11	0.12	0.10	0.14
0/100/0	U	0.09	0.16	0.15	0.14	0.09	0.12	0.10	0.18	0.12	0.13	0.13	0.15
2000	L	0.10	0.13	0.15	0.13	0.09	0.10	0.11	0.14	0.11	0.11	0.10	0.14
2/20/78	U	0.08	0.14	0.16	0.17	0.09	0.11	0.08	0.16	0.10	0.10	0.12	0.12
1000	L	0.07	0.12	0.11	0.10	0.09	0.09	0.09	0.13	0.08	0.09	0.07	0.15
2/20/78	U	0.07	0.12	0.15	0.14	0.11	----	0.09	0.17	0.13	0.13	0.12	0.11
2000	L	0.07	0.12	0.13	0.12	0.09	0.08	0.11	0.15	0.08	0.08	0.09	0.13
15/52/33	U	0.08	0.15	0.17	0.15	0.09	0.12	0.11	0.19	0.10	0.11	0.12	0.10
1000	L	0.08	0.18	0.18	----	----	----	0.09	0.15	0.10	0.10	0.09	0.13
15/52/33	U	0.06	0.11	0.13	0.11	0.08	0.06	0.11	0.20	0.12	0.12	0.13	0.14
2000	L	0.07	0.15	0.15	0.13	0.09	0.12	0.09	0.14	0.10	0.11	0.15	0.11
15/52/33	U	0.07	0.13	0.18	0.16	0.08	0.10	0.12	0.25	0.16	0.17	0.17	0.18
3000	L	0.08	0.14	0.15	0.13	0.08	0.09	0.11	0.14	----	----	----	----
30/0/70	U	0.04	0.14	0.16	0.14	0.08	0.11	0.08	0.15	0.08	0.09	0.09	0.10
1000	L	0.07	0.12	0.13	0.06	0.05	0.05	0.15	0.15	0.10	0.11	0.10	0.14
30/0/70	U	0.10	0.14	0.15	0.13	0.09	0.11	0.09	0.15	0.10	0.10	0.10	0.12
2000	L	0.08	0.12	0.12	0.11	0.08	0.09	0.11	0.16	0.09	0.09	0.08	0.11
FRA		0.09	0.16	0.14	0.14	0.14	0.12	0.09	0.16	0.14	0.14	0.14	0.12

TABLE III. 40 S

CALCIUM BALANCE
(gm Ca/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	-0.23	-0.84	-0.33	-0.20	-0.17	-0.14	-0.24	-0.28	-0.41	-0.42	-0.20	+0.24
	L	-0.28	-0.01	-0.42	-0.42	-0.11	+0.40	-0.15	-0.15	-0.47	-0.36	-0.18	+0.08
0/100/0	U	-0.27	-1.22	-0.28	-0.34	-0.09	+0.02	+0.01	-0.21	-0.31	-0.28	-0.84	+0.34
1000	L	-0.20	-0.02	-0.46	-0.49	-0.13	+0.41	-0.10	+0.09	-0.24	-0.27	-0.37	+0.06
0/100/0	U	-0.51	-1.52	-0.31	-0.47	-0.26	-0.08	-0.10	-0.86	-0.36	-0.38	-0.21	+0.39
2000	L	+0.01	-0.01	-0.24	-0.24	-0.06	+0.50	-0.48	-0.25	-0.36	-0.36	-0.08	+0.15
2/20/78	U	-0.54	-0.77	-0.80	-1.28	-0.10	+0.33	-0.11	-0.24	-0.21	-0.25	+0.34	+0.35
1000	L	+0.02	-0.09	-0.25	-0.27	+0.18	+0.09	-0.10	+0.10	-0.47	-0.51	-0.01	+0.35
2/20/78	U	+0.29	-0.52	-0.52	-0.55	-0.21	-----	-0.26	-0.31	-0.62	-0.67	-0.27	+0.09
2000	L	+0.28	+0.09	-0.22	-0.34	-0.06	+0.19	-0.24	-0.14	-0.42	-0.45	-0.56	+0.37
15/52/33	U	+0.09	-0.38	-0.63	-0.59	-0.25	+0.32	+0.14	-0.02	-0.22	-0.28	-0.08	-0.03
1000	L	+0.19	-0.16	-0.67	-----	-----	-----	-0.11	+0.11	-0.25	-0.32	-0.04	+0.42
15/52/33	U	+0.36	-0.01	-0.59	-0.43	-0.52	+0.19	+0.61	-0.21	-0.01	-0.25	-0.67	+0.08
2000	L	+0.29	-0.19	-0.35	-0.34	-0.02	+0.42	-0.36	-0.14	-0.21	-0.30	-0.12	+0.30
15/52/33	U	-0.12	-0.08	-0.32	-0.35	-0.16	+0.31	-0.51	-0.28	-0.19	-0.38	-0.35	-0.12
3000	L	-0.04	+0.05	-0.28	-0.28	-0.27	+0.62	-0.22	-0.03	-----	-----	-----	-----
30/0/70	U	-0.11	-0.27	-0.65	-0.73	-0.07	+0.26	-0.20	-0.31	-0.20	-0.43	-0.45	+0.37
1000	L	-0.15	-0.09	-0.51	-0.35	+0.05	+0.35	-0.24	-0.21	-0.34	-0.38	+0.04	+0.26
30/0/70	U	+0.14	-0.05	-0.57	-0.51	-0.36	-0.06	+0.39	-0.30	-0.46	-0.46	-0.24	+0.34
2000	L	+0.30	-0.10	-0.20	-0.37	+0.16	+0.15	-0.03	+0.15	-0.33	-0.61	-1.11	+0.07
FRA		-----	+0.02	-----	+0.02	+0.10	-0.35	-----	+0.02	-----	+0.02	+0.10	-0.35

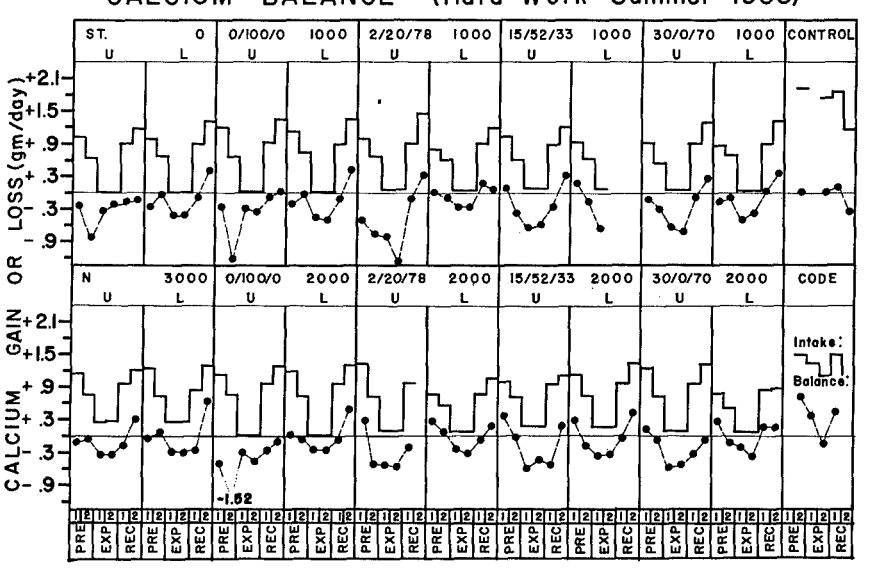


FIGURE III. 19. CALCIUM BALANCE: HARD WORK (SUMMER 1955).

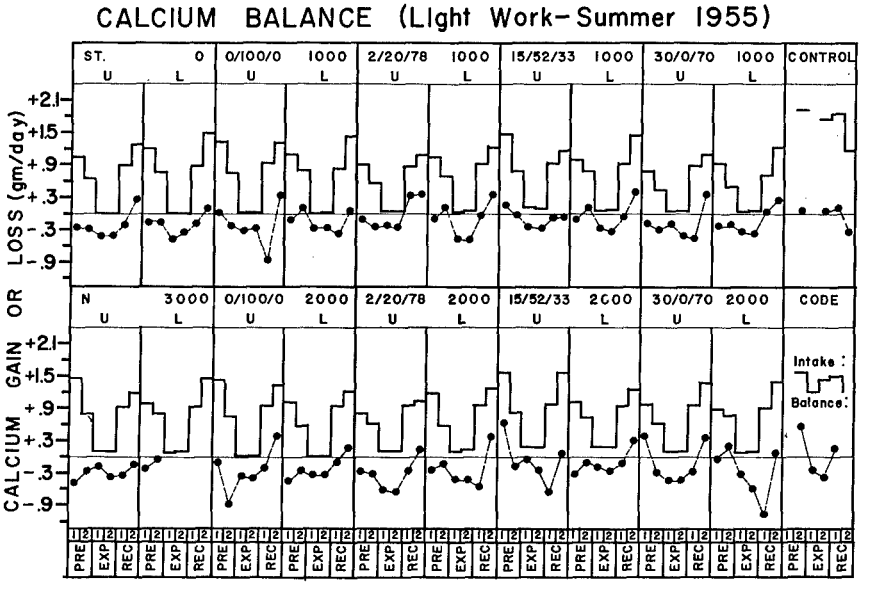


FIGURE III. 20. CALCIUM BALANCE: LIGHT WORK (SUMMER 1955).

9. Phosphorus Balance (Summer 1955)

Introduction. There is a negligible concentration of phosphorus in sweat; some observers have asserted that there is none at all. Therefore, balance calculations can be made without the necessity for making any assumptions on dermal loss, and we can trust our balance data because intake, urinary excretion, and fecal losses were all accurately measurable.

Pre-Period. Intake for both PRE I and PRE II was at or above National Research Council recommended allowances (Table III. 41 A). The onset of hot weather in PRE II caused appetites to diminish, and intake of phosphorus to decrease. Urinary phosphorus was less in PRE II than in PRE I, except among the controls (Table III. 41 B). Fecal phosphorus also diminished, except among the controls (Table III. 41 C). Balances were positive in PRE I and diminished in PRE II, but still remained positive (Table III. 41 D).

Experimental Period: Phosphorus Intake. Intake was zero in ST 0, 0/100/0 1000 and 2000; it was low in 2/20/78 1000; it was moderately low in 2/20/78 2000, 15/52/33 1000, and 30/0/70 1000; it was fairly high in 15/52/33 2000, 15/52/33 3000, and 30/0/70 2000. Among the controls, it was high (Table III. 42).

Experimental Period: Urinary Phosphorus. Phosphorus excretion by way of the urine never reached low levels in any groups of subjects. It tended to be highest among subjects of the highest intake (Table III. 43). Work load had some effect. If we take EXP II because of a possible "stabilization" period in EXP I, then hard work excretion was greater than for the same regimen in light work in 12 of 19 comparisons. Limitation of water tended to increase urinary excretion; in hard work, 8 of 9 comparisons; and in light work seven of nine comparisons. Increase of calories within a given hard work regimen decreased the urinary excretion: in hard work, in six of nine comparisons; in light work this correlation did not exist.

Experimental Period: Fecal Phosphorus. After PRE II, fecal phosphorus excretion diminished in all regimens, except in the controls (Table III. 44). It became least in regimens which produced the least fecal bulk: ST 0, 0/100/0 1000, and 0/100/0 2000. No other clear correlations existed with work load, water intake, phosphorus intake, nutrient ratios, or calorie intake.

Experimental Period: Phosphorus Balance. The data in Table III. 45 and Figures III. 21 and III. 22 are better scrutinized if rearranged:

PHOSPHORUS BALANCE IN EXP II

Regimen	Intake (gm P/day)	Balance (gm P/day) U (Hard Work)	L (Hard Work)	U (Light Work)	L (Light Work)
ST 0	0	-0.50	-1.03	-0.98	-0.93
0/100/0 1000	0	-0.72	-0.85	-0.44	-0.53
2/20/78 1000	0.16	-1.17	-0.48	-0.43	-0.61
15/52/33 1000	0.34	-0.49	----	-0.44	-0.44
30/0/70 1000	0.59	-0.61	-0.54	-0.31	-0.56
0/100/0 2000	0.00	-0.76	-0.63	-0.39	-0.29
2/20/78 2000	0.41	-0.18	-0.24	-0.25	-0.28
15/52/33 2000	0.74	-0.28	-0.34	-0.15	-0.14
30/0/70 2000	1.19	-0.24	-0.32	-0.21	-0.58
15/52/33 3000	1.08	+0.07	+0.24	0.00	-----
Controls	2.06	+0.21	-----	-----	-----

Work load had some slight effect: in light work, negativity was less in 11 of 18 comparisons. Water limitation increased negativity in 10 of 18 cases. Calorie increase at a given phosphorus intake decreased negativity in six of eight comparisons at zero intake; in four of four comparisons at intake over 1 gm of P/day; in four of four comparisons at intakes 0.59 and 0.74 gm of P/day; and in three of three comparisons at intakes of 0.34 and 0.41 gm of P/day. Most striking, increasing the phosphorus intake at a given calorie intake did not uniformly ameliorate a negative phosphorus balance.

We must conclude that situational factors invoked or tended to invoke a catabolic reaction such that phosphorus balance became negative and stayed negative even with fairly large phosphorus intake.

Recovery Period: Phosphorus intake increased in REC I to values above PRE II; there was a further increase in REC II, during which unrestricted feeding was permitted. In REC I, urinary excretion increased above that of EXP II in 29 of 38 possible comparisons. This increase was very small in comparison to the intake. A further small increase tended to occur in REC II. Fecal excretion increased by about 0.3 gm of P in REC I over EXP II. In REC II, in spite of an increased intake, fecal excretion decreased in 28 of 38 possible comparisons. We interpret this to mean a change for the better in gastrointestinal absorption of phosphorus.

In REC I phosphorus balance became positive in all groups of subjects regardless of previous regimen. There was no correlation between the positive balance recorded, and previous phosphorus deficit. In REC II, there was a further increase in positivity corresponding fairly closely with the increased phosphorus intake in that period.

Comparison of Phosphorus Balance in Cold, Temperate, and Warm Environments. Remarkably similar results were obtained on the average for the cold, temperate, and hot studies (Table III. 46). It would be difficult to ascribe such differ-

ences as obtained to cold weather or hot weather. Rather, the striking features are universal negativity at all levels of intake except in 15/52/33 3000 and controls, and the ameliorating effects of calories at any intake. We are dealing, therefore, with a general effect of nutrient regimen and not environmental factors.

TABLE III. 41

PRE-PERIOD DATA ON
PHOSPHORUS INTAKE, OUTPUT, AND BALANCE
(gm P/day)

Flight	P I		P II	
	Mean	Range	Mean	Range
		A. Intake		
1	2.84	1.24-3.66	1.91	0.98-2.31
2	2.57	1.38-3.46	1.88	1.43-2.41
3	3.07	1.92-3.96	1.96	0.88-2.61
4	2.76	1.89-3.34	1.97	0.97-2.29
FRA	----	---------	2.65	1.93-3.80
		B. Urinary Phosphorus		
1	1.16	0.76-1.60	0.94	0.69-1.18
2	1.09	0.65-1.44	0.99	0.81-1.26
3	1.27	0.62-1.70	1.06	0.67-1.34
4	1.16	0.62-1.45	1.05	0.75-1.20
FRA	0.94	0.53-1.40	1.21	0.83-1.45
		C. Fecal Phosphorus		
1	0.57	0.21-0.99	0.43	0.22-1.36
2	0.50	0.25-0.91	0.31	0.16-0.47
3	0.63	0.33-1.01	0.41	0.22-1.37
4	0.53	0.29-0.95	0.31	0.19-0.60
FRA	0.67	0.38-1.26	0.82	0.30-1.55
		D. Balance		
1	+1.08	(+0.28)-(+1.79)	+0.55	(-0.20)-(+1.04)
2	+1.01	(+0.09)-(+1.66)	+0.62	(+0.25)-(+1.24)
3	+1.18	(+0.20)-(+1.92)	+0.49	(-0.45)-(+0.89)
4	+1.07	(+0.36)-(+1.71)	+0.61	(-0.15)-(+0.98)
FRA	-----	----------	+0.62	(+0.30)-(+1.12)

TABLE III. 42s

PHOSPHORUS INTAKE
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	2.64	1.80	0	0	2.45	2.99	2.85	1.89	0	0	2.31	3.42
	L	2.57	1.85	0	0	2.28	3.23	3.11	2.15	0	0	2.39	3.74
0/100/0	U	3.10	2.00	0	0	2.34	3.10	3.47	2.13	0	0	2.34	3.49
1000	L	3.04	2.16	0	0	2.31	3.50	2.88	2.14	0	0	2.25	3.85
0/100/0	U	2.86	2.16	0	0	2.54	3.21	3.23	1.93	0	0	2.49	3.20
2000	L	3.21	2.05	0	0	2.54	3.25	2.76	1.49	0	0	2.43	3.54
2/20/78	U	2.78	2.11	0.16	0.16	2.33	4.09	2.46	1.86	0.16	0.16	2.28	3.18
1000	L	2.39	1.79	0.16	0.16	2.31	3.04	2.83	1.92	0.16	0.16	2.34	3.30
2/20/78	U	3.36	1.98	0.41	0.41	2.58	----	2.14	1.71	0.41	0.41	2.52	2.72
2000	L	2.12	1.75	0.41	0.41	2.07	2.93	3.01	2.18	0.41	0.41	2.51	3.57
15/52/33	U	2.73	1.75	0.34	0.34	2.26	3.08	3.48	2.28	0.33	0.33	2.34	3.16
1000	L	2.30	1.60	0.33	----	----	----	2.74	2.21	0.33	0.33	2.35	3.79
15/52/33	U	2.55	1.97	0.74	0.74	2.51	2.77	3.69	2.19	0.74	0.74	2.57	4.05
2000	L	2.81	2.07	0.74	0.74	2.58	3.68	2.71	2.10	0.74	0.74	2.56	3.36
15/52/33	U	2.88	2.01	1.08	1.08	2.49	2.95	3.94	2.53	1.08	1.08	2.57	3.50
3000	L	2.98	2.08	1.08	1.08	2.26	3.18	2.46	2.07	----	----	----	----
30/0/70	U	2.45	1.71	0.59	0.59	2.33	3.28	2.28	1.42	0.59	0.59	2.29	2.78
1000	L	2.19	1.92	0.59	0.59	2.23	2.93	2.39	1.69	0.59	0.59	1.74	3.19
30/0/70	U	3.31	2.17	1.19	1.19	2.57	3.56	2.63	1.93	1.19	1.19	2.55	3.73
2000	L	2.45	1.61	1.19	1.19	2.42	2.38	2.41	2.12	1.19	1.19	2.52	3.73
FRA		----	2.65	----	2.06	2.46	1.86	----	2.65	----	2.06	2.46	1.86

TABLE III. 43s

URINARY PHOSPHORUS
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	1.07	0.94	0.65	0.50	0.93	0.98	1.29	1.07	0.73	0.85	0.60	1.01
	L	1.07	0.97	0.90	0.91	0.64	0.79	1.28	1.12	0.78	0.87	0.83	1.08
0/100/0	U	1.07	0.86	0.53	0.56	0.71	0.67	1.55	1.25	0.47	0.41	0.91	1.17
1000	L	1.12	1.07	0.59	0.58	0.74	0.96	1.19	1.10	0.44	0.46	0.88	1.26
0/100/0	U	1.33	1.08	0.48	0.50	1.00	1.13	1.12	1.13	0.32	0.25	0.81	0.93
2000	L	1.37	1.02	0.51	0.51	0.60	0.90	1.33	1.06	0.54	0.19	0.70	1.40
2/20/78	U	1.26	0.92	0.66	0.51	0.68	0.80	1.23	0.92	0.34	0.51	0.67	0.97
1000	L	0.94	1.00	0.67	0.56	0.76	0.82	1.11	0.99	0.65	0.58	0.76	0.94
2/20/78	U	0.99	0.81	0.56	0.48	0.66	----	1.08	0.97	0.72	0.43	0.82	1.00
2000	L	1.16	1.02	0.56	0.49	0.75	1.15	1.05	0.97	0.46	0.49	0.86	1.02
15/52/33	U	1.27	0.87	0.67	0.62	0.94	0.97	1.16	1.09	0.57	0.58	0.95	1.28
1000	L	1.20	0.97	0.66	----	----	----	1.06	1.09	0.41	0.59	0.85	1.22
15/52/33	U	0.96	0.82	0.57	0.74	0.94	1.05	1.37	1.11	0.38	0.73	1.05	1.50
2000	L	1.04	1.11	0.94	0.77	0.70	0.95	1.19	1.12	0.48	0.68	0.92	1.18
15/52/33	U	1.16	1.10	0.84	0.72	0.93	1.10	1.41	1.23	1.06	0.86	1.17	1.25
3000	L	1.11	0.88	0.92	0.59	0.73	0.99	1.14	1.13	----	----	----	----
30/0/70	U	1.17	0.91	1.18	0.92	1.01	1.00	0.96	0.67	0.46	0.76	0.60	0.81
1000	L	1.09	1.04	0.99	1.03	0.45	0.90	1.23	0.98	0.76	1.01	0.81	1.05
30/0/70	U	1.54	1.11	1.75	1.28	1.16	1.52	1.22	0.94	1.42	1.20	1.24	1.31
2000	L	1.03	0.90	1.26	1.29	0.85	0.68	0.99	1.00	0.93	1.47	1.06	1.25
FRA		0.94	1.21	1.06	1.09	1.03	1.25	0.94	1.21	1.06	1.09	1.03	1.25

TABLE III. 44 S

FECAL PHOSPHORUS
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.43	0.33	0.11	0.00	0.58	0.73	0.65	0.33	0.11	0.14	0.64	0.40
	L	0.57	0.26	0.08	0.12	0.65	0.34	0.58	0.35	0.18	0.07	0.60	0.48
0/100/0	U	0.80	0.46	0.08	0.16	0.75	0.76	0.62	0.27	0.04	0.04	0.56	0.30
1000	L	0.58	0.32	0.27	0.27	0.59	0.47	0.39	0.29	0.07	0.07	0.59	0.41
0/100/0	U	0.77	0.51	0.19	0.27	0.50	0.46	0.74	0.98	0.15	0.15	0.52	0.32
2000	L	0.90	0.33	0.13	0.13	0.50	0.35	0.71	0.32	0.11	0.11	0.33	0.39
2/20/78	U	0.55	0.82	0.47	0.82	0.67	0.93	0.58	0.38	0.08	0.08	0.15	0.31
1000	L	0.41	0.37	0.09	0.09	0.31	0.44	0.46	0.26	0.20	0.20	0.51	0.47
2/20/78	U	0.81	0.83	0.10	0.11	0.39	----	0.36	0.41	0.20	0.23	0.41	0.37
2000	L	0.31	0.18	0.20	0.16	0.39	0.37	0.64	0.35	0.20	0.20	0.71	0.41
15/52/33	U	0.37	0.32	0.21	0.21	0.57	0.35	0.70	0.29	0.13	0.19	0.52	0.28
1000	L	0.31	0.30	0.15	----	----	----	0.41	0.21	0.14	0.18	0.39	0.34
15/52/33	U	0.55	0.40	0.25	0.28	0.84	0.45	0.68	0.41	0.10	0.17	0.80	0.41
2000	L	0.63	0.47	0.31	0.31	0.56	0.48	0.58	0.44	0.20	0.21	0.50	0.40
15/52/33	U	0.53	0.35	0.19	0.30	0.71	0.40	0.87	0.48	0.22	0.22	0.54	0.40
3000	L	0.59	0.32	0.37	0.26	0.71	0.36	0.63	0.31	----	----	----	----
30/0/70	U	0.47	0.30	0.20	0.29	0.48	0.39	0.40	0.29	0.05	0.19	0.79	0.52
1000	L	0.44	0.29	0.20	0.10	0.44	0.34	0.42	0.27	0.14	0.14	0.24	0.43
30/0/70	U	0.54	0.28	0.15	0.15	0.48	0.54	0.39	0.37	0.21	0.21	0.55	0.36
2000	L	0.44	0.32	0.10	0.22	0.43	0.42	0.40	0.27	0.09	0.30	0.41	0.35
FRA		0.67	0.82	0.65	0.76	0.76	0.58	0.67	0.82	0.65	0.76	0.76	0.58

TABLE III. 45S

PHOSPHORUS BALANCE
(gm P/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	+1.15	+0.53	-0.76	-0.50	+0.94	+1.28	+0.90	+0.49	-0.85	-0.98	+1.07	+2.02
	L	+0.92	+0.60	-0.99	-1.03	+1.00	+2.11	+1.25	+0.68	-0.91	-0.93	+0.96	+2.19
O/100/O	U	+1.24	+0.69	-0.61	-0.72	+0.88	+1.67	+0.81	+0.61	-0.50	-0.44	+0.88	+2.03
1000	L	+1.35	+0.77	-0.86	-0.85	+0.99	+2.07	+1.31	+0.76	-0.51	-0.53	+0.59	+2.18
O/100/O	U	+0.76	+0.57	-0.67	-0.76	+1.04	+1.62	+1.37	-0.18	-0.47	-0.39	+1.17	+1.93
2000	L	+0.94	+0.70	-0.63	-0.63	+1.44	+2.00	+0.73	+0.12	-0.64	-0.29	+1.40	+1.75
2/20/78	U	+0.98	+0.37	-0.95	-1.17	+0.98	+2.36	+1.15	+0.67	-0.26	-0.43	+1.41	+1.92
1000	L	+1.05	0.42	-0.60	-0.48	+1.24	+1.78	+1.26	+0.68	-0.68	-0.61	+1.08	+1.91
2/20/78	U	+1.57	+0.34	-0.24	-0.18	+1.53	-----	+0.70	+0.33	-0.51	-0.25	+1.30	+1.35
2000	L	+0.65	+0.53	-0.35	-0.24	+0.94	+1.42	+1.35	+0.44	-0.22	-0.28	+0.84	+2.14
15/52/33	U	+1.10	+0.51	-0.54	-0.49	+0.76	+1.76	+1.62	+0.90	-0.35	-0.44	+0.88	+1.60
1000	L	+0.80	+0.33	-0.48	-----	-----	-----	+1.27	+0.91	-0.22	-0.44	+1.12	+2.23
15/52/33	U	+1.04	+0.76	-0.08	-0.28	+0.73	+1.27	+1.65	+0.68	+0.27	-0.15	+0.72	+2.14
2000	L	+1.15	+0.50	-0.51	-0.34	+1.32	+2.25	+0.95	+0.54	+0.11	-0.14	+1.14	+1.78
15/52/33	U	+1.20	+0.57	+0.06	+0.07	+0.85	+1.45	+1.66	+0.83	-0.20	0.00	+0.87	+1.86
3000	L	+1.28	+0.89	-0.21	+0.24	+0.82	+1.83	+0.69	0.63	-----	-----	-----	-----
30/0/70	U	+0.82	+0.46	-0.79	-0.61	+0.84	+1.89	+0.92	+0.46	+0.08	-0.31	+0.90	+1.45
1000	L	+0.67	+0.59	-0.59	-0.54	+1.34	+1.69	+0.74	+0.45	-0.36	-0.56	+0.69	+1.71
30/0/70	U	+1.24	+0.79	-0.71	-0.24	+0.93	+1.51	+1.03	+0.62	-0.42	-0.21	+0.76	+2.06
2000	L	+0.96	+0.39	-0.17	-0.32	+1.14	+1.29	+1.03	+0.85	+0.17	-0.58	+1.05	+2.13
FRA		-----	+0.62	-----	+0.21	+0.67	+0.03	-----	+0.62	-----	+0.21	+0.67	+0.03

TABLE III. 46

COMPARISON OF PHOSPHORUS BALANCE IN EXP II,
COLD, TEMPERATE, AND HOT ENVIRONMENTS

Regimen	Phosphorus Balance, gm P/day (Average all subjects)		
	Cold Study 1954	Temperate Study 1953	Hot Study 1955
ST 0	-0.86	-0.71	-0.86
0/100/0 1000	-0.68	-0.63	-0.64
0/100/0 2000	-0.56	-0.51	-0.52
2/20/78 1000	-0.68	-0.45	-0.67
2/20/78 2000	-0.36	-0.63	-0.29
15/52/33 1000	-0.45	-0.48	-0.46
15/52/33 2000	-0.34	-0.34	-0.23
30/0/70 1000	-0.65	-0.59	-0.51
30/0/70 2000	-0.49	-0.31	-0.34
15/52/33 3000	-0.24	+0.05	+0.10
Controls	-----	-----	+0.21

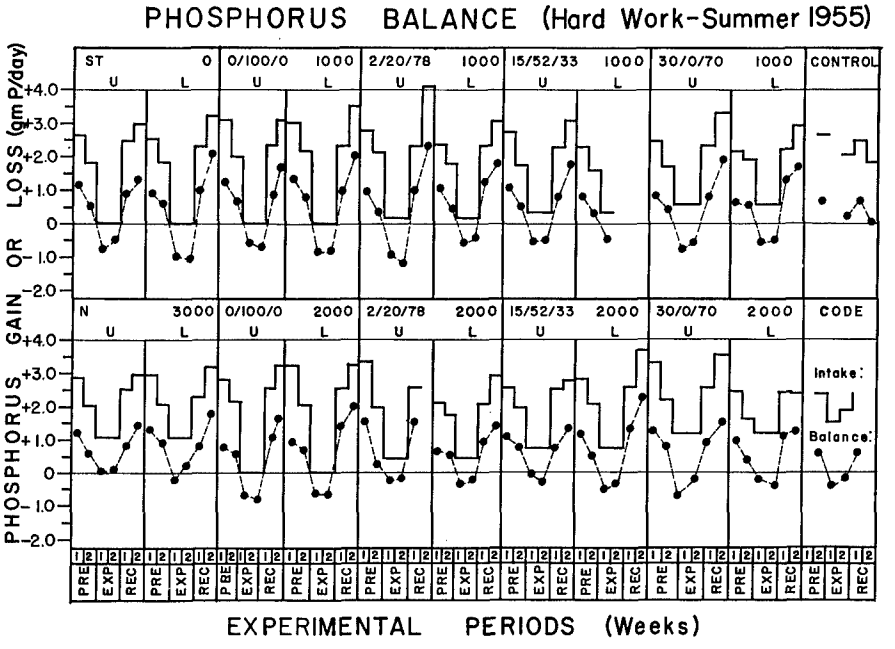


FIGURE III. 21. PHOSPHORUS BALANCE: HARD WORK (SUMMER 1955).

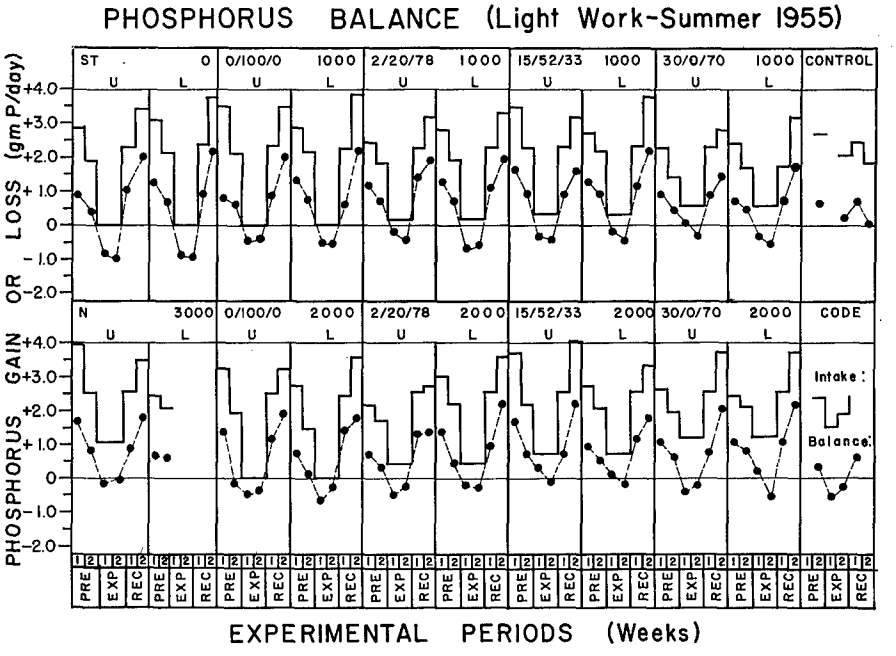


FIGURE III. 22. PHOSPHORUS BALANCE: LIGHT WORK (SUMMER 1955).

10. Acid-Base Balance

Urinary Acidity. Two measures of urinary acidity were used: (a) titrable acidity and (b) pH (by glass electrode). Both these determinations were carried out on the urine collected during the weekly three-hour test. The pre-period means and ranges for these measures of acidity for the five groups of subjects are summarized in Table III. 47. The subjects of the four flights who were subsisting on 5-in-1 ration did not secrete a urine which differed significantly in acidity from that of the subjects on the FRA ration.

a. Urinary pH

The data in Table III. 48 reveal that there were large changes in the acidity of the urine during the course of the investigation.

Control Subjects. Subjects who subsisted on Field Ration A actually exhibited relatively few variations in the urinary pH.

Work Load. There was a striking tendency for the subjects who were performing hard work during the experimental periods to excrete more acid in their urine than the subjects who were performing light work at the same time. This

trend is especially noteworthy in the case of subjects subsisting on 0/100/0 1000 and 2000 and 15/52/33 1000, 2000, and 3000. Subjects on 2/20/78 1000 and 2000, 30/0/70 1000 and 2000, and starvation were apparently uninfluenced by the relative work load.

Water Intake. An even more constant trend is noted in the effect of water on the excretion of acid. The majority of the subjects who subsisted on limited water excreted more acid urine than the subjects who subsisted on unlimited amounts of water. The effect of limitation of water is more striking in EXP I than in EXP II, for during the former period the limitation of water was more stringent. In EXP I it occurred in hard work in ten of ten comparisons; in light work it was present in six of nine comparisons.

Nutrient Combinations. With one exception, the subjects excreted a more acid urine during the experimental period than they did during the pre-period. The degree of acidity was generally greatest among the subjects who ate meat bar or who were starved. Similar changes were produced by the 0/100/0, 2/20/78, and 15/52/33 regimens. Taking into account the effect of limitation of water, it is true that the subjects on 15/52/33 2000 and 3000 exhibited the least deviation from the pre-period level of urinary pH. The results of this 1955 summer test are in striking contrast to those of the 1954 winter study. A number of subjects studied in the latter investigation, particularly those subsisted on 0/100/0 and 2/20/78, excreted strong alkaline urines. In fact, a number of the men had pH's exceeding 8.0. No such values were observed among the subjects of the hot weather test.

Recovery. In general, all of the subjects showed an increase in alkalinity of their urine during the recovery period. In some instances, the degree of alkalinity was very large, and frequently the pH rose to levels of 7.5 and above. Examples of this are seen in the hard work groups among the subjects who had been eating 15/52/33 2000 L and 30/0/70 1000 and 2000 L. Among the subjects doing light work such a trend is seen among those who had been on 0/100/0 2000 L and 30/0/70 1000 U. It is also striking that in many cases the subjects who had been on limited water passed a more alkaline urine during the recovery period than those who had been on unlimited water. The influence of limitation of water is more striking among the subjects who had performed hard work than among those who had performed light work. These various observations strongly suggest that during hot weather, limitation of water had an adverse effect on the acid-base equilibrium of the subject.

TABLE III. 47

PRE-PERIOD DATA ON URINARY pH AND TITRABLE ACIDITY

Flight	P I Mean	P I Range	P II Mean	P II Range
		A. Urinary pH		
1	6.78	4.92-7.70	7.11	5.38-7.96
2	6.46	5.40-7.85	6.95	5.68-8.43
3	7.40	6.68-7.98	7.29	5.81-8.20
4	7.04	5.23-7.83	6.70	5.35-7.89
FRA	6.79	5.48-7.98	6.68	5.55-8.04
		B. Titrable Acidity, microequivalents/min		
1	4.85	0.00-23.58	2.53	0.00-16.59
2	9.49	0.00-26.25	5.07	0.00-18.40
3	0.33	0.00- 7.02	2.18	0.00-14.55
4	2.72	0.00-17.23	7.19	0.00-44.54
FRA	6.74	0.00-17.01	9.52	0.00-31.04

b. Titrable Acidity

Both in tabular form (Table III. 49) and graphically (Figures III. 23 and III. 24), in general, we find a striking confirmation of the several trends observed in our analysis of the urinary pH. To reiterate, subjects on limited water had higher values of titrable acidity than subjects on unlimited water during the experimental period, but during the recovery period these same subjects tended to put out almost no titrable acidity. Hard work tended to accentuate the output of total urinary acids, and starvation and meat bar (30/0/70) were the nutrient combinations which provoked the greatest increase of acid output during the experimental period. It is quite probable that the great increase in titrable acidity can be ascribed to the large output of ketone bodies associated with subsistance on such regimens.

TABLE III. 48

ACID-BASE BALANCE--URINARY pH

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	7.00	7.54	6.02	5.91	6.85	6.78	7.28	7.62	5.46	5.49	6.74	6.49
	L	7.24	7.36	5.65	5.48	6.45	7.44	7.41	7.25	5.61	5.71	7.14	7.10
0/100/0	U	5.84	6.45	5.93	5.89	6.42	7.08	7.36	7.07	6.12	5.86	6.56	6.34
1000	L	6.62	7.30	5.54	5.48	5.83	6.79	7.06	7.52	6.14	5.92	6.47	6.44
0/100/0	U	7.06	7.16	6.64	6.60	6.02	5.90	7.84	7.86	7.25	6.40	7.36	6.40
2000	L	6.58	7.25	5.90	5.56	7.18	7.46	7.26	5.60	6.68	6.30	7.92	7.52
2/20/78	U	6.28	6.52	6.24	6.15	6.39	6.05	7.37	7.09	5.49	5.25	6.75	5.40
1000	L	5.68	6.59	5.56	6.11	6.28	6.56	7.08	7.02	5.81	6.06	6.99	7.40
2/20/78	U	6.79	7.59	7.16	6.84	7.03	----	7.36	7.02	7.46	7.10	7.24	7.20
2000	L	5.66	5.87	5.95	5.88	6.74	6.36	6.60	5.86	5.45	6.67	5.65	5.42
15/52/33	U	7.28	7.11	6.12	6.34	6.50	6.66	7.34	7.12	6.68	7.08	6.91	7.05
1000	L	6.21	6.82	5.52	----	----	----	7.50	7.32	6.20	6.19	7.19	6.76
15/52/33	U	6.57	7.08	6.22	6.13	6.79	5.91	7.32	7.14	7.04	7.21	6.65	6.53
2000	L	6.56	6.90	5.26	6.32	7.50	7.49	6.54	5.96	5.91	5.82	6.46	7.24
15/52/33	U	6.68	6.66	5.92	6.04	6.62	6.37	7.58	6.50	6.46	7.34	6.26	5.56
3000	L	6.82	7.16	5.64	6.96	6.80	7.48	7.22	7.64	----	----	----	----
30/0/70	U	7.53	7.46	5.74	5.84	6.41	7.14	7.74	7.88	5.91	5.93	7.49	7.13
1000	L	5.60	7.20	5.41	6.28	7.40	7.60	7.23	6.58	5.28	5.34	6.88	5.96
30/0/70	U	6.63	7.18	6.38	6.96	6.38	6.07	7.18	7.42	5.91	5.99	6.69	6.48
2000	L	6.92	6.63	5.47	5.42	6.90	7.85	6.18	6.38	5.18	5.18	7.39	6.78
FRA		6.79	6.68	6.80	6.72	7.05	6.26	6.79	6.68	6.80	6.72	7.05	6.26

TABLE III. 49

ACID-BASE BALANCE--URINARY TITRABLE ACIDITY
(microEq/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	3.58	0.82	15.85	16.78	3.82	6.07	1.40	0.00	22.89	14.55	7.71	7.66
	L	4.56	3.93	26.24	14.28	12.10	0.00	0.75	3.30	28.56	18.48	0.00	0.00
0/100/0	U	13.36	8.30	5.73	19.19	6.15	0.00	0.00	3.42	6.06	5.04	4.54	9.75
1000	L	4.48	0.00	23.08	11.82	15.80	3.72	3.10	0.00	12.06	9.24	9.19	10.01
0/100/0	U	1.93	1.72	12.56	8.69	14.95	12.08	0.00	0.00	1.93	2.83	0.00	11.28
2000	L	8.38	1.20	11.12	12.62	0.00	0.00	0.73	16.75	3.65	4.41	0.00	0.00
2/20/78	U	9.00	6.04	15.02	13.50	12.06	19.06	0.00	5.40	15.35	11.05	1.79	6.18
1000	L	14.94	9.91	22.54	7.98	10.36	9.44	0.00	0.66	23.16	10.29	4.00	0.00
2/20/78	U	5.00	0.00	3.30	4.73	0.00	-----	0.16	3.52	0.00	0.00	0.00	0.00
2000	L	12.38	16.70	18.26	10.36	3.14	9.39	5.93	28.45	19.60	1.87	15.90	24.12
15/52/33	U	0.00	1.26	17.02	14.58	7.30	10.28	0.00	4.16	5.46	0.00	5.10	0.00
1000	L	11.84	6.11	19.32	-----	-----	-----	0.00	1.74	14.68	8.54	2.32	9.32
15/52/33	U	6.57	1.48	7.76	17.02	3.93	9.42	0.00	0.00	0.00	0.00	4.44	6.08
2000	L	9.51	6.22	23.92	6.88	0.00	0.00	8.11	11.94	13.42	10.42	10.93	10.38
15/52/33	U	5.92	6.70	14.08	18.93	6.80	9.18	0.00	7.28	7.58	0.00	11.36	23.53
3000	L	5.49	2.12	17.53	2.55	5.54	0.00	0.70	0.00	-----	-----	-----	-----
30/0/70	U	0.00	0.72	24.53	29.48	8.64	2.59	0.00	0.00	16.00	10.99	0.00	0.00
1000	L	25.22	0.00	24.02	11.39	0.00	0.00	1.25	5.99	29.51	21.20	3.00	16.10
30/0/70	U	4.37	0.00	16.42	19.58	15.30	18.42	0.00	0.00	16.90	13.46	6.36	8.86
2000	L	3.04	5.70	25.46	30.79	3.10	0.00	8.62	6.98	32.76	27.26	0.00	4.02
FRA		6.74	9.52	5.42	3.50	3.10	15.69	6.74	9.52	5.42	3.50	3.10	15.69

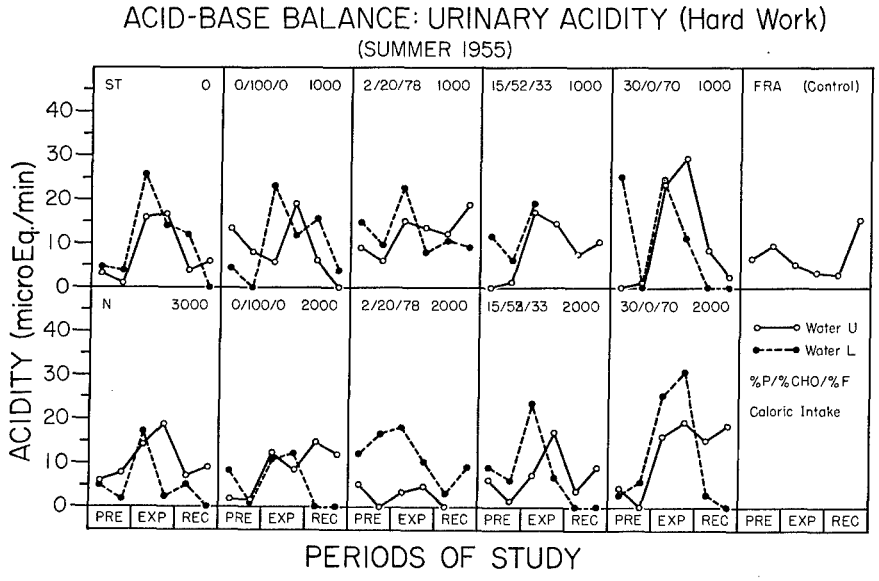


FIGURE III. 23. ACID-BASE BALANCE: URINARY ACIDITY (HARD WORK).

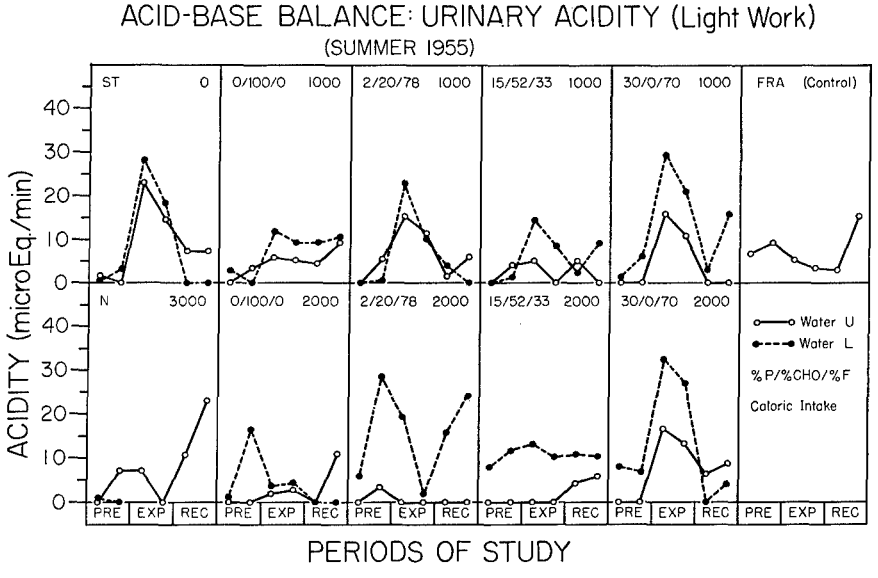


FIGURE III. 24. ACID-BASE BALANCE: URINARY ACIDITY (LIGHT WORK).

c. Ketonuria

Urine was collected under three different conditions from all subjects throughout the period of study. During the three-hour test a resting urine was collected over an interval of two hours. Prior to beginning the heat acclimatization test the subjects emptied their bladders. Immediately on terminating the one-hour march a urinary specimen was collected. This specimen was identified as the exercise urine. The subjects then returned to their barracks and after a one-hour rest, a post-exercise urine was collected. Each of these specimens was examined for the presence of ketone bodies by the method of Rothera (Sargent et al., 1954, 1955). In addition, daily 24-hour urinary specimens were collected from each of the subjects from Day 12 through Day 22 and were similarly examined for ketone bodies.

Resting Urine. During the pre-period only one subject excreted a resting urine which tested positive for ketone bodies during the two pre-periods (Table III. 50). In the experimental periods resting ketonuria was frequently observed among the subjects doing hard work (Table III. 50). The resting urine was positive for ketone bodies among men on ST 0; 2/20/78 1000 and 2000; 30/0/70 1000 and 2000; and 15/52/33 1000 and 2000. The intensity of the reaction generally was low among men on 15/52/33 regimens. None of the subjects on 0/100/0 1000 and 2000; 15/52/33 3000; and Field Ration A ever excreted urine testing positive for ketone bodies. There was no consistent tendency for the reaction to increase or decrease when EXP I was compared with EXP II. Water intake had no influence on ketonuria.

Among the subjects doing light work (Table III. 50) ketonuria was observed in urinary specimens collected from men subsisting on ST0; 2/20/78 1000 and 2000; 30/0/70 1000 and 2000; and 15/52/33 1000. Among the men doing light work, 15/52/33 2000 and 3000 and 0/100/0 2000 did not cause any ketonuria. One man on 0/100/0 1000 exhibited a trace in EXP II. With this exception there is really little difference between light and hard work groups. The same conclusions regarding water intake and adaptation to a high fat regimen made for the hard work groups applies to the light work groups. During both recovery periods the resting urinary specimens were uniformly negative for ketone bodies.

Exercise Urine. During the pre-periods not a single subject showed even a trace of ketonuria (Table III. 51). Among the urines collected during EXP I the distribution of positive reactions was very similar to that already noted for resting urine. The notable exceptions were the absence of any ketonuria among men on 2/20/78 2000 and 15/52/33 1000 and 2000. Among the men on 30/0/70 2000, there was a striking reduction in the intensity of the reaction, especially among the men doing light work (Table III. 51). Starving subjects, on the other hand, show no such amelioration of ketonuria. Urines were uniformly negative in both recovery periods.

Post-Exercise Urine. During the one-hour rest following the heat acclimatization test, there was no post-exercise ketonuria while the subjects were on the 5-in-1 ration (Table III. 52). In EXP I the distribution of positive reactions was very similar to that observed in the exercise urines. Here the notable

exception is the pure carbohydrate regimen. This regimen caused men in the light work flights to excrete urine which twice gave strongly positive reactions, namely a +1 and a +4. Five of the urines when tested yielded a brown color reaction which quickly faded. This type of reaction is atypical and is probably not caused by the presence of acetone and acetoacetic acid in large amounts. With this exception there is little evidence to support any claim for the presence of the well known post-exercise ketonuria (Sargent and Consolazio, 1950). This of course, is not unexpected, for the output of urinary ketone bodies following exercise does not reach its maximum until approximately five or six hours have elapsed.

Twenty-Four Hour Urine. In the pre-periods, 168 daily urine specimens were tested among men who were subsisting on 5-in-1 ration (Table III. 53). None of these were positive for ketonuria. Similarly, 22 specimens were collected for men on FRA rations and likewise these were uniformly negative (Table III. 54).

In the experimental periods 713 daily urinary specimens were collected from men on the several experimental nutrient mixtures and 99 from the FRA subjects. Among the latter, there was an exceedingly low incidence of ketonuria (Table III. 54). In fact, only 6 specimens reacted at the +3 or +4 level. In contrast, many of the experimental nutrient combinations were associated with consistent occurrence of ketonuria. Strongly positive reactions (+3 or +4) were present (Table III. 55) in the daily urine specimens collected from men subsisting on ST 0, 2/20/78 1000 and 2000, and 30/0/70 1000 and 2000. Occasional specimens from men on other regimens also tested strongly positive for ketone bodies. Three subjects doing hard work excreted, once each, urine testing +4: 0/100/0 2000 U in EXP II, 0/100/0 2000 L in EXP I, and 15/52/33 1000 U in EXP II. There was one similarly reacting subject among the men doing light work. This subject, who was subsisting on 15/52/33 1000 L, passed on one occasion a urine testing +4 in EXP II. We consider these occasional strongly positive reactions to be anomalous, principally because the finding was not repeated.

A conclusion reached from study of the 1954 winter data was that 250 gm of pure carbohydrate were not sufficient to prevent completely the occurrence of moderate ketonuria. If we define moderate ketonuria as a +2 reaction, we then find in the summer data (Table III. 53) that among subjects doing hard work there was one +2 reaction in a subject on 0/100/0 1000 and three +2 reactions among subjects on 0/100/0 2000. In the light work groups there were seven specimens testing +2 among subjects on 0/100/0 1000 and two specimens testing +2 on 0/100/0 2000. This finding does not agree with Gamble's (1947) report that 200 gm of carbohydrate are sufficient to inhibit ketonuria. Actually, our previous findings are extended. These results suggest that whether it be summer or winter, a pure carbohydrate diet does not necessarily inhibit ketonuria.

Since a careful record was kept of atypical color reactions in the course of conducting the Rothera test, it is possible to report that ten subjects during the first experimental period excreted a substance, or substances, in the urine that caused such color reactions as blue-purple, purple-brown, blue, green, green-brown, and yellow (Table III. 56). Of the 10 subjects passing atypically

reacting urine, seven were subsisting on the 0/100/0 regimen. The other three were starving (ST 0). This reaction may be related to the occurrence of the brown-color reaction noted when testing the post-exercise urine (Table III. 52). The only difference is that in the latter case all incidences were confined to light work subjects; whereas in the case of daily specimens all atypical reactions were noted among men doing hard work. In the case of the post-exercise urines there were five which tested brown; all five specimens were collected from men on pure carbohydrate. We have not previously seen such atypical reactions. It may be that the presence of color reacting substances was detected in the summer urine and not in the winter urine simply because the men excreted a more concentrated urine during the summer than during the winter. What the significance of these colors might be is difficult to say. It may be that they represent ingestion of heat processed carbohydrates. Such a relationship was established during field tests of World War II by R. M. Kark and his associates in the course of the Prince Albert Trials (1944).

TABLE III. 50

RESTING KETONURIA: HARD WORK
(0 to +4)

Experimental Regimen		PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	0,0,0,0	0,0,0,0	4,4,4	0	0,0,0	0,0,0
	L	0,0,0,0	0,0,0,0	3,4,4,4	3,3,4,4	0,0,0	0,0,0
0/100/0	U	0,0	0,0	0,0	0	0	0
1000	L	0,0	0,0	0,0	0,0	0,0	0,0
0/100/0	U	0,0	0,0	0,0	0,0	0,0	0,0
2000	L	0	0,0	0,0	0,0	0,0	0,0
2/20/78	U	0,0	0,0	3,4	4	0	0
1000	L	0,0	0,0	0,4	3,4	0	0
2/20/78	U	0,0	0,0	2,4	3	0	---
2000	L	0,0	0,0	0,tr	1,2	0,0	0,0
15/52/33	U	0,0	0	tr,2	tr,3	0,0	0,0
1000	L	0,0	0	tr	1	---	---
15/52/33	U	0,0	0,0	0,0	tr	0	0
2000	L	0,0	0,0	0	4	0	0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0
3000	L	0,0	0,0	0,0	0,0	0,0	0,0
30/0/70	U	0,0	0,0	4,4	4,4	0,0	0,0
1000	L	0,0	0,0	tr,4	0	0	0
30/0/70	U	0,0	0,0	1,4	2,4	0,0	0,0
2000	L	0,0	0,0	0,2	1,4	0,0	0,0
FRA*		0	0	0	0	0	0

*All subjects on Field Ration A excreted urine negative for ketone bodies.

TABLE III. 50 (Contd.)

RESTING KETONURIA: LIGHT WORK
(0 to +4)

Experimental Regimen		PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	0,0,0	0,0,0	1,4,4	1,4,4	0,0,0	0,0,0
		0,0	0,0	4,4	4,4	0,0	0,0
	L	0,0,0,0	0,0,0,0	4,4,4,4	4,4	0,0,0,0	0,0,0
0/100/0	U	0,0	0,0	0,0	0,tr	0,0	0,0
1000	L	0,0	0,0	0,0	0,0	0,0	0,0
0/100/0	U	0,0	0,0	0,0,0	0,0,0	0,0	0,0
2000	L	0,0	0,0	0	0	0	0
2/20/78	U	0,0	0,0	0	4	0	0
1000	L	0,0	0,0	3,4	3,4	0,0	0,0
2/20/78	U	0	0	0,0	tr,4	0,0	0,0
2000	L	0	0,0	0,1	tr	0	0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0
1000	L	0,0	0,0	0,0	1,1	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0
2000	L	0,tr	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0
3000	L	0,0	0,0	---	---	---	---
30/0/70	U	0	0	4	4	0	0
1000	L	0,0	0,0	4,4	0,4	0,0	0,0
30/0/70	U	0,0	0,0	0,3	0,2	0,0	0,0
2000	L	0,0	0,0	tr	1	0	0
FRA*		0	0	0	0	0	0

*All subjects on Field Ration A excreted urine negative for ketone bodies.

TABLE III. 51

EXERCISE KETONURIA
(0 to +4)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	0,0,0,0	0,0,0,0	4,4	0,0,0	0,0,0	0,0,0	0,0,0	4,4,4	0,0,0	0,0,0
							0,0	0,0	4,4	0,0	0,0
	L	0,0,0,0	0,0,0,0	4,4,4,4	0,0,0	0,0,0	0,0,0,0	0,0,0,0	3,4,4,4	0,0,0	0,0,0
0/100/0	U	0,0	0,0	0,0	0	0	0,0	0,0	0,0	0	0,0
1000	L	0,0	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0/100/0	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0,0	0,0	0,0
2000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0
2/20/78	U	0,0	0,0	3,4	0	0	0,0	0	2	0	0
1000	L	0,0	0,0	0,4	0,0	0,0	0,0	0,0	0,3	0,0	0,0
2/20/78	U	0,0	0,0	0,0	---	---	0	0	0,0	0,0	0,0
2000	L	0,0	0,0	0,0	0,0	0,0	0	0,0	0,4	0	0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1000	L	0,0	0	0	---	---	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,0	---	0,0	0,0	0,0	0,0	0,0
2000	L	0,0	0,0	0	0	0	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	---	---	---
30/0/70	U	0,0	0,0	4,4	0,0	0,0	0	0	3	0	0
1000	L	0,0	0,0	4,4	0	0	0,0	0,0	4,4	0,0	0,0
30/0/70	U	0,0	0,0	3,4	0,0	0,0	0,0	0,0	0,1	0,0	0,0
2000	L	0,0	0,0	0,4	0,0	0,0	0,0	0,0	0	0	0
FRA	U	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0,0	0,0,0,0
						0,0					
	L	0,0,0	0,0	0,0	0,0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
						0,0					

TABLE III. 52

POST-EXERCISE KETONURIA
(0 to +4)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	0,0,0,0	0,0,0,0	4,4	0,0	0,0,0	0,0,0 0,0	0,0,0 0,0	4,4,4 4,4	0,0,0 0,0	0,0,0,0
	L	0,0,0,0	0,0,0,0	4,4,4,4	0,0,0	0,0,0	0,0,0,0	0,0,0,0	3,3,4,4	0,0,0	0,0,0
0/100/0	U	0,0	0,0	0,0	0	0	0,0	0,0	0*,1	0,0	0,0
1000	L	0,0	0	0,0	0,0	0,0	0,0	0,0	0*,0*	0,0	0,0
0/100/0	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0*,4	0,0	0,0
2000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0*	0	0
2/20/78	U	0,0	0,0	0,4	0,0	0,0	0,0	0	1	0	0
1000	L	0,0	0,0	3,4	0,0	0,0	0,0	0,0	3,3	0,0	0,0
2/20/78	U	0,0	0,0	0,0	---	---	0	0	0,0	0,0	0,0
2000	L	0,0	0,0	0,0	0,0	0,0	0	0,0	2,4	0	0
15/52/33	U	0,0	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1000	L	0,0	0	0	---	---	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0	---	0,0	0,0	0,0	0,0	0,0
2000	L	0,0	0,0	0	0	0	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	---	---	---
30/0/70	U	0,0	0,0	3,4	0,0	0	0	0	3	0	0
1000	L	0,0	0,0	4,4	0	0	0,0	0,0	3,4	0,0	0,0
30/0/70	U	0,0	0,0	3,4	0,0	0,0	0,0	0,0	1,2	0	0,0
2000	L	0,0	0,0	0,3	0,0	0,0	0,0	0,0	0	0	0
FRA	U	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0 0,0	0,0,0	0,0,0	0,0,0	0,0,0,0	0,0,0,0
	L	0,0,0	0,0	0,0	0,0,0,0	0,0,0 0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0

*Brown color to reaction.

TABLE III. 53

PERCENTAGE DISTRIBUTION OF DEGREES OF KETONURIA VS. DIET AND WORK
(daily specimens)

Experimental Regimen		Phase	Hard Work No. Spec.	Hard Work Intensity of Reaction 0	tr	+1	+2	+3	+4	Light Work No. Spec.	Light Work Intensity of Reaction 0	tr	+1	+2	+3	+4
ST 0	U	PRE	8	100.0	0.0	0.0	0.0	0.0	0.0	10	100.0	0.0	0.0	0.0	0.0	0.0
		E I	21	4.8	0.0	0.0	0.0	9.5	85.7	35	14.3	17.1	0.0	5.7	0.0	62.9
		E II	1	0.0	0.0	0.0	0.0	0.0	100.0	10	0.0	10.0	0.0	0.0	20.0	70.0
ST 0	L	PRE	8	100.0	0.0	0.0	0.0	0.0	0.0	8	100.0	0.0	0.0	0.0	0.0	0.0
		E I	28	10.7	3.6	0.0	0.0	0.0	85.7	28	7.1	0.0	0.0	0.0	0.0	92.9
		E II	8	0.0	0.0	0.0	0.0	0.0	100.0	4	0.0	0.0	0.0	0.0	25.0	75.0
0/100/0 1000	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	92.9	7.1	0.0	0.0	0.0	0.0	14	85.7	0.0	0.0	14.3	0.0	0.0
		E II	4	75.0	0.0	0.0	25.0	0.0	0.0	4	50.0	25.0	0.0	25.0	0.0	0.0
0/100/0 1000	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	85.7	0.0	14.3	0.0	0.0	0.0	14	92.9	0.0	0.0	7.1	0.0	0.0
		E II	4	100.0	0.0	0.0	0.0	0.0	0.0	4	50.0	25.0	0.0	25.0	0.0	0.0
0/100/0 2000	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	100.0	0.0	0.0	0.0	0.0	0.0	14	100.0	0.0	0.0	0.0	0.0	0.0
		E II	4	50.0	0.0	0.0	25.0	0.0	25.0	4	75.0	25.0	0.0	0.0	0.0	0.0
0/100/0 2000	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	78.6	0.0	7.1	7.1	0.0	7.1	14	85.8	0.0	7.1	7.1	0.0	0.0
		E II	2	0.0	0.0	50.0	50.0	0.0	0.0	4	75.0	0.0	0.0	25.0	0.0	0.0
2/20/78 1000	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	2	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	21.4	0.0	0.0	0.0	7.1	71.5	7	28.6	0.0	14.3	0.0	0.0	57.1
		E II	2	0.0	50.0	0.0	50.0	0.0	0.0	2	50.0	0.0	0.0	0.0	50.0	0.0
2/20/78 1000	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	14.3	0.0	7.1	0.0	14.3	64.3	14	7.1	7.1	0.0	0.0	0.0	85.8
		E II	4	0.0	0.0	0.0	0.0	0.0	100.0	4	0.0	0.0	0.0	25.0	50.0	25.0
2/20/78 2000	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	2	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	35.7	0.0	7.1	7.1	7.1	42.8	14	42.8	7.1	7.1	0.0	7.1	35.7
		E II	2	0.0	0.0	50.0	0.0	50.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
2/20/78 2000	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
		E I	14	28.6	14.3	14.3	0.0	7.1	35.7	14	21.4	21.4	14.3	7.1	7.1	28.6
		E II	3	0.0	0.0	0.0	33.3	33.3	33.3	3	66.7	0.0	0.0	33.3	0.0	0.0

TABLE III. 53 (Contd.)

PERCENTAGE DISTRIBUTION OF DEGREES OF KETONURIA VS. DIET AND WORK
(daily specimens)

Experimental Regimen		Phase	Hard Work No. Spec.	Hard Work Intensity of Reaction 0	tr	+1	+2	+3	+4	Light Work No. Spec.	Light Work Intensity of Reaction 0	tr	+1	+2	+3	+4
15/52/33	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
1000		E I	14	57.2	7.1	0.0	28.6	7.1	0.0	14	92.9	0.0	0.0	7.1	0.0	0.0
		E II	4	50.0	0.0	0.0	25.0	0.0	25.0	4	100.0	0.0	0.0	0.0	0.0	0.0
15/52/33	L	PRE	2	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
1000		E I	7	71.4	28.6	0.0	0.0	0.0	0.0	14	35.7	42.8	7.1	14.3	0.0	0.0
		E II	1	100.0	0.0	0.0	0.0	0.0	0.0	4	50.0	25.0	0.0	0.0	0.0	25.0
15/52/33	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
2000		E I	14	92.9	7.1	0.0	0.0	0.0	0.0	14	100.0	0.0	0.0	0.0	0.0	0.0
		E II	3	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
15/52/33	L	PRE	2	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
2000		E I	7	100.0	0.0	0.0	0.0	0.0	0.0	14	92.9	7.1	0.0	0.0	0.0	0.0
		E II	2	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
3000		E I	14	100.0	0.0	0.0	0.0	0.0	0.0	14	85.8	7.1	7.1	0.0	0.0	0.0
		E II	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
15/52/33	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
3000		E I	14	78.6	21.4	0.0	0.0	0.0	0.0	8	100.0	0.0	0.0	0.0	0.0	0.0
		E II	4	100.0	0.0	0.0	0.0	0.0	0.0	0	-----	---	---	---	---	-----
30/0/70	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	2	100.0	0.0	0.0	0.0	0.0	0.0
1000		E I	14	0.0	7.1	0.0	0.0	7.1	85.8	7	28.6	0.0	0.0	0.0	0.0	71.4
		E II	4	0.0	0.0	0.0	0.0	0.0	100.0	2	0.0	0.0	0.0	0.0	0.0	100.0
30/0/70	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
1000		E I	12	0.0	0.0	7.1	0.0	7.1	85.8	13	7.7	0.0	0.0	7.7	0.0	84.6
		E II	2	0.0	0.0	0.0	0.0	0.0	100.0	4	0.0	0.0	0.0	0.0	0.0	100.0
30/0/70	U	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
2000		E I	14	21.4	7.1	0.0	7.1	7.1	57.3	14	42.8	0.0	14.3	0.0	14.3	28.6
		E II	4	0.0	25.0	0.0	25.0	25.0	25.0	4	50.0	0.0	0.0	0.0	50.0	0.0
30/0/70	L	PRE	4	100.0	0.0	0.0	0.0	0.0	0.0	4	100.0	0.0	0.0	0.0	0.0	0.0
2000		E I	13	0.0	15.4	7.7	15.4	15.4	46.1	8	12.5	0.0	12.5	50.0	12.5	12.5
		E II	4	0.0	0.0	0.0	0.0	0.0	100.0	2	0.0	0.0	0.0	0.0	0.0	100.0

TABLE III. 54

PERCENTAGE DISTRIBUTION OF DEGREES OF KETONURIA AMONG CONTROL (FRA) SUBJECTS
(Daily Specimens)

Phase	No. of Specimens	Intensity of Reaction					
		0	tr	+1	+2	+3	+4
PRE	22	100.0	0.0	0.0	0.0	0.0	0.0
EXP I	77	74.0	18.2	1.3	3.9	1.3	1.3
EXP II	22	63.6	13.7	0.0	4.5	13.7	4.5

TABLE III. 55

REGIMENS ASSOCIATED WITH OCCURRENCE OF 3+ OR 4+ KETONURIA*

Hard Work	Light Work
ST 0	ST 0
0/100/0 2000	2/20/78 1000
2/20/78 1000	2/20/78 2000
2/20/78 2000	15/52/33 1000
15/52/33 1000	30/0/70 1000
30/0/70 1000	30/0/70 2000
30/0/70 2000	

*All subjects, regardless of water intake.
Both experimental weeks included.

TABLE III. 56

ATYPICAL ROTHERA REACTIONS
(daily specimens)

Subject No.	July	Nutrient Mixture	Reaction
2	8	ST 0 U	4 Blue-purple
3	9	ST 0 U	4 Purple-brown
6	10	0/100/0 1000 U	0 Blue
7	10	0/100/0 2000 U	0 Blue
8	8	0/100/0 2000 U	0 Green
	9		3 Green-brown
	10		0 Yellow
23	6	ST 0 L	2 Brown
27	6	0/100/0 1000 L	0 Green-brown
	8		0 Green
	9		0 Green
	10		0 Green
28	8	0/100/0 1000 L	0 Green
	9		0 Brown
	10		0 Green
29	6	0/100/0 2000 L	0 Green-brown
	8		0 Green
	9		0 Brown
	10		0 Green
30	6	0/100/0 2000 L	0 Green-brown
	9		0 Blue
	10		0 Green

11. Carbohydrate and Fat Intakes

Introduction. The temperate study of 1953 and the cold weather study of 1954 led to the same conclusions with respect to "carbohydrate craving" and "fat craving" after a period of restriction. First, "carbohydrate craving" did not appear in subjects whose experimental period intakes were 2000 Calories or more. Second, severe calorie deprivation (intakes of 0 or 1000 Cal) combined with a low intake of carbohydrate led to "carbohydrate craving" in recovery. Third, "fat craving" was noticeable in REC II in subjects whose experimental regimens had been low in calories and low in carbohydrate (2/20/78 1000 and 30/0/70 1000). It will be interesting to scrutinize the data for the hot weather study of 1955 in these respects. Inasmuch as work load had no significant effect upon the results, the data have been averaged for hard and light work groups together; carbohydrate intake is shown in Table III. 57, fat intake in Table III. 58.

Carbohydrate Intake. All flights were eating items from the 5-in-1 in both pre-periods. During PRE I, the intake averaged about 480 gm/day. With the onset of hot weather, appetites diminished and intake in PRE II averaged only about 400 gm/day. During experimental periods, dietetic planning called for 0 intake in ST 0, 30/0/70 1000 and 30/0/70 2000; for low intakes in 2/20/78 1000, 2/20/78 2000, and 15/52/33 1000; intermediate intake in 0/100/0 1000 and 15/52/33 2000; and large intakes in 0/100/0 2000 and 15/52/33 3000. These planned intakes were achieved.

During REC I, rehabilitation was planned and controlled, and food intake increased stepwise. Therefore, "carbohydrate craving," if it existed, is to be sought only in REC II, when intakes were not limited. The lowest intakes were recorded, on the average, for N 3000 and 2/20/78 2000; the highest for ST 0 subjects and subjects previously on 2/20/78 1000. Within regimens there was an average correlation with calorie intake. In all comparisons except 30/0/70 1000 and 2000, carbohydrate consumption was greater in subjects who had been on 1000 Calories per day in experimental periods. This finding is in agreement with those of the temperate and winter studies. However, in the present hot weather study "carbohydrate craving" in rehabilitation appeared independently of the carbohydrate content of the experimental regimen, and this finding is different from those of the temperate and cold weather studies.

Fat Intake. During pre-periods fat intake declined from an average of about 130 gm/day in PRE I to about 120 in PRE II. Dietary planning called for zero fat intake in EXP I and II in ST 0, 0/100/0 1000 and 2000; for small amounts in 15/52/33 1000; for moderate amounts in 2/20/78 1000, 15/52/33 2000, 15/52/33 3000, and 30/0/70 1000; and large amounts in 2/20/78 2000 and 30/0/70 2000. These intakes were achieved according to plan. In REC I rehabilitation was controlled, so that evidences of "fat craving" should be sought only in REC II, when the subjects were permitted to eat without restriction of quantity.

Although there was no apparent correlation between fat intake in REC II and work load or water intake in experimental periods, there was a correlation with previous calorie consumption. In all comparisons except 30/0/70, subjects previously on 1000 Calories of a given regimen ate more fat than subjects previously on 2000 Calories. In the case of 30/0/70, this correlation was reversed.

No clear correlation existed between fat intake in recovery and experimental protein/carbohydrate/fat ratios. For instance, the largest average fat intake in REC II was for subjects previously on 2/20/78 1000 but an almost equally large intake occurred among subjects previously on 0/100/0 1000. These findings are different from those of the temperate and cold weather studies, in which caloric deprivation combined with a low carbohydrate intake led to "fat craving".

General Conclusion. All three studies led to one common conclusion; in rehabilitation after severe caloric deprivation, intakes of fat as well as carbohydrate are large. This must mean that there is a craving for food, regardless of protein/carbohydrate/fat ratios and no specific "fat craving" or "carbohydrate craving". On the basis of their field observations Johnson and Kark (1947) reached a similar conclusion for cold weather; i.e., that there is no convincing evidence for a specific "fat craving" in the cold.

TABLE III. 57

CARBOHYDRATE INTAKE*
(gm/day)

Experimental Regimen		PRE I	PRE II	EXP I	EXP II	REC I	REC II	X**
ST 0	U	452	433	0	0	382	692	696
	L	481	406	0	0	378	699	
0/100/0 1000	U	462	414	252	252	388	626	661
	L	481	413	252	252	375	696	
0/100/0 2000	U	486	478	504	504	418	627	614
	L	464	351	504	504	421	600	
2/20/78 1000	U	455	416	46	46	384	698	668
	L	446	384	46	46	382	638	
2/20/78 2000	U	480	438	94	94	415	584	552
	L	444	404	94	94	394	521	
15/52/33 1000	U	484	416	135	135	386	610	618
	L	413	376	135	135	393	626	
15/52/33 2000	U	474	484	268	268	419	645	598
	L	442	400	268	268	428	552	
15/52/33 3000	U	558	528	401	401	416	581	584
	L	495	484	401	401	407	586	
30/0/70 1000	U	447	443	0	0	386	614	600
	L	421	388	0	0	350	592	
30/0/70 2000	U	445	430	0	0	422	644	616
	L	406	383	0	0	415	587	

*Hard and light work groups combined

**Mean REC II, U+L

TABLE III. 58

FAT INTAKE*
(gm/day)

Experimental Regimen		PRE I	PRE II	EXP I	EXP II	REC I	REC II	X**
ST 0	U	129	122	0	0	96	166	172
	L	132	120	0	0	92	177	
0/100/0	U	138	128	0	0	90	169	174
1000	L	138	130	0	0	85	178	
0/100/0	U	134	124	0	0	112	156	160
2000	L	137	107	0	0	114	163	
2/20/78	U	135	116	89	89	86	196	178
1000	L	134	122	89	89	88	159	
2/20/78	U	126	114	179	179	114	148	161
2000	L	132	121	179	179	109	174	
15/52/33	U	135	114	38	38	88	163	172
1000	L	134	124	38	38	92	182	
15/52/33	U	130	131	76	76	114	162	167
2000	L	132	128	76	76	116	172	
15/52/33	U	146	148	115	115	111	164	155
3000	L	143	140	115	115	116	146	
30/0/70	U	126	121	75	75	86	148	156
1000	L	132	125	75	75	85	163	
30/0/70	U	137	137	151	151	114	184	172
2000	L	128	120	151	151	114	160	

*Hard and Light work groups combined

**Mean REC II, U+L

12. Osmotic Balance

We regard the concept of osmotic equilibrium of the body to be important in interpreting normal and pathologic changes, just as is the concept of acid-base equilibrium. These two concepts do not conform to standard thinking on nutrient balance; e.g., in the case of nitrogen, schematically, true balance involves two parameters only:

INTAKE OF NUTRIENT ⟶ [NUTRIENT BALANCE] ⟶ EXCRETION

a) Renal
b) Gastrointestinal
c) Dermal
d) Pulmonary

The term "acid-base balance" involves three parameters:

INTAKE OF POTENTIAL ACIDS AND BASES ⟶ [ENDOGENOUS EVENTS / ACID-BASE EQUILIBRIUM] ⟶ EXCRETION

a) Renal
b) Gastrointestinal
c) Dermal
d) Pulmonary

Customarily, intake and excretion of acids and bases are not measured; total endogenous production is difficult, if not impossible, to measure. However, two types of acidosis and alkalosis are generally recognized: respiratory and metabolic. What is actually measured is acid-base equilibrium at a given moment, in terms of pH, $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$; $H_3PO_4 \rightleftharpoons H^+ + H_2PO_4^-$; and organic acids.

We propose that a similar generalizing concept of "osmotic balance" is possible in terms of three parameters:

INTAKE OF POTENTIALLY OSMOTICALLY ACTIVE SUBSTANCES PLUS WATER ⟶ [ENDOGENOUS EVENTS / OSMOTIC EQUILIBRIUM] ⟶ EXCRETION

a) Renal
b) Gastrointestinal
c) Dermal
d) Pulmonary

The fundamental measurements would be osmolar concentration in the body fluids, total body water, and total osmotic content of the body. The first might be assumed to be proportional to the serum osmolarity; the second can be measured directly; the third cannot at present be measured, but could be calculated from the first two: Osmolarity=(total osmotic content) (total body water).

An important assumption has to be made in calculating "osmotic content" from serum osmolarity and total body water; viz., that extracellular and intracellular fluid and solutes exist in an equilibrium which correlates with the total body water and the serum osmolarity. It is conventional to regard sodium and chloride as extracellular, potassium and phosphate as intracellular, and water and urea as freely exchangeable between extracellular and intracellular spaces. However, there has to be some kind of coordinated movement of all these substances such that in a sense they are mathematically related in the several compartments. For want of anything better, we shall assume that serum osmolarity is correlated somehow with the sum total of osmotic activity of the body. All the classical assumptions listed above neglect the possibly important place that the "skeletal sodium reserve" may hold in the homeostasis of extracellular fluid. This "reserve" amounts to about 1/3 of the total body sodium, and over half of it seems to be readily exchangeable. Its potential importance in relation to sodium turnover is obvious and yet as of the present very little is known about its normal variations and its control.

Calculations of "osmotic content" in our subjects have been made according to the equation:

"Total Osmotic Content" = (D_2O Space, liters) x
(Serum Osmolar Concentration Osm/liter).

This derived number showed a very slight increase among the control subjects between PRE II and EXP. Among the experimental subjects it decreased among all subjects except those on 15/52/33 2000 Hard Work. There was no clear correlation with work load, water intake, calorie intake, or "osmotic intake." In other words, this derived number changed in the expected way between controls and experimental subjects, but was not discriminatory among regimens.

Thinking that the total osmotic content should be correlated with body size, we recalculated the data in Table III. 59 in terms of percentage of body weight at the time of observations, as shown in Table III. 60. This derived number, "total osmotic percentage concentration of body," has some interesting characteristics. It was remarkably constant from subject to subject, the overall range being 17.22 to 20.56 in PRE II. It increased very slightly between PRE II and EXP among the control subjects, and decreased among all experimental subjects except 2/20/78 U Hard Work, 15/52/33 2000 U and L Hard Work, 30/0/70 1000 L Hard Work, 0/100/0 1000 U Light Work, and 2/20/78 2000 U Light Work. There was a small tendency for restriction of water to result in a greater drop in this number than occurred in unlimited water subjects, but this was not a consistent trend. There were no clear correlations with osmotic intake, calorie intake, or nutrient ratios.

In short, the measurements that we have of deuterium oxide space and serum osmolarity do not seem to be a completely satisfactory source of calculation on bodily osmotic depletion. Therefore, other measurements must be sought which will permit quantitative expression of osmotic status. Apparently factors not correlated with serum osmolarity are important.

We have tried to utilize urinary excretion of osmotically active substances

TABLE III. 59

"TOTAL OSMOTIC CONTENT OF BODY"*
(Osmols)

Experimental Regimen		HARD WORK PRE II	HARD WORK EXP	HARD WORK Δ	LIGHT WORK PRE II	LIGHT WORK EXP	LIGHT WORK Δ
ST 0	U	12.89	11.00	-1.89	14.08	12.03	-2.05
	L	11.86	9.62	-2.24	13.62	10.99	-2.63
0/100/0	U	12.58	10.94	-1.64	12.66	12.28	-0.38
1000	L	10.63	9.68	-0.95	14.35	10.79	-3.56
0/100/0	U	13.44	11.59	-1.85	14.10	13.04	-1.06
2000	L	11.88	10.84	-1.04	12.71	11.93	-0.78
2/20/78	U	13.38	13.05	-0.33	12.85	11.75	-1.10
1000	L	11.86	9.59	-2.27	13.04	11.22	-1.82
2/20/78	U	14.30	14.53	+0.23	12.42	12.24	-0.18
2000	L	12.52	11.48	-1.04	14.70	13.26	-1.44
15/52/33	U	13.31	12.25	-1.06	14.12	12.76	-0.18
1000	L	12.58	10.91	-1.67	12.90	12.01	-0.89
15/52/33	U	10.90	11.36	+0.46	15.04	14.41	-0.63
2000	L	13.09	13.65	+0.56	13.47	12.54	-0.93
15/52/33	U	11.35	10.82	-0.53	14.93	14.05	-0.88
3000	L	13.06	11.53	-1.53	-----	-----	-----
30/0/70	U	13.54	12.23	-1.31	11.89	10.62	-1.27
1000	L	12.71	11.97	-0.74	12.36	11.23	-1.13
30/0/70	U	13.50	12.59	-0.91	11.89	10.74	-1.15
2000	L	12.47	10.52	-1.95	15.79	12.90	-2.89
FRA		14.26	14.58	+0.32	14.26	14.58	+0.32

*Calculated as total osmols from the equation:
"Total Osmotic Content" = (D_2O Space, liters) x (Serum Osmolarity, Osm/liters).

as a correlate of osmotic status. An analysis of data from both the cold weather study and the hot weather study is of considerable interest in this respect, in that it does suggest that dietary intake and urinary excretion are very closely related, even in the face of caloric deficit and endogenous production of ketone bodies which are excreted in the urine. The data are summarized in Figures III. 25 and III. 26, and in Tables III. 61, III. 62, III. 63, and III. 64.

Several assumptions had to be made for this calculation. First, it was assumed that all protein ingested was metabolized and the nitrogen was excreted as urea. Second, it was assumed that the preponderant substances for osmotic activity in the urine are normally urea, sodium, potassium, chloride, and phosphate (dibasic plus monobasic). Third, it was assumed that the minute osmotic excretion in the "three hour test" in the summer study and the minute osmotic excretion in the twenty-four hour samples in the winter study could be compared directly. Accordingly, "osmotic intakes" were calculated according to the hypothesis:

"Osmotic Intake" = Urea Intake (calculated from nitrogen intake, gm/day, ÷ 28) + Phosphorus Intake (calculated from gm P/day x 1000/32 x 1.5) + Sodium Intake + Potassium Intake + Chloride Intake.

All of these values were measured and have been recorded in appropriate sections above. "Osmotic Intake" for the winter study is given in Table III. 61; and for the summer study in Table III. 62. There were small differences in the two studies, especially in the 15/52/33 regimens. The range was from effectively 0 to about 1000 mOsm/day. For calculation we omitted starvation as being anomalous.

With these intakes as y, and the daily osmotic excretion as x (Table III. 63), straight regression lines were calculated by the method of least squares according to the hypothesis:

"Osmotic Intake" = a + b x (Osmotic Excretion).

The results are shown in Figure III. 25. Excellent correlation coefficients were obtained for both the winter and the summer study, with satisfactorily small standard errors of measurement. For low intakes and excretion, the two sets of data are very close. However, with increasing intakes and excretion, they diverge markedly.

In order to try to explain this divergence, we argued that the sweat gland would compete with the kidney for osmotically active substances, and therefore in the summer study urinary excretion for a given intake would be less than in the winter. This hypothesis was tested by adding to the values for the summer urinary excretion the values calculated for dermal loss of nitrogen, sodium potassium, and chloride calculated for the balance calculations (Table III. 64). (An addition of 20% was made to account for the deficit in sweat between known osmotic total concentration and the sum of measured constituents. This phenomenon will be discussed in detail in a later section on composition of sweat.) The sum of (urine + sweat) was then fitted against "osmotic intake" by the method of least squares, and another excellent fit was obtained (Figure III. 26).

At the lower end of the lines, the winter and summer data are in the same population, up to intakes of about 600 mOsm/day. Thereafter, they diverge. We have not yet been able to explain this interesting difference between winter and summer results. If we say that osmotic balance is achieved when urinary excretion equals intake (winter study) or when (urinary + dermal) excretion equals intake (summer study) then the winter subjects never achieved balance at any intake. However, the summer subjects did achieve balance at intakes of just under 1000 mOsm/day. We are at a loss to explain this difference, but postulate that there was a continuing "cold diuresis" in the cold weather study, with loss of extracellular fluid not operative in the hot weather study.

Clearly there is a close correlation between intake and excretion, and for want of any better definition we shall continue to use the following: "Osmotic

state is correlated with minute urinary osmotic excretion. When the output exceeds the calculated intake, osmotic depletion will ensue." This definition leaves much to be desired. It does not account satisfactorily for endogenous events, notably ketosis and fluctuations in carbon dioxide metabolism and retention, which Meschia and Barron (1956) have emphasized as important in osmotic balance. The definition also might break down in the face of actual renal pathology, in which osmotic excretion may be impaired. Finally, it does not make possible a direct comparison of conditions of minimal sweating and conditions of profuse sweating, when extra-renal excretion of osmotically active materials may actually exceed renal excretion.

In spite of its defects, however, this approach to osmotic depletion has led to fruitful generalizations, and there is no doubt that the concept of osmotic balance is very important. With a quantitative knowledge of deuterium oxide space, dietary intake, and urinary osmotic excretion, we can begin to distinguish rationally between osmotic retention and osmotic depletion; and among hypohydration, normal hydration, and excessive hydration. Furthermore, we can begin to describe osmotic balance in terms of exogenous intake, endogenous events, and the relative effects of various avenues of osmotic excretion. Again, we can discuss within this general framework the generally recognized types of hydropenia: salt depletion hydropenia; pure water depletion hydropenia; and mixed water and salt depletion hydropenia. We add another sort of hydropenia to these categories: osmotically obligatory hydropenia which occurs when the sum of protein and salt intake is large, and water intake is inadequate to handle these normally.

TABLE III. 60

"TOTAL OSMOTIC PERCENTAGE CONCENTRATION OF BODY"
(Osmols/100 kg body weight)

Experimental Regimen		HARD WORK PRE II	HARD WORK EXP	HARD WORK Δ	LIGHT WORK PRE II	LIGHT WORK EXP	LIGHT WORK Δ
ST 0	U	19.34	18.11	-1.23	20.25	19.03	-1.22
	L	19.30	17.32	-1.98	20.89	18.38	-2.51
0/100/0	U	18.48	17.35	-1.13	20.46	21.36	+0.90
1000	L	18.13	17.93	-0.20	21.81	17.49	-4.32
0/100/0	U	19.93	18.27	-1.66	20.22	18.84	-1.38
2000	L	17.06	16.47	-0.59	19.88	19.30	-0.58
2/20/78	U	20.40	21.24	+0.84	18.04	17.51	-0.53
1000	L	18.96	16.35	-2.61	20.24	18.48	-1.76
2/20/78	U	19.50	20.65	+1.15	17.22	17.66	+0.44
2000	L	19.25	18.46	-0.79	21.79	20.04	-1.75
15/52/33	U	18.78	18.49	-0.29	20.10	19.45	-0.65
1000	L	20.52	18.84	-1.68	19.94	19.62	-0.32
15/52/33	U	18.96	20.21	+1.25	19.80	19.76	-0.04
2000	L	20.91	22.47	+1.56	20.73	19.82	-0.91
15/52/33	U	18.55	17.81	-0.74	19.98	19.24	-0.74
3000	L	20.46	18.51	-1.96	20.18	-----	-----
30/0/70	U	19.02	18.60	-0.42	18.79	17.74	-1.05
1000	L	17.68	17.76	+0.08	19.70	18.96	-0.74
30/0/70	U	18.52	18.14	-0.38	19.20	18.38	-0.82
2000	L	19.95	17.93	-2.02	22.43	19.18	-3.25
FRA		19.10	19.29	+0.19	19.10	19.29	+0.19

TABLE III. 61

"OSMOTIC INTAKE"--WINTER 1954--EXP
(mOsm/day)

Experimental Regimen		N	Na	K	Cl	P	Σ
ST 0		0	1	0	0	0	1
0/100/0	1000	0	6	0	0	0	6
0/100/0	2000	0	9	0	0	0	9
2/20/78	1000	46	78	3	79	3	209
2/20/78	2000	79	154	6	155	9	403
15/52/33	1000	200	62	22	37	9	330
15/52/33	2000	407	178	42	90	15	732
15/52/33	3000	593	212	61	110	22	998
30/0/70	1000	429	55	28	1	12	525
30/0/70	2000	811	104	53	2	24	994

FIGURE III. 25. DAILY OSMOTIC EXCRETION IN URINE VS. CALCULATED DAILY INTAKE OF POTENTIALLY OSMOTICALLY ACTIVE MATERIALS.

FIGURE III. 26. "OSMOTIC INTAKE" VS. OSMOTIC EXCRETION IN URINE AND SWEAT (WINTER 1954 AND SUMMER 1955).

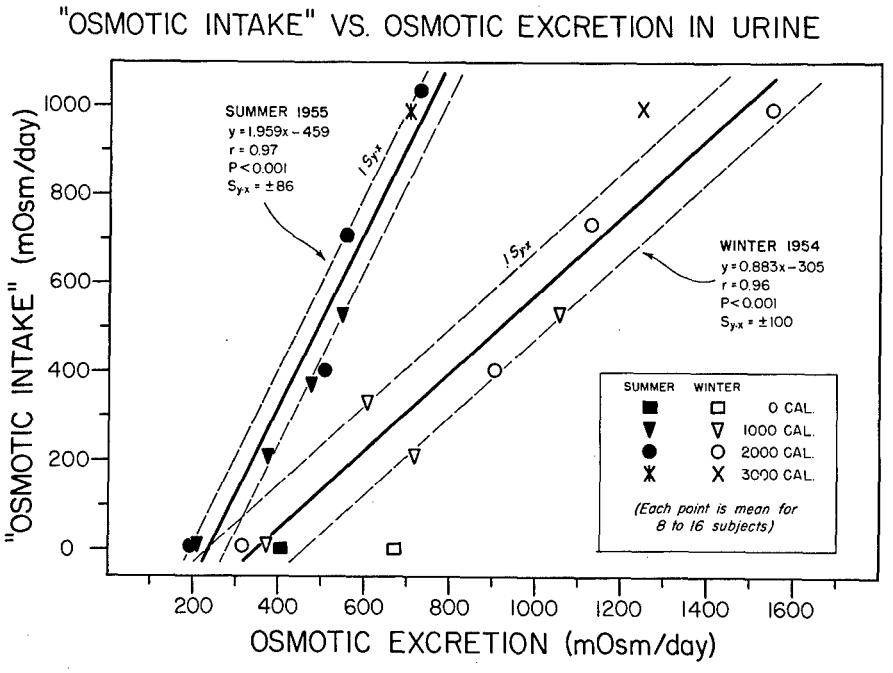


FIGURE III. 25

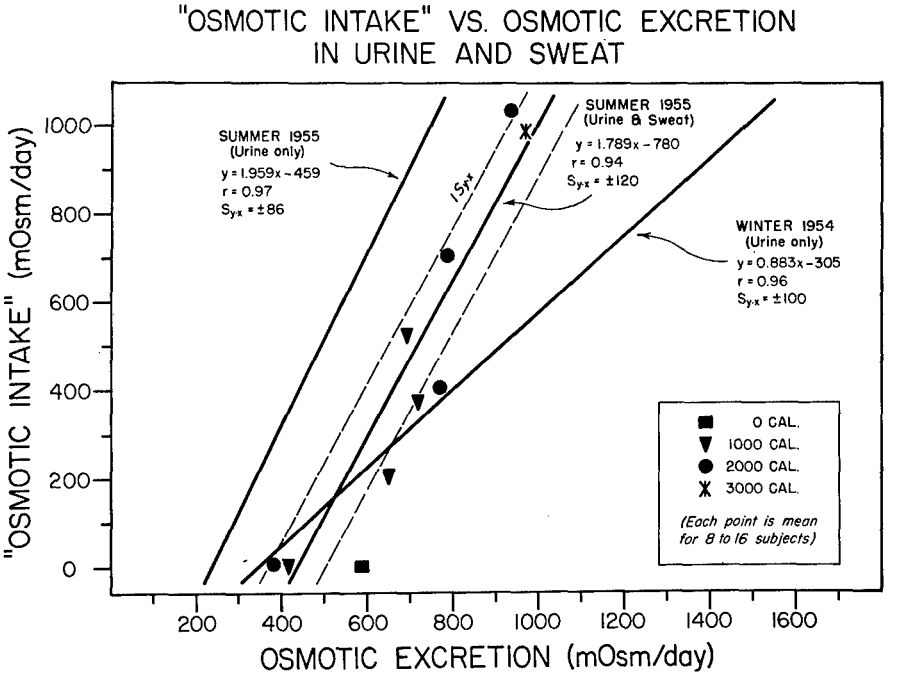


FIGURE III. 26

TABLE III. 62

"OSMOTIC INTAKE"--SUMMER 1955--EXP
(mOsm/day)

Experimental Regimen	N	Na	K	Cl	P	Σ
ST 0	0	1	0	0	0	1
0/100/0 1000	0	6	0	0	0	6
0/100/0 2000	0	9	0	0	0	9
2/20/78 1000	46	76	3	78	3	206
2/20/78 2000	79	153	6	156	9	403
15/52/33 1000	196	89	22	53	7	367
15/52/33 2000	407	146	49	89	15	706
15/52/33 3000	600	177	63	126	22	988
30/0/70 1000	429	53	27	1	12	522
30/0/70 2000	850	106	55	2	24	1037

TABLE III. 63

OSMOTIC EXCRETION--EXP II
(mOsm/day)

Experimental Regimen	Winter 1954	Summer 1955		Σ**
		Urine	Sweat*	
ST 0	670	402	186	588
0/100/0 1000	370	208	208	416
0/100/0 2000	315	194	186	380
2/20/78 1000	716	372	269	649
2/20/78 2000	902	506	263	769
15/52/33 1000	602	470	248	718
15/52/33 2000	1123	557	229	786
15/52/33 3000	1246	701	262	963
30/0/70 1000	1054	544	148	692
30/0/70 2000	1547	722	210	932

*Sweat = osmols due to N (as urea) + Na + K + Cl
**Sum of urine osmols + sweat osmols.

TABLE III. 64

DAILY OSMOTIC LOSS IN SWEAT--SUMMER 1955
(mOsm/day)

Experimental Regimen	(as urea) N	Na	K	Cl	Σ	"True"*
ST 0	33	45	31	46	155	186
0/100/0 1000	42	52	35	44	175	208
0/100/0 2000	40	44	30	41	155	186
2/20/78 1000	39	81	27	77	224	269
2/20/78 2000	39	71	37	72	219	263
15/52/33 1000	39	61	41	66	207	248
15/52/33 2000	38	56	43	54	191	229
15/52/33 3000	47	63	44	64	218	262
30/0/70 1000	34	32	26	31	123	148
30/0/70 2000	37	52	34	52	175	210

*"True" is defined as Σ of N, Na, K, Cl with addition of 20%.

C. BODY COMPOSITION

1. Body Weight

Pre-period data for body weight are summarized in Table III. 65. The means indicate that, on the average, the five groups did not differ much insofar as weight was concerned. The remarkable fact is the constancy of the weight from P I to P II. Only the FRA group changed appreciably; they gained 1.3 kg. These men probably gained because of the greater freedom of their dietary regimen.

The mean maximum weight losses for those subjects who completed nine full days of the 40 experimental regimens are given in Table III. 66. Only in the case of two regimens--15/52/33 1000 L, Hard Work, and 15/52/33 3000 L, Light Work--were all subjects eliminated because of infectious disease. All other regimens are covered by at least one man. There are five men for ST 0 U, Light Work, because Subject 54 refused to eat his ration of meat bar (30/0/70 1000).

Certain trends are evident in the data of Table III. 66. Maximum weight loss occurred among those men who were starved and the least weight was lost by those men who ate the 3000-Calorie nutrient mixture. The weight losses were intermediate in the cases of men on the 1000- and 2000-Calorie regimens, the former losing more weight than the latter. Among most regimens limitation of water and work load had little consistent effect on maximum weight loss (see below). The meat bar and the 15/52/33 3000 regimens, however, did show the expected accentuation of weight loss by limitation of water and hard work. Most likely the greater weight loss under these conditions was caused by the large obligatory urine volume (high solute load) and the resultant exaggerated negative water balance.

The day-by-day variations in body weight during the experimental and recovery periods are illustrated in Figures III. 27 and III. 28. The arrows indicate when extra water was given to the subjects on restricted intake of water. This water was allowed because some men on limited water developed anhidrosis and hypohidrosis. Study of Figure III. 27 for men performing hard work brings out several significant facts. First, weight losses tend to be proportional to caloric deficit. Men on ST 0 lost the most weight; men on 15/52/33 3000 (N 3000) lost the least weight. Second, the rate of weight loss and the magnitude of the weight loss were not influenced by the water intake among those men on ST 0, 0/100/0 1000 and 2000, and 2/20/78 1000. These regimens are low in osmotic activity and tend to produce voluntary dehydration by their failure to provoke thirst. Third, when the osmotic intake was increased, men on restricted water lost weight much more rapidly than men on unlimited water. This reaction was present among men subsisting on 2/20/78 2000 (high salt), 15/52/33 1000, 2000, and 3000, and 30/0/70 1000 and 2000 (high protein). Maximum weight losses, however, were not greatly different for the simple reason that men on restricted water were given increased allowances. From the slopes of the curves for these men it is evident that they would have rapidly become seriously dehydrated if additional water had been withheld. As it was, three men on limited water became anhidrotic before the

extra water was allowed; eight became markedly hypohidrotic. Fourth, in the case of the 30/0/70 regimen, the influence of caloric intake was offset by the influence of osmotic drain on body water. Men on 2000 Cal/day lost almost as much weight as those on 1000 Cal/day. The same trends of body weight may be seen in Figure III. 28 for men performing light work.

In the recovery periods, most of the subjects regained the weight lost during the experimental periods. In point of fact, a number of men even gained some additional weight. Early in recovery, the regain was rapid. Late in recovery the rate of weight gain was much less. In several instances the weight stabilized. These trends strongly support previous observations made during the 1953 temperate study and 1954 winter study. In the face of strongly positive caloric balance, little change occurs in body weight. No satisfactory explanation of this phenomenon has been forthcoming.

TABLE III. 65

PRE-PERIOD DATA ON BODY WEIGHT
(kg)

	P I		P II	
Flight	M	Range	M	Range
1	66.8	57.3-89.1	66.9	57.4-88.6
2	64.2	52.4-82.6	64.2	52.6-82.0
3	69.4	56.0-78.4	69.6	56.2-77.7
4	66.1	56.2-87.8	66.1	56.2-88.4
FRA	72.7	63.3-84.6	74.0	64.0-84.7

TABLE III. 66

MEAN MAXIMUM WEIGHT LOSS
IN FORTY EXPERIMENTAL REGIMENS
(kg)

Nutrient Regimen	Light Work		Hard Work	
	U	L	U	L
ST 0	6.9 (5)*	6.4 (2)	6.8 (1)	7.6 (4)
0/100/0 1000	4.6 (2)	4.2 (2)	4.6 (2)	4.9 (2)
0/100/0 2000	3.8 (1)	3.0 (2)	4.2 (2)	4.4 (2)
2/20/78 1000	4.2 (1)	3.8 (2)	4.4 (1)	4.4 (2)
2/20/78 2000	2.8)2)	3.0 (2)	3.1 (1)	3.8 (2)
15/52/33 1000	4.5 (2)	4.0 (2)	4.4 (2)	-------
15/52/33 2000	3.1 (2)	3.0 (2)	2.0 (1)	3.5 (1)
15/52/33 3000	1.8 (2)	-------	1.1 (2)	2.8 (2)
30/0/70 1000	-4.0 (1)	4.4 (2)	5.3 (2)	6.2 (2)
30/0/70 2000	3.2 (2)	4.3 (1)	3.6 (2)	4.6 (2)

*Numbers in parenthesis indicate numbers of subjects, "STO U, Light Work" had five men because Subject 54 refused to eat more than nibbles of the meat bar (30/0/70 1000).

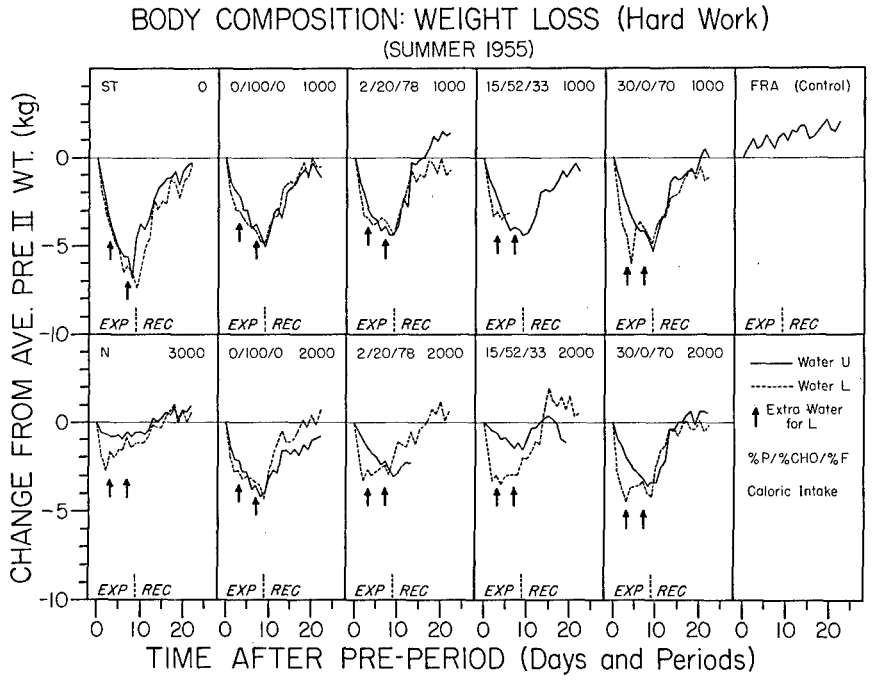


FIGURE III. 27. WEIGHT LOSS: HARD WORK.

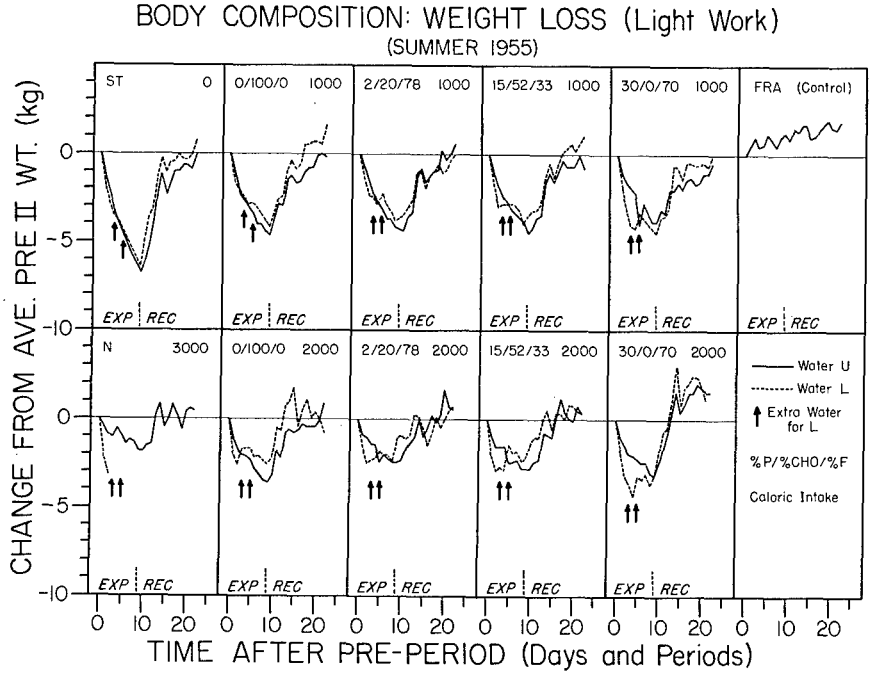


FIGURE III. 28. WEIGHT LOSS: LIGHT WORK.

2. Body Water
(Written by G. N. Wogan)

a. Osmotic Excretion

In a previous study, Sargent et al. (1955) pointed out that a relationship exists between the osmotic load of a nutrient regimen and the observed changes in D_2O-space. Osmotic load is defined as the minute urinary excretion of osmotically active substances, determined by freezing point depression, and expressed as microosmols excreted per minute. The quantity of such material excreted obviously depends upon a number of factors; viz., the intake of inorganic materials and nitrogenous substances which are actually or potentially osmotically active, as well as compounds such as urea, ketone bodies, bicarbonate, etc., which are produced endogenously and excreted in the urine. Table III. 67 presents the osmotic load of the various nutrient regimens of the present study as well as those of the previous one. The two studies had very similar experimental designs, except that in the earlier one subjects were exposed to environmental conditions of moderate cold, in the present one to heat.

In both series of data, rank-order correlation results in the observation that the 30/0/70 2000 regimen imposes a very high osmotic load, while 0/100/0 regimens present very low loads. The other regimens are intermediate, the position in rank-order being very similar in both studies. It will be noted, however, that with one exception (15/52/33 1000) the osmotic loads in the summer data are lower than those from the winter. (The discrepancy in the case of the single exception can probably be explained in terms of different intake of osmotic material.) This lower load presumably reflects the loss of osmotically active material in sweat since this avenue of loss is of considerable magnitude in the hot-weather study and practically non-existent in the winter study. Lichton (1953) has shown that kidney and sweat gland act competitively in osmotic regulation.

It is of interest to point out that the greatest differences in load between summer and winter data appear in those experimental regimens (excluding controls) which impose the four highest osmotic loads. From a purely speculative standpoint, this may represent a compensatory mechanism to reduce the isosmotic urine volume, thereby reducing the amount of osmotic work required of the kidney under these circumstances. It is also of interest that the loads imposed by these regimens are supplied from two sources; in the 15/52/33 diets, the osmotic load is predominantly electrolyte (NaCl), while in the 30/0/70 diets it is predominantly nitrogenous.

TABLE III. 67

RELATIVE OSMOTIC LOADS OF VARIOUS REGIMENS
(Means of Exp I and Exp II, U and L, all subjects)

Experimental Regimen	Winter, 1954 Osmotic Load*	Rank-order	Summer, 1955 Osmotic Load**	Rank-order	(Winter-Summer)
ST 0	465	8	402	8	63
0/100/0 1000	257	10	208	10	49
0/100/0 2000	219	11	172	11	47
2/20/78 1000	497	7	372	9	125
2/20/78 2000	626	6	506	6	120
15/52/33 1000	418	9	470	7	-52
15/52/33 2000	780	4	557	4	223
15/52/33 3000	865	2	700	3	165
30/0/70 1000	732	5	544	5	188
30/0/70 2000	1074	1	722	2	352
FRA	825	3	863	1	-38

*Micro-osmols excreted per minute during a two-hour (*) or three-hour (**) period of collection.

b. Body Water

Before the results of the estimation of body water are presented, it will be necessary to describe several special methods, assumptions, and observations which were intimately connected with the calculation of the D_2O-space data as they will be presented in their final form. The method used in these calculations is outlined briefly in the methods section of this report, and described in detail in Appendix I. In essence, it involves the computation of the degree of dilution of an administered dose of D_2O by the body fluids. Ample evidence exists that D_2O administered intravenously (Schloerb et al., 1950) or orally (Pascale et al., 1954) rapidly distributes itself completely throughout the body fluids, equilibrium being established among the various fluid compartments within eight to ten hours after administration. After this equilibrium has been reached, it has been found (Pascale et al., 1954) that dilution of the administered dose can be computed using the urinary D_2O/H_2O ratio as the index. As described earlier, the D_2O-space was computed after a period of eighteen hours or more had elapsed following the D_2O administration. Since D_2O appears in the urine within three hours after its administration, some of the dose is lost via this route, and presumably also by the extra-renal routes of water loss (skin and lungs) during the equilibration period. The absolute amount of D_2O lost by all routes must be estimated as quantitatively as possible before the true degree of dilution of D_2O remaining in the body can be calculated. The renal loss can be estimated accurately by collecting all urine excreted during the period in question and determining the D_2O/H_2O ratio in that urine.

Method of Estimation of Extra-renal D_2O Loss. The extra-renal D_2O loss, however, is more difficult to assess accurately. Although it has long been recognized that insensible perspiration and sweat contain D_2O following its administration, no attempts to correct for loss by these avenues have been

reported in any former studies of D_2O-space. According to the report of Hevesy (1934), the D_2O/H_2O ratios in human sweat, expired water, and urine collected simultaneously in an equilibrium state following D_2O administration are identical. Since, in the current study, sweat and insensible water losses were of such significant magnitude quantitatively, it was decided to repeat the observations of Hevesy. For this purpose, seven of the control (FRA) subjects were chosen for experiments in which sweat and urine or insensible perspiration and urine were collected simultaneously. They were chosen because it was assumed that no inestimable variables such as dehydration or caloric restriction would confound the D_2O/H_2O ratios in the fluids to be collected.

The experiments, in which sweat and urine were to be collected simultaneously, were carried out 48-72 hours after D_2O had been administered orally. In some cases, thermal sweat was collected; in others, sweating was induced by exercise. In the former case, the subjects were placed in enclosures at high temperature, and were allowed to remain sedentary for several hours in this environment. In the exercise experiments, the subjects were marched in the sun for one hour. In both cases, sweat was collected by enclosing both forearms and hands (previously shaved, rinsed in distilled water, and dried) in elbow-length obstetrical rubber gloves which were secured and sealed at the cuffs by rubber bands. Therefore, sweat was collected from both forearms and hands of each subject. At the time the gloves were donned, each subject emptied his bladder. At the end of the collection period, the bladder was again emptied, this urine being used for analysis for D_2O/H_2O ratios. Specimens of sweat and urine were frozen immediately upon collection, and were kept frozen until the analyses were carried out.

The experiments in which expired water and urine were collected simultaneously involved only two subjects. Collections were made 72 hours after D_2O administration in both the pre-period test and the experimental period test. Expired moisture was collected by directing the expired air of the subject through a two-way Douglas valve and thence through a previously dried heavy metal cylinder which was immersed in crushed solid CO_2. Moisture from the expired air was thus frozen and at the end of the collection period (2.7-4.1 hr.) was melted and collected. Urine was collected during the same period according to the protocol described above in the sweat experiments. Again, urine and expired water were stored in the frozen state until analyzed.

The D_2O/H_2O ratios were determined in sweat, expired water, and urine according to the method described in Appendix I. The results of these analyses are presented in Tables III. 68 and III. 69.

Inspection of these data allows several generalizations to be made. First, in every case, the D_2O/H_2O ratio in sweat or expired moisture is lower than that in urine collected during the same period. Second, the discrepancy between these two ratios is highly variable among subjects, and even in the same subject when a number of comparisons are made on one subject. Similarly, the absolute ratios in urine and sweat are variable among individual subjects or in the same subject. In only one case is there a trend toward constancy; viz., in the absolute D_2O/H_2O ratios in expired moisture. However, the limited

TABLE III. 68

D_2O CONTENT OF SWEAT AND URINE COLLECTED SIMULTANEOUSLY

Subject	Date of D_2O Administration	Date of Specimen Collection	Specimen	D_2O/H_2O Ratio,%	Sweat Ratio as % of Urine Ratio
90	July 4	July 8	Urine	0.0829	85.6
			Sweat	0.0710	
90	July 14	July 17	Urine	0.0862	
			Sweat	0.0837	97.1
92	July 4	July 8	Urine	0.0779	
			Sweat	0.0420	53.9
94	July 14	July 17	Urine	0.0746	
			Sweat	0.0540	72.4
96	July 15	July 17	Urine	0.0779	
			Sweat	0.0577	74.1
98	July 4	July 8	Urine	0.0804	
			Sweat	0.0622	77.4
99	July 4	July 8	Urine	0.0889	
			Sweat	0.0220	24.7
100	July 15	July 17	Urine	0.0862	
			Sweat	0.0594	68.9
Control	None	July 8	Urine	0.0000	
			Sweat	0.0000	
				Mean	69.3

TABLE III. 69

D_2O CONTENT OF EXPIRED WATER AND URINE COLLECTED SIMULTANEOUSLY

Subject	Date of D_2O Administration	Date of Specimen Collection	Specimen	D_2O/H_2O Ratio,%	Expired Water Ratio as % of Urine Ratio
90	July 4	July 7	Urine	0.0857	
			Expired Water	0.0360	42.0
90	July 14	July 18	Urine	0.0770	
			Expired Water	0.0461	59.9
100	July 4	July 7	Urine	0.0761	
			Expired Water	0.0418	54.9
100	July 15	July 18	Urine	0.0717	
			Expired Water	0.0479	66.8
				Mean	55.9

number of experiments precludes the extraction of any valid conclusion regarding this point. It may be speculated that, since the evaporation of water in the lungs presumably takes place by simple physical processes, the mere difference in vapor pressure between D_2O and H_2O might account both for the constancy of the ratio of one to the other, and for the discrepancy between this ratio and that in urine.

It cannot logically be assumed that the discrepancy is due to inadequate equilibration, since the experiments were carried out long after the equilibration period should have been attained (Edelman, 1953). Similarly, it is exceedingly difficult to rationalize the proposal that either sweat glands or lung epithelium differentiate between molecular D_2O and H_2O. Further exploration of the validity of these results and the mechanisms responsible for them is to be the subject of subsequent experimentation.

The estimation of D_2O lost by these routes during the equilibration period is critical in the calculation of true D_2O space. For the purpose of calculation, it was necessary to estimate the total amount of sweat and insensible water lost during the periods in question (see Appendix I). It was also necessary to assume a D_2O/H_2O ratio for these fluids which would be justified in light of the experiments described above. Consequently, it was deemed most reliable to choose a ratio which would relate the sweat and insensible water D_2O content to the concurrent urine ratio for each subject, rather than to select arbitrarily an absolute ratio to be used for all subjects. The ratio finally adopted was one which approximated the mean value (sweat ratio/urine ratio x 100) for each of the two above experiments; viz., that ratio which represented 60% of the concurrent urinary D_2O/H_2O ratio. For example, if the urine collected during the equilibrium (post) period contained D_2O in proportion to H_2O as 0.1000, the sweat and insensible water lost during that period were assumed to have a D_2O/H_2O ratio of 0.0600. In this fashion, the extrarenal D_2O loss was estimated, with the intent of increasing the accuracy of the final computation of D_2O-space.

Method of Calculation of D_2O Decrement in Experimental Period. A second procedure used in computation of total body water which requires description is the procedure for accounting for the influence of previously administered D_2O upon the urinary D_2O/H_2O ratios during a subsequent determination. It will be recalled that D_2O-space estimations were carried out twice on each subject; i.e., at the end of the pre-period and near the end of the experimental period. Although ten days or more elapsed between these two tests, D_2O from the first dose was still being excreted in the urine of all subjects at the time the second dose was administered. Therefore, it was necessary to assess quantitatively the effect which this residual D_2O would exert upon the ratios determined following the second administration. This was done by determining the decrement in the urinary D_2O/H_2O ratios of four subjects ("Decrement Controls") who received D_2O at the end of the pre-period, but not at the end of EXP II (Table III. 70). These ratios were plotted as a function of the mid-points of the collection periods on July 4, 5 and July 14, 15. Since the decrement in the ratios appeared to be linear on the latter dates, these data were extrapolated back to the mid-point of the post-D_2O period on July 4 by means of best

TABLE III. 70

CORRECTED URINARY D_2O/H_2O RATIOS FOR DECREMENT CONTROLS

Date	Specimen	Subject Number 40	58	91	101
July 4	Pre-D_2O	0.0000	0.0000	0.0000	0.0000
July 4	D_2O	0.1225	0.1312	0.1102	0.1182
July 5	Post-D_2O	0.1159	0.1214	0.1044	0.1124
July 14	Pre-D_2O	0.0328	0.0277	0.0231	0.0151
July 14	D_2O	0.0351	0.0284	0.0205	0.0105
July 15	Post-D_2O	0.0290	0.0225	0.0208	0.0041

fit of a line connecting the three July 14,15 ratios. The mean difference between observed and extrapolated July 4 post-D_2O period ratios was found to be -0.0388.

This factor was intended to be used in the correction of the urinary ratios of all subjects in the experimental test by a graphic method (see Appendix I for detailed description). It was proposed to extend a line from the value obtained by subtracting 0.0388 from the post-D_2O (July 4) ratio through the pre-D_2O (July 14) ratio as determined analytically. The values obtained at the intercept of this line with the mid-points of the D_2O and post-D_2O periods (July 14, 15) were to be subtracted from the analytically derived ratios. The value resulting from this subtraction would represent the true urinary D_2O/H_2O ratio caused by the second dose of D_2O, and could then be used in calculation of D_2O lost during these periods.

The validity of this method of correction for decrement was tested by several trial calculations on control (FRA) data. Since D_2O-spaces which had been determined on these subjects at the end of the pre-period (in which case the problem of decrement correction was not encountered) agreed well with values reported by us and by others on the basis of this and other techniques, it was decided to establish a method for decrement correction which would cause a minimum deviation of the experimental period D_2O spaces (expressed as % body weight) in these subjects from the pre-period values. With this purpose in mind, the first method tested was that described above; viz., graphic solution of the problem, using the value resulting from the subtraction of 0.0388 from the post-D_2O (July 5) mid-point ratio as the origin of the projected line. As a result of these calculations, the mean D_2O-space (% body weight) of the FRA subjects in the experimental period was found to be 70.7%, as compared to 68.8% in the pre-period. The computations were repeated, using the post-D_2O mid-point ratio (uncorrected) as the origin of the decrement line. The result was a mean experimental body water of 66.0% of body weight, again as compared with the pre-period value of 68.8%. These calculations were repeated a third time, using an intermediary correction factor, 0.0200, which resulted in a mean experimental value of 68.1% body weight. Since the agreement with the pre-period value was considered adequate, this value was finally adopted for calculation of all data obtained from the experimental subjects. In this fashion, the influence of the first D_2O administration upon the urinary D_2O/H_2O ratios of the second D_2O-space determination was assessed, and

accurate estimation of the latter entity was made possible.

Results. Pre-period measurement. The application of these methods and calculations according to the experimental design yields a series of data regarding total body water, as this compartment exists in normal men and is affected by the various restrictions and regimens to which the men were subjected. These data will be presented in several sections dealing with control (pre-period) measurements and changes in total body water brought about by the experimental treatments. Greatest emphasis will be placed upon the relationships among changes in D_2O-space, osmotic load of the regimens, and water diuresis, primarily as the latter two variables relate to the first.

In the pre-period measurements, the mean absolute total body water of the 99 subjects was found to be 46.82 liters, the range being 34.71 to 64.03 liters (Table III. 71A). When expressed as a proportion of the subject's body weight, the mean total body water becomes 69.7%; range, 56.9% to 79.5% of body weight (Table III. 71B). In order to facilitate interpretation of data obtained during

TABLE III. 71

PRE-PERIOD DATA ON BODY WATER

Flight	No.	Mean D_2O Space	s.d.	C.V.
		A. Liters D_2O Space		
1	22	45.86	4.44	9.68
2	22	43.74	4.21	9.63
3	22	47.63	4.97	10.43
4	22	47.94	3.92	8.18
FRA	11	51.00	5.49	10.76
		B. D_2O Space as % Body Weight		
1	22	69.0	4.42	6.40
2	22	68.5	5.14	7.54
3	22	68.9	4.37	6.34
4	22	72.8	3.89	5.22
FRA	11	68.8	4.87	7.08

"t" Test

No significant differences between flights or between flights and FRA.

the experimental period, regarding the effects of work performed, the control data from subjects grouped in flights were compared by the "t" test. When the grouped data were analyzed statistically, it was found that there were no significant differences between mean values among flights, or between any flight and the FRA subjects. It is evident in this table that there was, however, considerable individual variability both in the absolute body water and this compartment expressed as a percentage of body weight. Such variability is expected in a randomly selected group of subjects of widely different

physical characteristics, the most important of which, in this case, is degree of obesity (McCance et al., 1951).

Experimental period. Near the end of the experimental period, determination of the D_2O-spaces of the subjects yielded the results shown in Tables III. 72 and III. 73. In the light work group with free access to water, the mean total body water was 44.33 liters or 67.4% of body weight. In subjects who performed light work, but whose water intake was limited to 910 ml per day, the average deuterium oxide space was 41.58 liters, or 68.2% of body weight. Men who performed hard work during the experimental period, and whose water intake was restricted showed an average total body water of 42.46 liters (67.7% of body weight). In those who performed hard work and simultaneously received only 910 ml water per day these values become 37.74 liters and 63.5% of body weight. Great individual variation is shown in the ranges of these values. For the light work, unlimited water group, the ranges were 34.24 to 54.44 liters, 54.4 to 84.0% body weight; for light work, limited water group, 34.17 to 47.20 liters, or 62.5 to 73.9% of body weight. In the hard work unlimited water group, the ranges were 35.04 to 50.10 liters, or 55.3 to 78.6% body weight; for the corresponding limited water group, 30.62 to 45.73 liters, and 57.4 to 68.7% body water.

These data represent the sum total of the effects of all the various regimens and restrictions on the total body water; viz., dietary composition, caloric intake, water intake, and work load. In order that these variables may be segregated and evaluated, the combined data for each regimen are presented in Tables III. 72 and III. 73, expressed as D_2O space on an absolute (liter) basis and as a percentage of body weight. Since endogenous events occurring during caloric restriction are exceedingly difficult to assess or are entirely unknown, the data regarding changes in total body water as a function of body weight are difficult to interpret. Therefore, interpretative discussion will be based primarily on these changes as they occurred on an absolute (liter) basis.

Inspection of Table III. 72 reveals that limitation of water uniformly caused a decrease in total body water in both the light work and hard work groups. There was a tendency for the decrease to be intensified by hard work, but this was not true in every case. This relationship is complicated by the increased water allowance of the hard work groups which was necessitated by the excessive water loss caused by sweating. As pointed out in an earlier section, the water intake of the hard work group was increased to three canteens (2730 ml) per day on July 8, 48 hours after the beginning of the experimental period. At the same time, the water allowance of the light work group was increased to two canteens (1820 ml) per day. On July 11 the latter flight began to receive three canteens per day also. Subjects subsisting on experimental regimens which allowed free access to water demonstrated decreases in body water whether they were performing light work or hard work. There was a tendency for the decrease to be intensified by hard work, but the response in relation to work was extremely variable. In only two groups was there an increase in the absolute D_2O-space during the experimental period. These were the 15/52/33 3000 Hard Work group, and the 0/100/0 1000 Light Work group. These results are not in agreement

TABLE III. 72

BODY WATER
(D_2O Space in Liters)

Experimental Regimen		Hard Work PRE	Hard Work EXP	Hard Work Δ* (Pre-Exp)	Light Work PRE	Light Work EXP	Light Work Δ* (Pre-Exp)
ST 0	U	46.98	38.77	-6.78	49.41	42.83	-6.58
	L	41.78	34.86	-6.92	48.06	39.32	-8.74
0/100/0	U	41.05	40.00	-3.74	43.96	44.68	+0.72
1000	L	37.56	35.17	-2.39	50.34	39.03	-11.32
0/100/0	U	48.52	42.16	-6.36	49.26	47.13	-2.13
2000	L	43.33	39.23	-4.10	44.36	42.94	-3.06
2/20/78	U	45.99	47.30	-0.47	45.10	41.95	-2.67
1000	L	41.96	35.20	-6.76	45.92	40.57	-5.35
2/20/78	U	47.59	50.10	-0.97	44.11	43.78	-0.34
2000	L	45.03	40.22	-2.23	48.94	47.20	-3.50
15/52/33	U	46.72	44.49	-2.23	49.19	45.20	-3.98
1000	L	46.32	39.82	-4.95	45.43	43.19	-2.24
15/52/33	U	42.09	41.31	+0.65	52.76	50.77	-2.00
2000	L	-----	-----	-----	47.00	44.95	-2.06
15/52/33	U	41.19	38.44	-2.75	51.82	49.80	-2.02
3000	L	46.24	40.75	-5.49	-----	-----	-----
30/0/70	U	48.31	43.79	-4.51	44.18	37.39	-4.04
1000	L	46.69	41.46	-5.23	43.12	39.89	-3.24
30/0/70	U	49.13	44.48	-4.65	41.76	37.53	-4.23
2000	L	43.98	36.91	-7.08	51.67	48.43	-8.55
FRA		51.00	51.36	+0.49	51.00	51.36	+0.49

*Δ Calculated as mean of individual decrements, not as difference between mean Pre and Exp values.

TABLE III. 73

BODY WATER
(D_2O Space in % Body Weight)

Experimental Regimen		Hard Work PRE	Hard Work EXP	Hard Work (Pre-Exp) Δ*	Light Work PRE	Light Work EXP	Light Work (Pre-Exp) Δ*
ST 0	U	70.4	63.9	-4.6	71.1	67.6	-3.5
	L	68.1	62.8	-5.3	73.7	65.8	-7.9
0/100/0	U	65.6	63.5	-0.8	71.1	77.8	+6.8
1000	L	64.1	65.2	-0.5	76.6	63.3	-13.3
0/100/0	U	73.7	66.5	-7.3	69.4	69.3	-0.2
2000	L	62.2	59.7	-2.5	69.4	69.9	-0.7
2/20/78	U	69.6	77.0	+4.2	66.0	62.5	-0.1
1000	L	67.1	60.0	-7.1	71.3	66.9	-4.6
2/20/78	U	70.3	71.2	-1.5	63.4	63.2	-0.2
2000	L	69.3	64.7	-4.6	76.6	71.3	-3.8
15/52/33	U	65.9	67.0	+1.1	70.1	69.0	-1.1
1000	L	72.4	68.7	-4.3	70.3	70.6	+0.3
15/52/33	U	71.2	73.5	+2.8	69.5	69.7	-4.4
2000	L	----	----	----	72.4	71.0	-1.3
15/52/33	U	67.3	63.3	-4.0	69.4	68.2	-1.2
3000	L	72.5	65.5	-7.1	----	----	----
30/0/70	U	67.8	66.5	-1.3	65.5	62.4	-2.6
1000	L	65.1	61.8	-3.3	68.6	66.4	-1.2
30/0/70	U	67.4	64.1	-3.3	67.4	64.3	-3.2
2000	L	70.4	63.0	-7.5	76.9	68.3	-9.1
FRA		68.8	68.1	0.0	68.8	68.1	0.0

*Δ Calculated as mean of individual decrements, not as difference between mean Pre and Exp values.

with those of Sargent et al. (1955) who observed an increase of the total body water in all subjects subsisting on identical regimens, but exposed to environmental conditions of cold.

We have pointed out earlier that a relationship exists between osmotic excretion and change in total body water. In the cold-weather study, it was observed that the increase of total body water in subjects on unlimited water regimens followed a linear progression related directly to the osmotic load presented by the regimens. Thus, the increase of D_2O-space was greatest in regimens which were characterized by the highest osmotic loads and was least in those presenting low osmotic loads. No such clear relationships exist in the present results. In every case except two (see above), the men on unlimited water suffered a decrease in body water. According to the former results, it was thought that the greatest losses would occur at very low osmotic loads, while smallest losses were expected in high osmotic regimens. This is not the case. Greatest losses were suffered by ST O U subjects, in both Hard and Light Work groups. This regimen results in a low osmotic excretion. Losses were equally great in subjects in the 0/100/0 U Hard Work group, which also exhibits the lowest osmotic load. These results fit the hypothesis that at low osmotic loads, the subjects become osmotically depleted, and therefore exhibit salt-depletion hydropenia. However, here the agreement ends. Men on high osmotic load diets; e.g., 30/0/70 2000 Hard Work, exhibit decreases in D_2O-space comparable to that at the very low loads. Regimens imposing intermediate loads give highly variable results: 2/20/78 U Hard and Light Work groups show a mean decrease in body water of 0.66 liters, and an osmotic load of 506 μOsm/min; 15/52/33 1000 U Hard Work and Light Work groups, with an osmotic load only slightly lower (470 μOsm/min), demonstrate a decrease in body water of 3.11 liters. The relationship between osmotic excretion and D_2O-space in these subjects will be considered further in a subsequent section.

The results obtained from subjects on limited water are equally difficult to interpret. When related to osmotic load, it is seen that the decrement in D_2O-space tends to be greatest in the very high osmotic load regimens (30/0/70 2000, and 15/52/33 3000) and in the very low (0/100/0 1000 and 2000). In the former case, the hydropenia is presumed to be due to "pure water depletion", while the latter reflects salt-depletion. The regimens imposing intermediate osmotic loads present variable degrees of hydropenia presumably of the mixed salt and water type. In two regimens, 2/20/78 and 15/52/33, increase in the caloric level results in an apparent preservation of body water.

The effects of the various nutrient regimens on total body water expressed as % body weight are presented in Table III. 73. It is seen that limitation of water caused a decrease in the proportion of body water to body weight in every case except in the 15/52/33 1000 L regimen. It can be assumed therefore, that in these subjects, body water was lost at a higher rate than was tissue substance. Work load exerted no consistent influence upon these results, the loss in body water being greater in the Hard Work subjects on some regimens (0/100/0 2000 L and 2/20/78 1000 and 2000 L), while in other cases the reverse is true (0/100/0 1000 L and 30/0/70 2000 L). Similarly, in certain regimens, an increased caloric intake diminished body water loss (0/100/0 and 2/20/78), and in

others it caused an accentuation of the loss (30/0/70).

In the unlimited water groups, body water as a proportion of body weight in general decreased. These are, however, four exceptions; 0/100/0 1000 Light Work, 2/20/78 1000 Hard Work, 15/52/33 1000 Hard Work, 15/52/33 2000 Hard Work. Again, it can be seen that work load had an inconsistent effect.

There are, however, relationships to osmotic load. When expressed in this fashion, decreases in D_2O-space are again greatest at very high osmotic loads and in subjects whose osmotic excretion was very low. In regimens which result in intermediate osmotic loads, loss of body water is variable in degree.

It has been mentioned that the results presented here have failed to agree in several particulars with those of the winter study, while being confirmatory in other respects. The quantitative magnitude of extra-renal water loss in the present study, and complications arising from this source of variation are considered to be major causes of discrepancy. Even in the face of such disagreement in detail, several important general concepts have resulted from considerations of combined data from the two studies. These concepts will be presented in a subsequent section.

c. Water Diuresis

Pre-period Results. All subjects were given the water diuresis test according to the same procedures followed in the 1954 winter study. Two tests were conducted in the pre-period (Table III. 74). The mean values and the variability measures for the five groups of subjects were remarkably uniform. For two groups there were significant differences between the means of P I and P II. The large fall in net recovery for Flight 2 from 85.2% in P I to 54.4% in P II was in part due to the fact that these men took a four-mile march in the evening prior to the test at a time when the weather was very hot (4 July). Their canteens had been taken from them at supper that night. Since they had no access to water, the sweat loss during the march could not be replaced. This fact clearly brings out the sensitivity of this test as a measure of dehydration. The men on the Field Ration A also exhibited a significant decrease in net per cent recovery of the oral load in P II. These men served as KP's. They worked in a hot environment. The excessively hot weather on 4 July probably accentuated their dehydration at a time when they could not replace their sweat loss. Flights 1, 3, and 4 exhibited no significant changes. Two groups, 1 and 4 showed decreased recoveries, again probably due to the especially hot weather on the day prior to the second water diuresis test.

Control Subjects. Throughout the 36-days of the field test, men on Field Ration A performed moderate work in the mess halls and the clinical laboratory. They were allowed water ad libitum. That these subjects tended to maintain a reasonably constant state of hydration is brought out in the data of Table III. 75. Only in P I does the value for net recovery deviate much from 65%. It may be that the cool weather of P I caused the higher value. After P I the weather remained rather constantly hot.

Experimental Period Results. The experimental regimens provoked marked alterations in the renal response to the oral water load (Table III. 76; Figures III. 29 and III. 30). There is evidence that the work load affected the diuretic response of men on unlimited water. Regardless of which of the ten nutrient regimens the men were subsisting on, hard work tended to cause a greater decrease of net recovery from P II to EXP than did light work:

		Net Recovery, %	
		P II	EXP
Hard Work	U	72.8	52.5
Light Work	U	81.3	71.2

These data suggest that the men doing hard work were not voluntarily able to keep pace with dehydrating effects of sweating evoked by the greater work output. Inspection of the data reveals that this "voluntary" dehydration was not a function of nutrient regimen.

There is also evidence that osmotic load is related to the net % recovery of the oral water load. The diuretic response tended to be intensified in those regimens imposing high osmotic loads as compared to the response in subjects on lower osmotic load regimens. Though not universal, this tendency was fairly uniform.

Limitation of water evoked drastic changes in the diuretic response. Although work load exerted no consistent influence on the pattern of alteration, the influence of osmotic load was marked. In general, the findings of the 1954 winter study have been confirmed; viz., the data on water diuresis in men whose water intake was restricted were segregated into several distinct groups when related to osmotic load.

Low osmotic loads: In this study, low osmotic load regimens were 0/100/0 1000 and 2000. The mean recovery of the water load in subjects on these regimens with unlimited water was 58.5%; with limited water 53.3%. These values are not significantly different from the pre-period mean values on normally hydrated individuals. It has previously been determined (Sargent et al., 1955) that any diuretic effect exceeding 50% net recovery may be considered normal. Thus, a normal diuretic response was obtained in both groups in spite of the deficit of total body water suffered by each. The mean decreases in D_2O-space in these subjects were 2.88 liters in the U group and 5.22 liters in the limited water group. Failure of water limitation to lead to a marked antidiuretic response in these low osmotic regimens is attributed to the subjects' state of osmotic (salt) depletion.

High osmotic loads: In contrast to the above results, limitation of water on the highest solute load regimens, 30/0/70 2000 and 15/52/33 3000, was strongly antidiuretic. The mean net % recoveries of water loads in the limited water groups on these regimens was 7.5%, as compared with the data of their pair-fed mates on unlimited water, 78.0%. These results are interpreted as indicating a condition in which water was lost in excess of osmotically active substance in

the limited water group, who therefore demonstrate a water depletion hydropenia.

Comment: Thus, the diuretic responses of individuals subsisting on limited water regimens at extremes of the osmotic-load spectrum are clearly distinguished by the water loading test used in this study. Men who become hydropenic on regimens which impose very low solute loads are unable to retain water given in a single large dose. In contrast, man dehydrated by limitation of water but not simultaneously osmotically depleted retain practically all water administered in this way. It is of interest to point out that the latter condition obtains whether the large osmotic load consists primarily of inorganic material (15/52/33), or of nitrogenous compounds (30/0/70).

Intermediate osmotic loads: These regimens, in order of increasing load are: 2/20/78 1000 (372 μOsm/min), ST 0, 15/52/33 1000, 2/20/78 2000, 30/0/70 1000, and 15/52/33 2000 (557 μOsm/min). (See Table III. 67). When accompanied by limitation of water, these regimens segregate into two distinct groups according to the diuretic response studied. As osmotic loads grow progressively larger, the net % recovery of the water load becomes smaller, in a relationship described by a sigmoid curve. In the first three regimens above, the osmotic loads are 372, 402, and 470 μOsm/min; the corresponding mean % recoveries are 33.7, 42.3, and 25.1 respectively. In the remaining regimens with higher osmotic loads, mean recovery of the water load was uniformly less than 10%, and in most cases was 5% or less (Table III. 76). Thus, antidiuretic activity of a regimen is related to osmotic load in a fashion in which there is practically no transition phase, ability to retain a water load being abruptly distinguished from inability.

TABLE III. 74

PRE-PERIOD DATA ON WATER DIURESIS
(Net Recovery, %)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	78.8	19.4	24.6	21	71.7	17.2	24.0
2*	21	85.2	18.5	21.7	21	54.4	21.8	40.1
3	21	73.1	17.3	23.6	20	81.1	20.6	25.4
4	21	76.8	18.0	23.5	22	66.6	18.3	27.5
FRA**	12	78.6	14.9	19.0	11.	62.6	12.5	20.0

*P I vs. P II: $t = 4.89$, $P < 0.01$.
**P I vs. P II: $t = 2.68$, $P < 0.02$.

TABLE III. 75

WATER DIURESIS
AMONG MEN ON FIELD RATION A
(Net Recovery, %)

Period				
P I	12	78.6	14.9	19.0
P II	11	62.6	12.5	20.0
EXP I	11	68.3	16.2	23.8
REC I	14	67.2	18.9	28.1

TABLE III. 76

WATER DIURESIS
(Net Recovery, %)

Experimental Regimen		Hard Work				Light Work			
		P I	P II	EXP	REC	P I	P II	EXP	REC
ST O	U	76.9	60.2	38.0	73.7	74.0	78.6	49.4	76.3
	L	86.6	53.3	38.6	102.0	86.8	79.4	46.1	75.8
0/100/0	U	105.5	75.9	50.2	79.6	57.2	76.8	61.9	97.1
1000	L	100.5	37.1	48.1	79.3	81.3	73.1	47.4	71.4
0/100/0	U	85.5	81.6	53.8	92.2	59.2	81.1	65.7	80.3
2000	L	85.6	53.4	57.9	66.7	36.2	46.9	59.7	94.7
2/20/78	U	64.3	51.6	37.9	93.0	76.1	79.6	60.3	73.5
1000	L	100.0	28.0	33.4	57.0	92.0	59.1	34.1	86.3
2/20/78	U	88.5	93.8	67.4	----	67.0	76.6	70.9	57.3
2000	L	65.2	46.2	0.4	54.3	74.4	58.2	0.0	75.0
15/52/33	U	82.4	77.6	38.3	66.4	63.9	76.8	64.6	81.4
1000	L	65.9	61.2	37.0	70.5	78.5	76.0	13.2	88.2
15/52/33	U	92.8	57.9	66.2	66.2	71.9	89.3	74.6	78.4
2000	L	72.8	67.5	0.0	108.6	66.0	83.0	1.8	54.6
15/52/33	U	47.3	90.1	83.0	80.9	91.4	72.0	83.7	70.4
3000	L	91.8	73.9	13.9	85.6	71.7	63.7	----	----
30/0/70	U	87.0	65.5	32.9	73.8	95.4	76.5	92.8	89.6
1000	L	98.7	73.9	23.0	105.8	85.3	56.8	6.8	66.0
30/0/70	U	59.0	74.0	57.4	83.8	84.4	105.5	87.8	82.8
2000	L	83.7	50.4	8.6	77.3	85.7	56.6	0.0	85.7
FRA		78.6	62.6	68.3	67.2	78.6	62.6	68.3	67.2

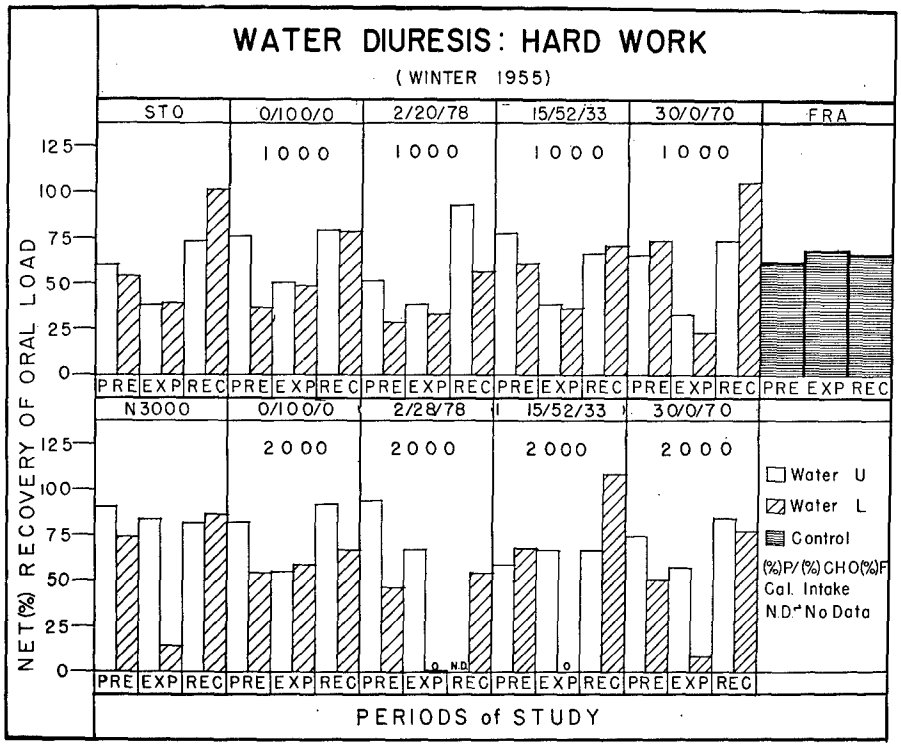


FIGURE III. 29. WATER DIURESIS: HARD WORK.

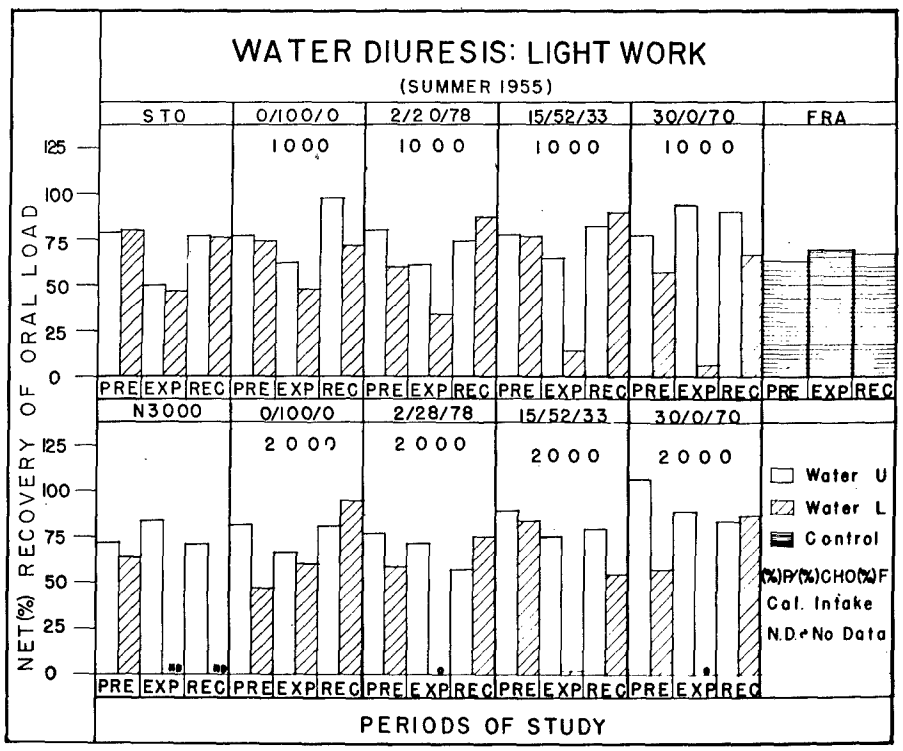


FIGURE III. 30. WATER DIURESIS: LIGHT WORK.

d. Interrelations among Osmotic State, Body Water, Water Balance, and Water Diuresis.

In order to assist the study of these several variables as functions of one another in a quantitative fashion, the summer data for each individual subject for water diuresis, osmotic excretion, and total body water have been tabulated (Tables III. 77, and III. 78). Further, we have combined the data for the winter study of 1954 and the summer study of 1955 (Table III. 79) to aid in the fitting of curves to the quantitative data (Figure III. 31).

Curves were fitted to the combined data in a fashion which was considered to express most accurately the relationship between two variables. The graphic relation between ΔD_2O space and osmotic excretion in the unlimited water subjects is best expressed by a linear correlation. The line has been plotted according to the method of least squares, and is described by the equation $Y = -4.087 + 0.0041X$, where Y represents ΔD_2O space and X represents osmotic excretion. Correlation between these two variables is high ($r = +0.82$). A similar linear relationship was found to exist between the net recovery of a water load (water diuresis) and osmotic excretion in subjects on unlimited water regimens. The linear relationship is expressed by the equation $Y = 47.6 + 0.0265X$, where Y is the % recovery and X the osmotic excretion. There is also a high degree of correlation between these two variables, $r = +0.99$.

In the limited water subjects, ΔD_2O space is related to osmotic excretion in such a manner that maximum changes in D_2O space occur at the extremes of the osmotic excretion range, loss of body water being minimum at a point between these extremes. The quantitative data suggest that this relationship can be described with some accuracy as an arc of a circle, the diameter of which is determined by both osmotic excretion and ΔD_2O space. Such an arc was circumscribed by the equation $(X - 510)^2/75 + (Y - 12)^2 = (7.5)^2$, where Y represents ΔD_2O space, X the osmotic excretion. The radius of the circle is expressed in the units of Y (liters). Note that the point for starvation was anomalous.

Data for the limited water groups regarding water diuresis and osmotic excretion can be fitted satisfactorily by a sigmoid relationship, which takes the form $R = -a(X - b)^{1/n} + c$ where: R is the per cent recovery of the water dose; a is related to the percentage recovery at very low osmotic excretion; b is the osmotic excretion at the point of maximum slope; n is a constant related to the rapidity with which the slope falls off between the two points of inflexion; and X is the osmotic excretion (Sargent and Johnson, 1956). The combined data can be closely fitted by the sigmoid equation $R = -21 [(X - 470)/100]^{1/5} + 28$. This relationship accurately describes the renal response to a water load in subjects on limited water whose osmotic excretion varied from very low to very high.

Although good mathematical correlation exists among the three variables when the combined data are considered, it has been pointed out that there are several points of disagreement between summer and winter data. A major disagreement was found between changes in D_2O space caused by the experimental regimens which allowed unlimited water intake. In the winter study, un-

limited water resulted in an increase in total body water in subjects on every nutrient mixture. This was not the case in the summer study; increases in body water occurred in only two regimens (see above). The discrepancy between the two series of data is interpreted as a reflection of the failure, by practically all of the men in the summer study, to keep pace with the extrarenal water loss (sweat) by voluntary ingestion of water, even though water was available in unlimited quantity.

Such an interpretation is supported by Table III. 73, in which D_2O-space is expressed as per cent body weight. Decrements expressed in this unit uniformly follow the absolute (liter) changes in direction, and in most cases there is also a quantitative relationship. For example, in the 15/52/33 2000 U Hard Work group, there was a mean increase in total body water of 0.65 liters, and a simultaneous increase in D_2O-space (% body weight) of 2.8%. In these subjects, water was evidently retained while tissue was being lost. In contrast, the mean decrease in D_2O-space in subjects on 0/100/0 2000 U Hard Work was 6.36 liters, while a decrease of body water in proportion to body weight amounted to 7.3%. These men evidently lost water at a rate only slightly lower than that at which body tissue was destroyed. The latter case is further complicated by "voluntary dehydration," a phenomenon observed by Sargent et al. (1955). Subjects subsisting on very low osmotic regimens voluntarily dehydrate themselves by decreased water intake conditioned by lack of thirst.

A further explanation for the discrepancy may lie in the method of calculation of extrarenal D_2O loss in the winter subjects. The quantity of water lost by this route was estimated by the method outlined in Appendix I of this report, but the D_2O/H_2O ratio of this fluid was assumed to be identical with that of the urine. Thus, the D_2O lost via this route was probably overestimated, with the result that the final dilution of D_2O remaining in the body was probably overestimated as well. The magnitude of overestimation, however, is probably so small as to be ineffective in explaining the gross differences in the two series of data.

For purposes of evaluating the accuracy of methods used in the summer study, total water deficit incurred by each subject during the period between the two D_2O-space measurements was calculated by a method similar to, but not identical with that employed by Gamble (1947). Daily water balance was estimated for each day during the period, and the cumulative negative balances for men on each regimen were computed over the appropriate period of time that elapsed between the two body water determinations. When these data are compared with the decrements in D_2O-space presented in Table III. 72, it was found that the two methods were mutually confirmatory. Calculated net water deficit is related linearly to measured ΔD_2O-space, the line describing the relationship being expressed by the equation $Y = 6.95 + 0.59X$, where Y is the calculated net water deficit (liters), and X represents ΔD_2O-space (liters). The coefficient of correlation between the two variables is +0.49 (P less than 0.05). A marked degree of variability exists: s.d. of Y on X is 2.25 liters.

Although there is good agreement between these two methods, it is seen that the calculated water deficit exceeds the measured deficit by some 7 liters.

If the D_2O-space data are presumed to represent the true loss in total body water, then the calculated deficit has been overestimated by the above value. Such overestimation probably resulted in the process of computation of sweat loss during the period in question. Thus, although the calculated total water deficit is probably in error on an absolute basis, the relative position of each regimen on a comparative scale is not altered.

Before considering further the relationships expressed in Figure III. 31, it seems appropriate to review the theoretical concepts of Pandazi (1954) and Sargent and Johnson (1956) regarding the mathematical expression of the interdependence which exists among osmotic state of the body, total body water, and diet. The mathematical expression involves four variables: (1) O, the osmotic content of the body; (2) V, the total body water; (3) C, the total body osmotic concentration (O/V); and (4) R, the net per cent recovery in four hours of a water load equivalent to two per cent of the body weight. For purpose of discussion, the expression becomes $C = O/V$. (The significance of R will be pointed out subsequently). This mathematical expression can be used to describe in quantitative terms certain of the homeostatic mechanisms which serve to maintain total body water (or compensate for water loss), and regulate the bodily osmotic state.

Thus, in a situation in which body water is lost by water deprivation, and osmotic content is maintained or increased by dietary intake (as in the 30/0/70 2000 L subjects), the expression becomes $C_1 = O_1(V - \Delta V)$, where ΔV represents the volume of water lost. In such a state of water deprivation hydropenia, replacement of ΔV by a water load would result in a retention of the ingested water. R then becomes a function of ΔV; if the water load volume were less than ΔV, R would be very low. Experimental evidence supporting this point is presented in Figure III. 31; viz., in limited water subjects who demonstrated a high osmotic load and in whom % recovery was low.

Conversely, when water and osmotic depletion occur simultaneously, as in subjects subsisting on limited water and a low osmotic regimen (0/100/0), the equation becomes $C_2 = O - \Delta O/(V - \Delta V)$. Thus, if an attempt were made to replace ΔV by an oral water load, the load would be excreted to prevent further depression of O. Therefore, R would be high. This condition is represented by subjects on limited water whose osmotic excretion is very low (Figures III. 31).

In a normally hydrated, well fed subject, administration of a water load would cause the equation to be $C = O/(V + \Delta V)$; i.e., it would tend to decrease the value C by dilution, and it is therefore excreted. The FRA subjects (controls) exhibit this type of response to a water load in Figure III. 31

It is implied that those homeostatic mechanisms which are responsible for regulation of body water and osmotic state operate in some fashion to maintain that entity which has been ascribed as "C" in the above mathematical treatment at a constant value. Although considerable variation in body water volume can be tolerated, great effort is exerted to prevent changes in the osmotic pressure of body fluids (Gaunt and Birnie, 1951). Regulation of

osmotic pressure is achieved primarily by regulation of rates of water and salt excretion. In both of these functions, the kidney represents a sort of gyroscopic control designed to maintain internal constancy in the face of wide variations in extrarenal osmotic and water losses. However, renal regulation of water loss and salt (osmotic) loss is conditioned by modifying influences of the endocrine system, through the posterior pituitary and adrenal glands. Furthermore, functions of both the kidney and the endocrine regulating mechanisms are themselves controlled by dietary intake of osmotic material and water. Thus, discussion of the homeostatic control of total body water and osmotic state becomes exceedingly complex. Inasmuch as such a discussion must include data regarding renal function, osmotic intake and excretion, voluntary water intake, water diuresis, and total body water, in a subsequent section we will correlate these variables in a speculative treatment of the functional organization of the systems involved.

From a consideration of the data described in Figure III. 31, one interesting generalization can be made. Heretofore, the three variables—total body water, water diuresis, and osmotic excretion—were considered to be independent. However, it is evident in the figure that in either of the two populations (unlimited water or limited water), the three variables are mathematically not independent but are interrelated. When one of the three is considered, then the other two are no longer separate and distinct entities, but are mathematically related to the first.

Important aspects of this mutual interdependence are illustrated by the limited water groups. It was thought earlier that state of hydration could not be accurately predicted by the renal response to a water loading test in subjects exhibiting a low osmotic excretion. It is seen, however, that if the osmotic excretion is low and the diuretic effect of water is pronounced, then an individual who has been subjected to water deprivation will be in a state of hydropenia of predictable degree. Conversely, knowing the state of hydration and rate of osmotic excretion, the renal response to water can be predicted.

It was pointed out in the previous section of this report that subjects subsisting on high osmotic regimens with limited water were sharply distinguished from those on low osmotic regimens with respect to the diuretic effect of a water load. The sigmoid relationship between the two variables, osmotic excretion and water diuresis, is shown in Figure III. 31. The steep slope of the curve has been remarked upon earlier. Attention is called to the diuretic response (% recovery) in subjects whose osmotic excretion is 400 μOsm/min. This value (49% recovery) lies within the range of values obtained on normally hydrated individuals, who were presumably in osmotic balance (pre-period tests). When the osmotic excretion is increased to 470 μOsm/min, the net % recovery becomes 25%, a value abnormally low. This point coincides with the mid-point of the slope between the two points of inflexion. At an osmotic excretion of 500 μOsm/min, the diuretic action of the water load has almost disappeared (net recovery: 10%). We interpret these findings as an indication that the narrow range of osmotic excretion, 450 to 500 μOsm/min, represents a critical minimum rate of excretion of osmotic substance, below which

the renal tubule fails to perform its water-conserving function even in the face of severe bodily dehydration.

The reflection of this influence of osmotic load on renal water reabsorption is evident in the changes in total body water in these subjects. It is shown in the accompanying figure that a minimum degree of hydropenia was produced by water deprivation in those subjects who subsisted on regimens providing osmotic material for excretion at the rate of approximately 500 μOsm/min. In these men, the renal reabsorption of water was very efficient (see above). At higher rates of osmotic excretion, hydropenia became progressively more severe as osmotic load increased. A similar response though opposite in direction, was noted in lower osmotic loads. In the former case, dehydration presumably was of the water deprivation type; in the latter, of the mixed salt and water variety. Thus, the ideal regimen for individuals whose water intake must be restricted should include osmotic substances in amount sufficient to provide a rate of osmotic excretion within the above critical range if the body water is to be preserved to an optimal degree.

This conclusion fails to agree with those of Gamble (1947) and many other investigators, who advocate the use of pure carbohydrate (low osmotic) regimens for the purpose of preservation of body water during water restriction. Although it is true that low osmotic regimens permit small minimum daily urine volume, the present results indicate that they do not prevent salt-depletion dehydration.

It should be noted that the ST 0 regimen has been distinguished from all other regimens in Figure III. 31. This has been done because observations upon starving subjects have frequently failed to comply with theoretical principles, or to correspond with results on diets similar to ST 0 in certain respects. It has therefore been omitted, as anomalous, in many formulations of general hypotheses. We feel this omission is justifiable because of the multitude of poorly understood concomitants of starvation. In this connection, it is of interest to point out that these data support Gamble on one point. It is obvious (Figure III. 31) that when water is restricted, a low osmotic regimen (pure carbohydrate) causes a relatively lower (but still severe) hydropenia than does starvation. Many of Gamble's conclusions are based on comparisons between carbohydrate regimens and starvation. It is clear from the present data that neither of these two regimens is desirable in conditions which force water restriction.

TABLE III. 77

WATER DIURESIS TEST, OSMOTIC EXCRETION, AND TOTAL BODY WATER: HARD WORK

Experimental Regimen		Subject	Water Diuresis Test (% Recovery) PRE II	EXP	Δ	Osmotic Excretion (mOsm/min) PRE II	EXP II	Δ	Total Body Water (liters) PRE II	EXP	Δ
ST O	U	1	36.6	2.2	-34.4	618	331	-287	44.04	36.25	-2.79
		2	75.6	----	-----	568	---	----	51.25	-----	-----
		3	63.0	53.8	- 9.2	704	443	-261	40.19	35.04	-5.15
		4	65.9	58.1	- 7.8	818	355	-463	52.43	45.03	-7.40
	L	23	73.5	28.7	-44.8	633	341	-292	44.94	40.18	-4.76
		24	33.9	29.2	- 4.7	559	643	+ 84	41.63	30.62	-11.01
		25	37.0	41.9	+ 4.9	466	567	+101	44.61	36.82	-7.79
		26	69.1	54.6	-14.5	863	396	-467	35.93	31.82	-4.11
0/100/0 1000	U	5	64.1	31.2	-32.9	974	61	-913	38.35	-----	-----
		6	87.8	69.2	-18.6	1109	249	-860	43.74	40.00	-3.74
	L	27	5.1	41.2	+36.1	425	69	-356	34.71	32.22	-2.49
		28	69.2	55.2	-14.0	913	300	-613	40.40	38.11	-2.29
0/100/0 2000	U	7	64.4	59.0	- 5.4	912	255	-657	53.71	46.91	-6.80
		8	98.9	48.7	-50.2	852	106	-746	43.33	37.41	-5.92
	L	29	48.1	46.4	- 1.7	634	247	-387	48.08	43.13	-4.95
		30	58.6	69.3	+10.7	479	177	-302	38.57	35.33	-3.24
2/20/78 1000	U	13	49.0	16.9	-32.1	965	313	-652	44.20	-----	-----
		14	54.2	58.9	+ 4.7	870	393	-477	47.77	47.30	-0.47
	L	35	33.5	53.7	+20.2	365	366	+ 1	41.26	34.68	-6.58
		36	22.5	13.2	- 9.3	1014	198	-816	42.66	35.72	-6.94
2/20/78 2000	U	15	85.1	72.6	-12.5	906	458	-448	51.07	50.10	-0.97
		16	102.6	62.3	-40.3	1234	605	-629	44.11	-----	-----
	L	37	63.3	0.9	-62.4	656	298	-358	43.49	39.55	-3.94
		38	29.2	0.0	-29.2	652	321	-331	46.57	40.88	-5.69

TABLE III. 77 (Contd.)

WATER DIURESIS TEST, OSMOTIC EXCRETION, AND TOTAL BODY WATER: HARD WORK

Experimental Regimen		Subject	Water Diuresis Test (% Recovery) PRE II	EXP	Δ	Osmotic Excretion (mOsm/min) PRE II	EXP II	Δ	Total Body Water (liters) PRE II	EXP	Δ
15/52/33	U	17	71.7	36.4	-35.3	1079	544	-535	49.15	45.22	-3.93
1000		18	83.6	40.2	-43.4	932	348	-584	44.28	43.76	-0.52
	L	39	68.0	37.0	-31.0	664	480	-184	44.77	39.82	-4.95
		40	54.4	----	-----	----	---	----	47.86	-----	-----
15/52/33	U	19	43.5	64.6	+21.1	1132	739	-393	40.66	41.31	+0.65
2000		20	72.3	67.9	- 4.4	986	494	-492	43.51	-----	-----
	L	41	56.8	----	-----	541	---	----	44.96	-----	-----
		42	78.3	0.0	-78.3	776	629	-147	47.93	-----	-----
15/52/33	U	21	92.0	69.8	-22.2	1093	788	-305	41.87	38.88	-2.99
3000		22	88.6	96.2	+ 7.6	969	912	- 57	40.50	37.99	-2.51
	L	43	59.2	24.2	-35.0	639	888	+249	47.57	42.73	-4.84
		44	88.7	3.6	-85.1	673	904	+231	44.90	38.77	-6.13
30/0/70	U	9	59.3	40.4	-18.9	994	767	-227	51.44	42.84	-8.60
1000		10	71.7	25.5	-46.2	758	764	6	45.17	44.75	-0.42
	L	31	50.8	----	-----	849	606	-243	50.84	45.73	-5.11
		32	97.0	23.0	-74.0	1318	687	-631	42.53	37.19	-5.34
30/0/70	U	11	78.0	58.4	-19.6	1222	959	-263	46.40	42.50	-3.90
2000		12	70.1	56.4	-13.9	1097	1085	- 12	51.85	46.46	-5.39
	L	33	61.4	0.0	-61.4	612	658	+ 46	46.12	37.89	-8.23
		34	39.5	17.3	-22.2	519	854	+335	41.84	35.92	-5.92
FRA		90	72.2	88.8	+16.6	763	926	+163	50.15	52.49	+2.34
		91	51.6	68.5	+16.9	1351	1692	+341	54.22	-----	-----
		92	68.7	72.6	+ 3.9	606	727	+121	41.73	47.21	+5.48
		94	50.2	39.6	-10.6	2790	1201	-1589	54.03	56.81	+2.78
		95	47.2	63.8	+16.6	645	973	+328	53.27	52.07	-1.20
		102	----	----	-----	----	---	-----	-----	41.79	-----

TABLE III. 78

WATER DIURESIS TEST, OSMOTIC EXCRETION, AND TOTAL BODY WATER: LIGHT WORK

Experimental Regimen		Subject	Water Diuresis Test (% Recovery) PRE II	EXP	Δ	Osmotic Excretion (mOsm/min) PRE II	EXP II	Δ	Total Body Water (liters) PRE II	EXP	Δ
ST 0	U	45	93.9	30.7	-63.2	922	276	-646	42.85	37.28	-5.57
		46	38.8	49.0	+10.2	933	326	-607	52.59	47.45	-5.14
		47	94.9	60.8	-34.1	991	286	-785	52.21	41.27	-10.94
		48	107.5	68.6	-38.9	1506	216	-1290	52.47	47.13	-5.34
		54	57.9	38.3	-19.6	802	360	-442	46.92	41.01	-5.91
	L	67	82.6	63.7	-18.9	829	358	-471	45.12	34.79	-10.33
		68	74.4	49.5	-24.9	661	379	-282	48.23	39.52	-8.71
		69	78.1	56.5	-21.6	495	398	-97	48.79	40.40	-8.39
		70	82.8	14.7	-68.1	771	408	-363	50.08	42.57	-7.51
0/100/0 1000	U	49	91.0	51.8	-39.2	589	167	-422	48.41	49.32	+0.91
		50	62.7	72.1	+ 9.4	866	125	-741	39.51	40.03	+0.52
	L	71	62.9	37.8	-25.1	717	208	-509	47.02	36.79	-10.23
		72	83.3	57.1	-26.2	599	177	-422	53.66	41.26	-12.40
0/100/0 2000	U	51	78.6	83.5	+ 4.9	708	173	-535	50.71	46.88	-3.83
		52	83.6	42.2	-41.4	855	107	-748	51.37	47.09	-4.28
	L	73	72.9	59.7	-13.2	568	137	-431	43.01	41.82	-1.19
		74	20.9	71.6	+50.7	748	147	-601	45.70	40.72	-4.92
2/20/78 1000	U	57	78.1	60.3	-17.8	787	327	-460	44.62	41.95	-2.67
		58	81.1	----	-----	662	---	----	45.58	-----	-----
	L	79	60.4	30.6	-29.8	682	461	-221	46.18	40.15	-6.03
		80	57.9	37.6	-20.3	717	356	-361	45.65	40.98	-4.67
2/20/78 2000	U	59	81.1	72.4	- 8.7	---	541	----	40.94	46.96	+6.02
		60	72.2	69.4	- 2.8	454	380	-74	47.28	40.59	-6.69
	L	81	71.8	0.0	-71.8	614	573	-41	50.70	47.20	-3.50
		82	44.6	0.0	-44.6	1501	---	----	47.17	-----	-----

TABLE III. 78 (Contd.)

WATER DIURESIS TEST, OSMOTIC EXCRETION, AND TOTAL BODY WATER: LIGHT WORK

Experimental Regimen		Subject	Water Diuresis Test (% Recovery) PRE II	EXP	Δ	Osmotic Excretion (mOsm/min) PRE II	EXP II	Δ	Total Body Water (liters) PRE II	EXP	Δ
15/52/33	U	61	94.3	60.1	-34.2	932	557	-375	50.67	48.95	-1.78
1000		62	59.3	69.1	+ 9.8	956	378	-578	47.70	41.53	-6.17
	L	83	93.4	12.2	-81.2	984	446	-538	48.00	44.56	-3.44
		84	58.7	14.2	-44.5	670	372	-298	42.85	41.82	-1.02
15/52/33	U	63	70.2	66.7	- 3.5	859	660	-199	50.13	44.79	-5.34
2000		64	108.4	82.4	-26.0	1146	706	-440	55.39	56.74	+1.35
	L	85	86.1	----	-----	481	377	-104	47.28	45.29	-1.99
		86	79.9	1.8	-78.1	444	423	- 21	46.72	44.60	-2.12
15/52/33	U	65	43.3	76.6	+33.3	730	546	-184	48.33	45.16	-3.17
3000		66	100.6	90.8	- 9.8	1167	704	-463	55.31	54.44	-0.87
	L	87	39.1	----	-----	807	---	-----	57.34	-----	-----
		88	88.3	----	-----	780	---	-----	51.59	-----	-----
30/0/70	U	53	76.5	92.8	+16.3	678	343	-335	41.43	37.39	-4.04
1000	L	75	78.4	2.4	-76.0	537	485	- 52	46.58	45.60	-0.98
		76	35.2	11.3	-23.9	574	423	-151	39.66	34.49	-5.49
30/0/70	U	55	101.9	90.0	-11.9	995	506	-489	36.17	34.24	-1.93
2000		56	109.1	85.6	-23.5	1054	714	-340	47.34	40.82	-6.52
	L	77	60.4	----	-----	-----	---	-----	48.87	-----	-----
		78	52.9	0.0	-52.9	648	595	- 53	54.47	45.92	-8.55
FRA		96	71.2	86.6	+15.4	1000	1123	+123	64.03	65.36	+1.33
		97	57.9	89.1	+31.2	597	741	+144	47.00	47.02	+0.02
		98	80.0	83.4	+ 3.4	797	793	- 4	45.65	46.43	+0.78
		99	44.8	30.4	-14.4	421	508	+ 87	48.88	49.58	+0.70
		100	62.9	56.1	- 6.8	535	630	+ 95	51.76	45.30	-6.46
		101	81.9	92.8	+10.9	723	719	- 4	50.27	-----	-----

TABLE III. 79

WATER DIURESIS, OSMOTIC EXCRETION, AND ΔD_2O SPACE
COMBINED DATA; WINTER 1954, SUMMER 1955
MEAN, ALL SUBJECTS

Experimental Regimen		No. of Subjects	Water Diuresis Test Exp II (Net % Recovery)	Osmotic Excretion Exp II (MOsm/min)	ΔD_2O Space Pre-Exp (liters)
ST 0	U	15	49.2	371	-4.53
	L	15	49.5	435	-8.48
0/100/0	U	8	57.2	173	-2.92
1000	L	8	48.4	207	-7.15
0/100/0	U	7	52.5	191	-3.59
2000	L	8	63.4	188	-4.95
2/20/78	U	6	62.0	448	-1.17
1000	L	8	47.0	393	-5.48
2/20/78	U	8	70.8	612	+0.28
2000	L	8	9.7	527	-5.35
15/52/33	U	7	55.0	458	-1.97
1000	L	7	32.3	428	-4.40
15/52/33	U	8	65.2	826	+0.08
2000	L	5	0.0	567	-3.44
15/52/33	U	8	76.1	727	-0.79
3000	L	6	10.3	881	-5.61
30/0/70	U	7	58.2	686	-2.47
1000	L	7	6.8	585	-4.80
30/0/70	U	8	70.7	828	-2.06
2000	L	7	6.5	886	-797
FRA		21	71.2	884	+1.13

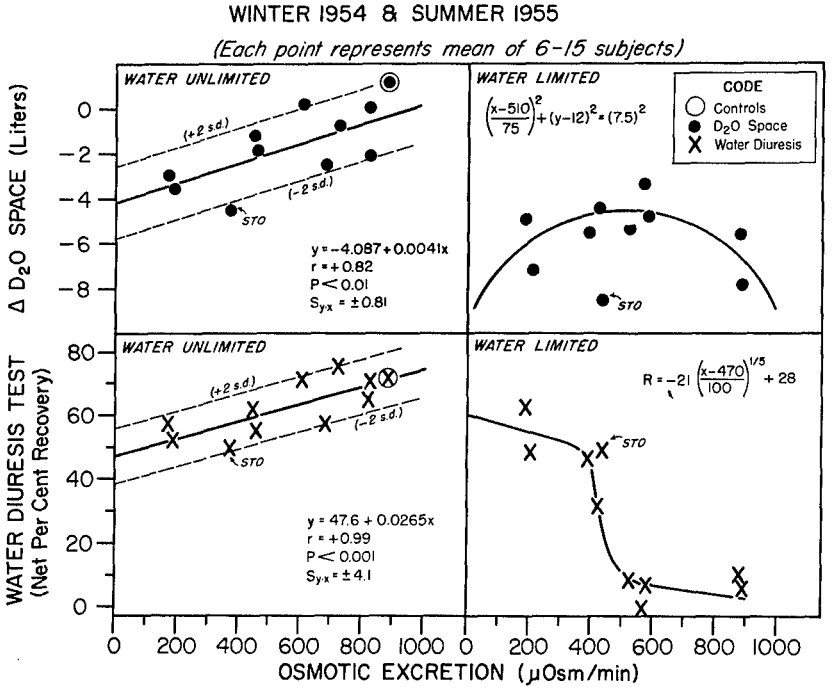


FIGURE III. 31. WATER DIURESIS, OSMOTIC EXCRETION, AND ΔD_2O SPACE. COMBINED DATA: WINTER 1954, SUMMER, 1955, MEAN ALL SUBJECTS.

3. Body Fat

Previous experience (WADC TR 53-484, Part 2) indicated that measurement of skinfold thickness by different individuals introduced wide variations into the estimates of body fat on the same subject. For this reason, during the summer study, all measurements were made by one individual (F.S.). If personal errors were made, they were at least constant. Therefore, we feel that the data collected during this study are much more reliable and consistent than those collected during winter study of 1954.

The pre-period data on body fat are given in Table III. 80. Insofar as per cent body fat is concerned there is reasonably close agreement among the five groups (Table III. 80A). The differences that are present correlate well with body weight. The lightest flight--Flight 2--is the leanest and the heaviest group--FRA--is the fattest. Three groups--Flights 2 and 4, and FRA--gain body fat during the pre-period. The other two groups do not change significantly. Similar trends are evident in the data for kilograms of body fat (Table III. 80B). Here, however, the variations are smaller in magnitude.

Effect of Experimental Regimens. Data on per cent body fat are detailed in Table III. 81. Inspection of the table indicates that only small variations occurred. Per cent body fat tended to decrease during the experimental periods and to increase again in recovery. In general, the men were leaner at the end of recovery than they had been when the investigation began. Work load did not play a large role, nor did nutrient regimen. There is a suggestion that less fat was lost by men on limited water than by men on unlimited water.

Turning to absolute changes in body fat (Tables III. 82), we find striking confirmation of these observations. In order to clarify the trends and more fully to evaluate the influence of work load, nutrient regimen, and water, Table III. 83 has been prepared. There we show the per cent decrease in kilograms of body fat from the pre-period to EXP II. The data were calculated from the following equation:

$$\% \text{ Decrease} = 100x \frac{(\text{av. kg Body Fat in P I + P II}) - (\text{kg Body Fat in EXP II})}{(\text{av. kg Body Fat in P I + P II})}$$

Examination of Table III. 83 brings out several significant facts. (1) Men on starvation lost the greatest amount of fat. (2) Men on 1000-Calorie regimens tended to lose more body fat than those on 2000-Cal/day. (3) Work load did not consistently modify magnitude of fat loss. (4) Men on limited water lost less fat than men on unlimited water. This last observation was true for eight of ten hard work regimens and five of nine light work regimens. The reason for this effect of work is not at once apparent, but a working hypothesis is that differences in degree of dehydration may account for it. We, at any rate, consider that the data confirm a conclusion reached in the temperate study of 1953. Limitation of water alters tissue turgor in such a way as to yield an apparent increase in body fat or to reduce the magnitude of the decrease that would have been measured had dehydration not been present. Basically then the changes in skin-fold thickness cannot be used accurately to calculate changes in body fat when there are concurrent swings in tissue hydration.

TABLE III. 80

PRE-PERIOD DATA ON BODY FAT

Flight	P I M	P I Range	P II M	P II Range
		A. Per Cent Body Fat		
1	5.1	2.5-16.3	5.1	3.0- 8.9
2	4.8	3.0-10.0	5.6	2.8-11.9
3	6.2	3.0-11.5	6.0	3.5-11.1
4	5.0	3.0-11.5	5.6	3.0-15.0
FRA	5.8	3.2-13.2	6.7	2.6-12.7
		B. kg Body Fat		
1	3.6	1.6-14.6	3.4	1.7- 7.3
2	3.2	1.7- 8.3	3.7	1.8- 9.8
3	4.4	2.1- 8.8	4.2	2.4- 8.6
4	3.4	1.8-10.2	3.8	2.1-13.3
FRA	4.3	2.1-11.4	5.1	2.6-12.7

TABLE III. 81

PER CENT BODY FAT

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	4.3	4.6	4.1	5.6	4.8	4.5	6.1	6.3	5.1	4.3	5.0	5.5
	L	5.0	6.2	5.1	4.4	6.0	5.7	4.6	5.0	4.0	4.0	4.5	4.7
0/100/0	U	4.6	5.0	4.2	5.2	5.9	5.9	5.8	5.2	5.0	5.0	5.2	5.2
1000	L	5.7	7.2	5.5	5.6	7.0	6.2	5.0	5.4	4.6	4.4	4.8	5.4
0/100/0	U	5.1	5.5	5.6	5.1	5.1	5.4	5.9	5.3	5.1	4.6	5.5	6.1
2000	L	4.2	4.4	4.0	4.2	4.6	3.9	3.5	3.6	3.4	3.1	3.6	3.7
2/20/78	U	3.5	4.2	3.3	2.6	3.5	3.3	6.2	5.8	5.6	5.2	5.6	5.2
1000	L	5.1	5.9	5.6	5.0	5.2	5.2	5.0	5.8	5.0	4.6	4.4	4.8
2/20/78	U	4.2	5.0	4.6	4.5	4.7	---	8.7	8.6	7.2	7.0	7.0	7.2
2000	L	5.0	4.2	4.8	4.8	4.4	4.7	4.4	4.6	4.1	3.5	3.8	3.7
15/52/33	U	9.6	9.6	8.4	8.4	8.4	7.8	4.4	4.8	4.6	4.0	4.3	4.4
1000	L	3.4	4.4	4.4	4.0	---	---	5.5	6.5	5.4	5.0	5.2	5.9
15/52/33	U	4.0	4.6	4.6	4.1	5.2	5.0	4.6	4.2	4.2	4.0	4.0	4.1
2000	L	4.0	4.3	4.8	5.5	5.5	5.5	4.6	5.2	4.3	4.1	4.9	4.6
15/52/33	U	4.1	4.8	4.2	4.1	4.6	4.6	6.8	7.6	8.0	7.6	6.8	7.6
3000	L	3.4	3.8	3.8	3.6	3.9	3.9	7.8	9.5	---	---	---	---
30/0/70	U	5.2	6.0	6.0	5.4	5.1	6.0	11.5	10.2	8.8	8.8	9.0	8.2
1000	L	7.5	9.0	7.2	5.2	5.5	5.3	5.8	6.8	5.2	5.2	5.2	6.0
30/0/70	U	7.8	7.8	7.8	6.8	7.3	7.4	4.6	4.1	4.2	3.9	4.2	4.6
2000	L	4.6	5.2	4.6	4.6	4.5	4.6	4.0	4.0	3.1	2.8	3.6	4.0
FRA		5.8	6.7	6.6	6.6	6.8	6.6	5.8	6.7	6.6	6.6	6.8	6.6

TABLE III. 82

KILOGRAMS BODY FAT

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	2.8	3.1	2.5	3.3	3.1	3.0	4.3	4.4	3.3	2.9	3.4	3.8
	L	3.4	4.2	3.2	2.7	4.0	3.9	3.0	3.3	2.4	2.3	3.0	3.1
0/100/0	U	2.9	3.2	2.6	3.3	3.8	5.9	3.6	3.2	3.0	2.8	3.1	3.2
1000	L	3.5	4.4	3.2	3.2	3.6	3.8	3.3	3.6	3.0	2.6	3.1	3.6
0/100/0	U	3.4	3.6	3.5	3.2	3.2	3.4	4.4	3.9	3.6	3.2	4.0	4.5
2000	L	2.9	3.0	2.6	2.7	3.1	2.8	2.4	2.3	2.0	2.3	2.5	2.6
2/20/78	U	2.3	2.8	2.1	1.6	2.3	2.2	4.3	4.0	3.7	3.5	3.9	3.7
1000	L	3.2	3.8	3.3	3.0	3.2	3.2	3.2	3.7	3.1	2.8	2.8	3.0
2/20/78	U	2.8	3.4	3.1	3.2	3.3	---	6.6	6.4	5.2	5.2	5.2	5.4
2000	L	3.3	2.8	3.0	3.0	2.8	3.2	3.0	2.9	2.6	2.3	2.6	2.5
15/52/33	U	8.2	8.2	6.6	6.5	6.6	6.2	3.1	3.4	3.2	2.6	3.0	3.0
1000	L	2.1	3.1	2.5	2.3	---	---	3.6	4.2	3.4	3.1	3.4	3.8
15/52/33	U	2.3	2.6	2.6	2.3	3.0	2.8	3.4	3.2	3.1	3.0	3.0	3.2
2000	L	2.5	2.8	3.0	3.5	3.6	3.7	3.0	3.4	2.7	2.6	3.2	3.0
15/52/33	U	2.6	3.0	2.6	2.5	2.9	2.8	5.2	6.0	5.8	5.5	5.1	5.7
3000	L	2.2	2.4	2.4	2.2	2.4	2.5	6.4	8.0	---	---	---	---
30/0/70	U	4.0	4.6	4.4	3.8	3.8	4.5	7.4	6.5	5.3	5.3	5.6	5.1
1000	L	5.7	6.8	5.0	3.0	3.3	3.3	3.8	4.4	3.2	3.2	3.3	3.9
30/0/70	U	5.6	5.7	5.5	4.7	5.3	5.4	2.8	2.6	2.4	2.3	2.6	2.9
2000	L	2.8	3.2	2.6	2.8	2.8	2.8	2.6	2.6	2.1	1.9	2.6	2.9
FRA		4.3	5.1	5.0	4.9	5.2	5.0	4.3	5.1	5.0	4.9	5.2	5.0

TABLE III. 83

PER CENT LOSS OF BODY FAT DURING EXPERIMENTAL PERIOD: ALL REGIMENS

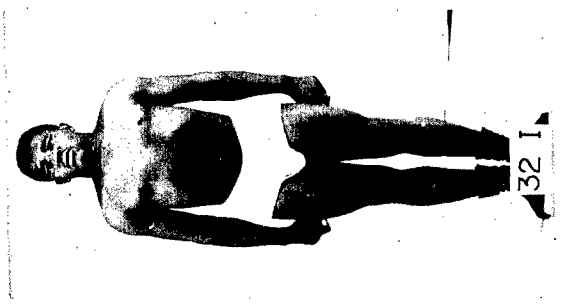
Nutrient Regimen	Hard Work		Light Work	
	U	L	U	L
ST 0	29.0 (1)*	30.6 (4)	37.7 (5)	24.2 (2)
0/100/0 1000	22.4 (1)	21.2 (2)	14.3 (2)	22.6 (2)
2/20/78 1000	17.9 (1)	13.7 (2)	21.4 (1)	19.0 (2)
15/52/33 1000	22.8 (2)	2.1 (1)	18.6 (2)	20.0 (2)
30/0/70 1000	12.6 (2)	16.7 (1)	23.8 (1)	21.6 (2)
0/100/0 2000	11.8 (2)	8.6 (2)	15.4 (3)	-15.0 (1)
2/20/78 2000	9.8 (1)	-4.4 (2)	4.6 (1)	13.2 (1)
15/52/33 2000	8.0 (1)	-25.0 (1)	11.2 (2)	19.6 (2)
30/0/70 2000	17.0 (2)	10.2 (2)	14.0 (2)	9.5 (1)
15/52/33 3000	12.4 (2)	3.8 (2)	-3.2 (2)	---
FRA	-5.8 (11)	---	-5.8 (11)	---

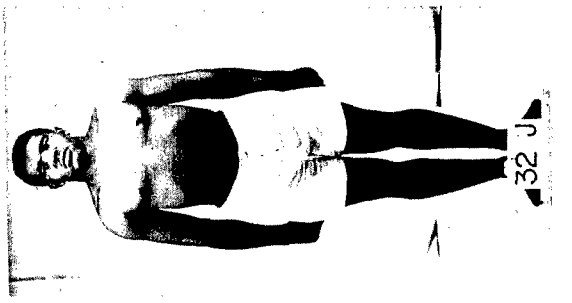
4. Photographic Record of Subject's Bodies

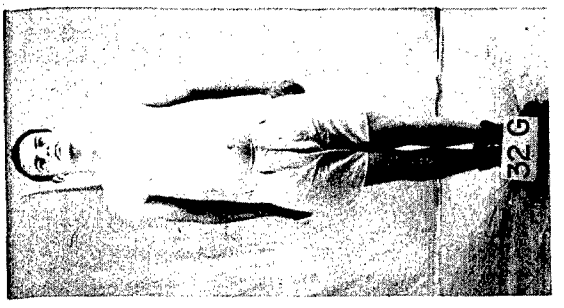
Two photographs, one front and one side view, were taken of each subject during the pre-period and again at the time of physical examination at the termination of the experimental period. Sometimes a photograph will show changes which cannot be described effectively in words. Of the many photographs thus accumulated, we show examples from the two flights which were most different: Flight 2, Hard Work, Limited Water; and Flight 3, Light Work, Unlimited Water. "Before" and "After" front views are shown for subjects with each calorie intake and for most of the different nutrient combinations. In Flight 2, photographs are missing for both subjects on 15/52/33 1000, and in Flight 3 for both subjects on 0/100/0 2000. The photographs are grouped as follows: Figure III. 32, Hard Work, Limited Water, Starvation 1000-Calorie regimens, and one FRA; Figure III. 33, Hard Work, Limited Water, 2000-and 3000-Calorie regimens; Figure III. 34, Light Work, Unlimited Water, Starvation and 1000-Calorie regimens; Figure III. 35, Light Work, Unlimited Water, 2000-and 3000-Calorie regimens, and one FRA. Starvation, dehydration, 1000 Calories, and hard work all produced marked bodily changes. Higher calorie intakes and adequate hydration were still associated with a "thinning down" of the subjects. The FRA's, as might be expected, showed few changes that could be detected photographically.

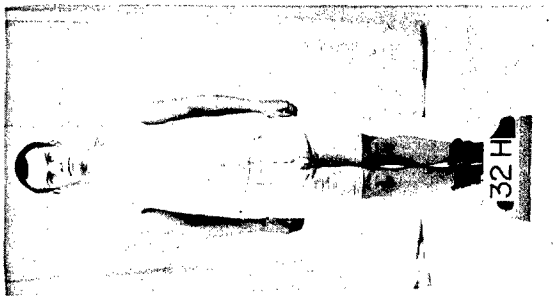
FIGURE III. 32. SUBJECTS OF FLIGHT 2 BEFORE AND AFTER EXPERIMENTAL PERIODS (ST 0 AND 1000 CALORIES, LIMITED WATER: FRA).

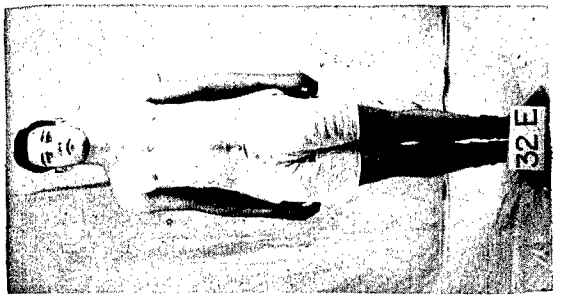
A. Subject 26: PRE
B. Subject 26: Starvation
C. Subject 27: PRE
D. Subject 27: 0/100/0 1000
E. Subject 32: PRE
F. Subject 32: 30/0/70 1000
G. Subject 36: PRE
H. Subject 36: 2/20/78 1000
I. Subject 95: FRA (PRE)
J. Subject 95: FRA (EXP)

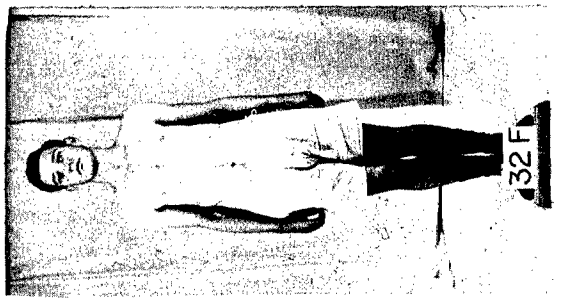

32 I

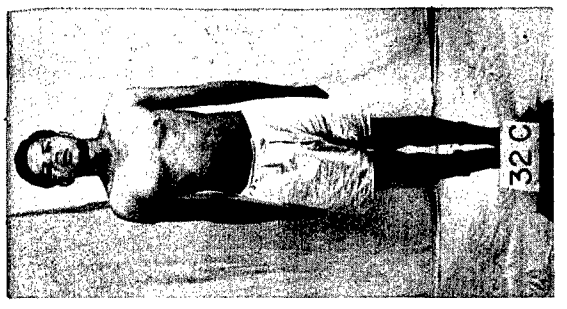

32 J

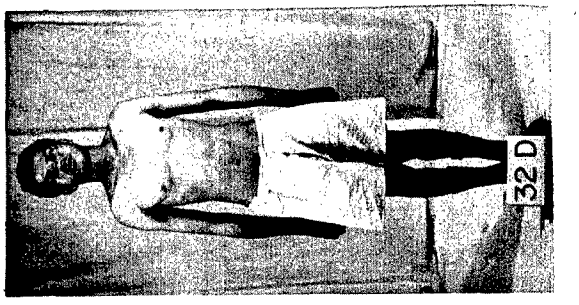

32 G

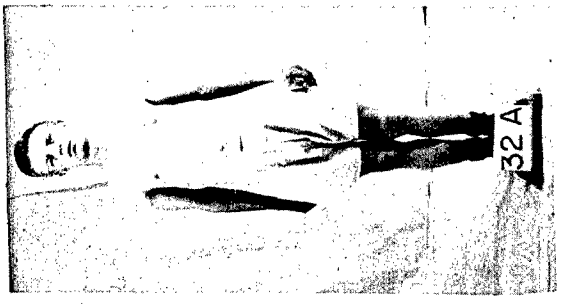

32 H


32 E


32 F


32 C


32 D


32 A

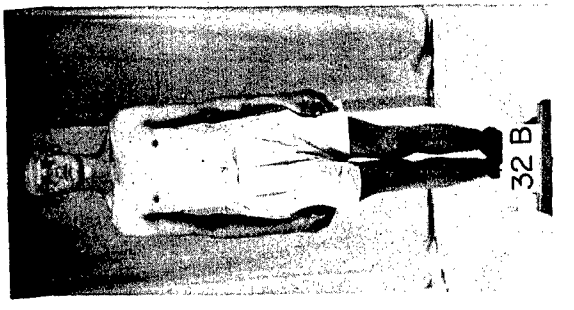
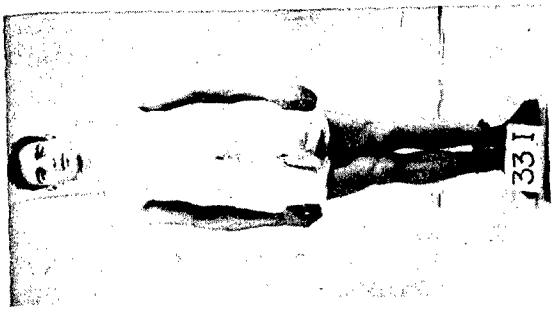
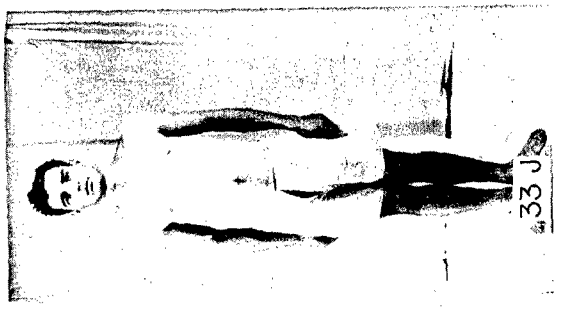
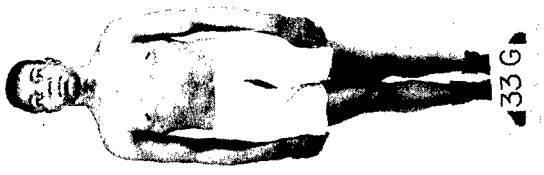

32 B

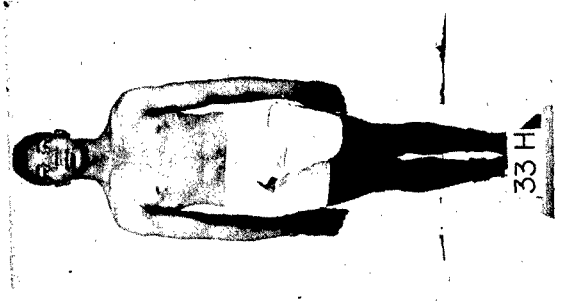
FIGURE III. 33. SUBJECTS OF FLIGHT 2 BEFORE AND AFTER EXPERIMENTAL PERIODS (2000 and 3000 CALORIES, LIMITED WATER).

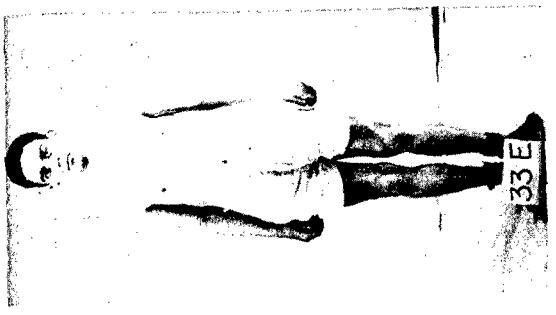
A. Subject 29: PRE
B. Subject 29: 0/100/0 2000
C. Subject 33: PRE
D. Subject 33: 30/0/70 2000
E. Subject 38: PRE
F. Subject 38: 2/20/78 2000
G. Subject 42: PRE
H. Subject 42: 15/52/33 2000
I. Subject 43: PRE
J. Subject 43: 15/52/33 3000

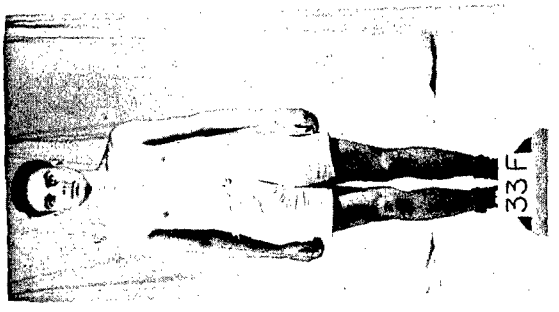

33 I

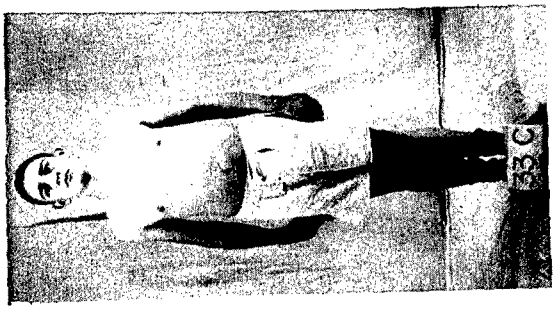

33 J

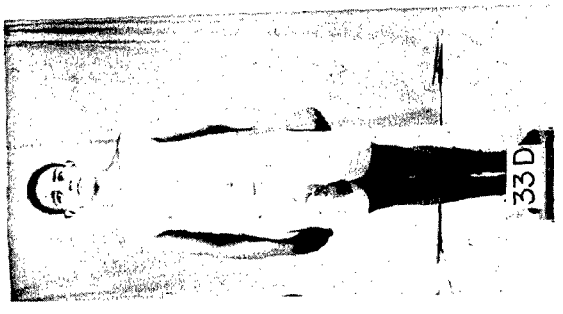

33 G

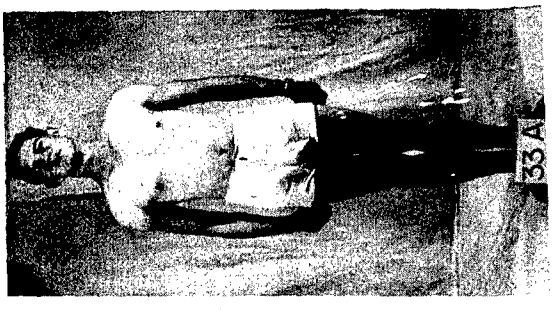

33 H


33 E


33 F


33 C


33 D


33 A

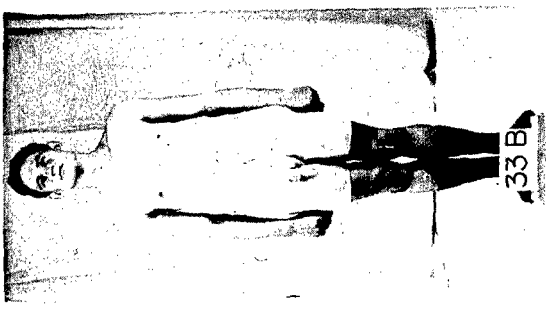
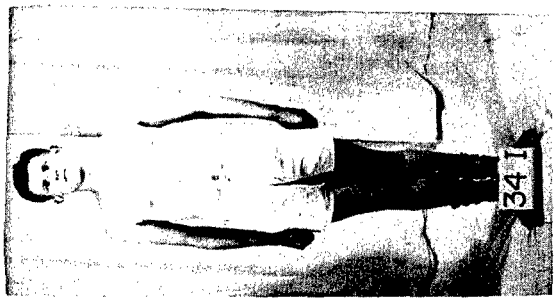
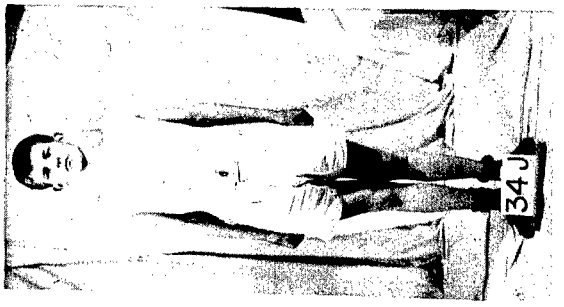
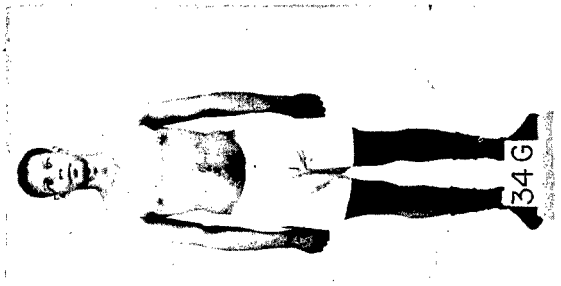

33 B

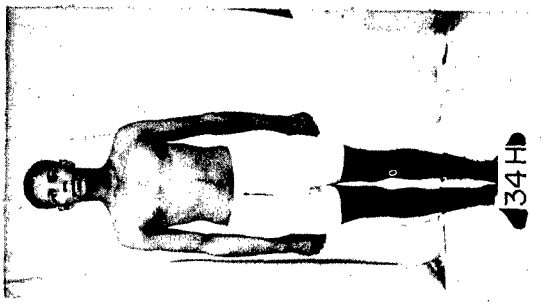
FIGURE III. 34. SUBJECTS OF FLIGHT 3 BEFORE AND AFTER EXPERIMENTAL PERIODS (ST 0 AND 1000 CALORIES, UNLIMITED WATER).

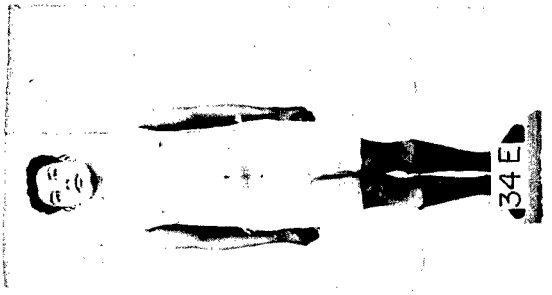
A. Subject 48: PRE
B. Subject 48: Starvation
C. Subject 49: PRE
D. Subject 49: 0/100/0 1000
E. Subject 53: PRE
F. Subject 53: 30/0/70 1000
G. Subject 57: PRE
H. Subject 57: 2/20/78 1000
I. Subject 62: PRE
J. Subject 62: 15/52/33 1000

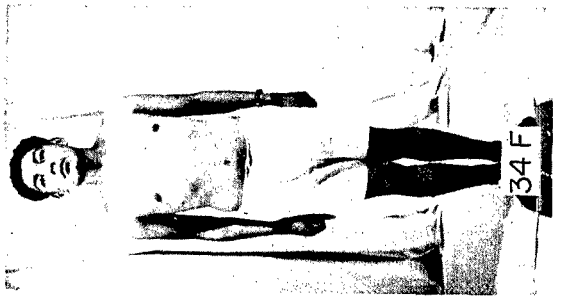

34 I

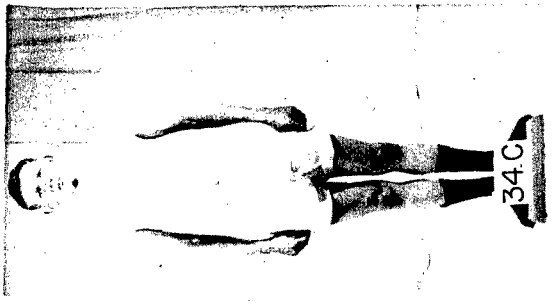

34 J

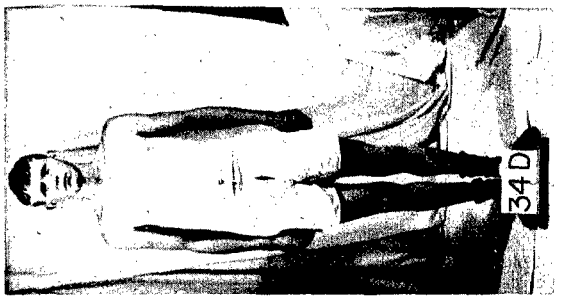

34 G

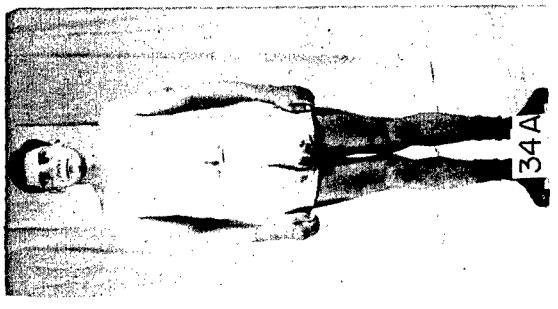

34 H


34 E


34 F


34 C


34 D


34 A

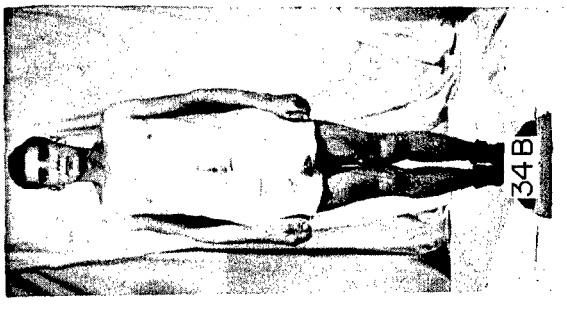
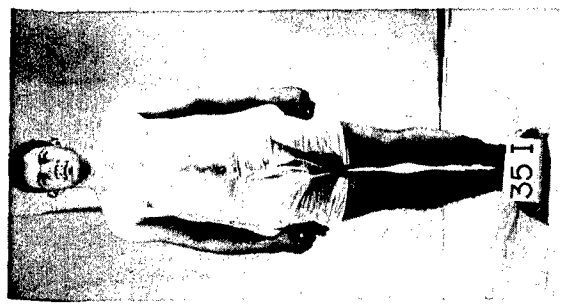
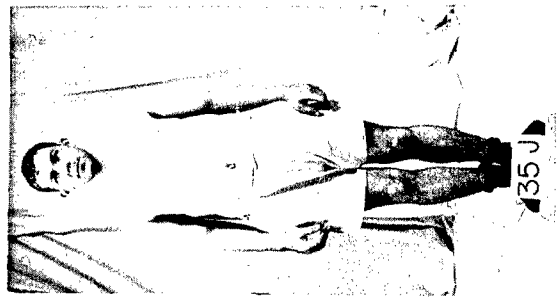
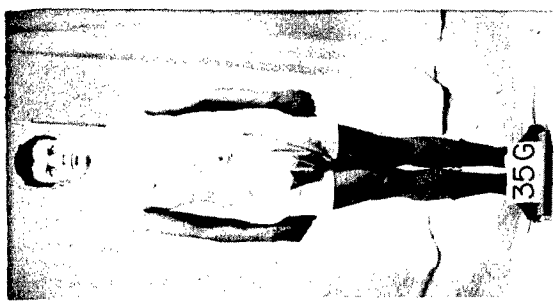

34 B

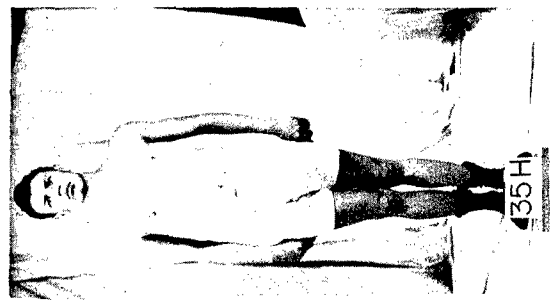
FIGURE III. 35. SUBJECTS OF FLIGHT 3 BEFORE AND AFTER EXPERIMENTAL PERIODS (2000 AND 3000 CALORIES, UNLIMITED WATER; FRA).

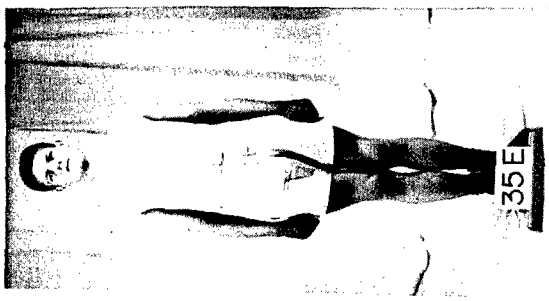
A. Subject 55: PRE
B. Subject 55: 30/0/70 2000
C. Subject 60: PRE
D. Subject 60: 2/20/78 2000
E. Subject 63: PRE
F. Subject 63: 15/52/33 2000
G. Subject 66: PRE
H. Subject 66: 15/52/33 3000
I. Subject 100:FRA (PRE)
J. Subject 100:FRA (EXP)

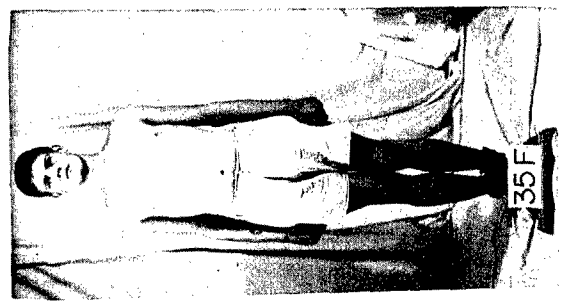

35 I

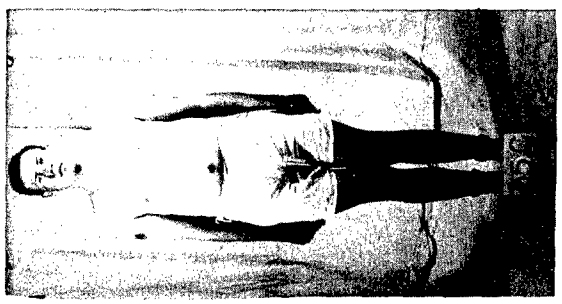

35 J

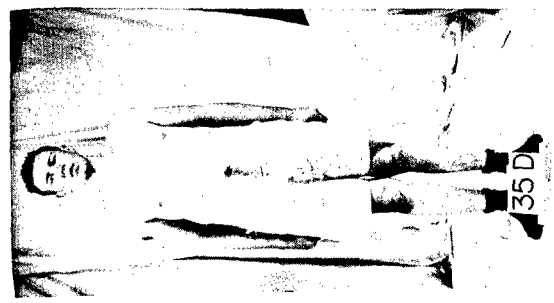

35 G

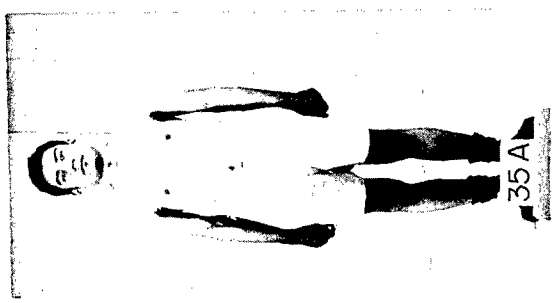

35 H

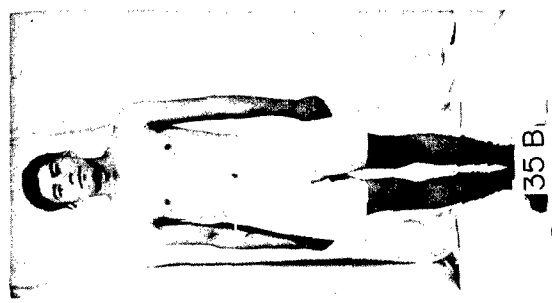

35 E


35 F




35 D


35 A


35 B

D. REACTION TO HEAT

1. Weather during Heat Acclimatization Test

The heat acclimatization test was designed for subjects to perform a standard work load under the prevailing ambient weather. The men performed a paced march walking around a track at 3.75 m.p.h. For the average subject weighing approximately 68 kg, this work involved an energy expenditure of 4.3 Cal/kg/hr x 68 kg or 290 Cal/hr. If the weather proved to be hot, it would allow us to evaluate the heat tolerance of subjects subsisting on various regimens of restricted food and water intake.

The principal meteorological observations are summarized in Table III. 84. There we have averaged the half-hourly observations made during each two-hour period of testing. The dry-bulb temperature (D.B.T.) ranged from 79.7° to 96.4°F; the wet-bulb temperature (W.B.T.), from 62.3° to 79.9°F. The air motion was never excessive and the wind velocity ranged from 197 to 477 ft/min. From these parameters we derived, with the use of appropriate nomograms, the two indices of heat stress; viz., effective temperature and predicted four-hour sweat rate. (Table III. 84). The "effective temperature" (E.T.) was read from the "basic effective temperature scale" of Bedford (1950). Our subjects generally marched dressed only in shorts, shoes and socks, and cap. The predicted four-hour sweat rate (P.4.S.R.) was calculated from the basic four-hour sweat rate using assumptions regarding work-load and the nomograms of Smith (1955).

During four of the five weeks the weather was very warm. We were particularly fortunate in that during the P II (2 and 3 July) and EXP (10 and 11 July) tests on Flights 2 and 4 the men weather conditions were essentially identical. This fact has simplified much of the statistical work which will be described below.

TABLE III. 84

MEAN AMBIENT WEATHER DURING HEAT ACCLIMATIZATION TESTS TOGETHER WITH DERIVED INDICES OF HEAT STRESS

Date of Test	Flight	Dry Bulb Temp., °F	Wet Bulb Temp., °F	Air Motion, ft/min	Effective Temp., °F	Basic* Sweat Rate (L)	Predicted** Sweat Rate (L)
26 June	1	80.4	64.3	289	65.1	-0.50	1.05
26 June	2	79.7	62.6	322	70.2	-0.55	1.00
27 June	3	82.2	63.8	356	65.5	-0.40	1.15
27 June	4	84.8	64.8	321	67.8	-0.20	1.35
2 July	1	93.8	78.5	335	79.8	+0.55	2.10
2 July	2	94.8	78.3	224	80.8	+0.60	2.15
3 July	3	95.1	77.1	246	80.0	+0.60	2.15
3 July	4	94.6	77.1	197	79.5	+0.60	2.15
10 July	1	96.0	79.9	201	82.4	+0.70	2.25
10 July	2	94.9	78.2	256	80.5	+0.60	2.15
11 July	3	92.3	71.7	477	74.2	+0.30	1.85
11 July	4	94.3	70.5	337	75.8	+0.50	2.05
19 July	1	85.2	77.0	215	75.4	-0.15	1.40
19 July	2	88.2	77.2	355	75.5	+0.05	1.60
20 July	3	90.0	78.4	276	78.0	+0.25	1.80
20 July	4	89.8	78.2	293	77.8	+0.25	1.80
24 July	1	86.7	76.1	227	75.5	-0.10	1.45
24 July	2	81.3	76.0	205	72.5	-0.35	1.20
25 July	3	96.4	75.6	221	80.0	+0.65	2.20
25 July	4	94.0	73.4	226	77.8	+0.50	2.05

*Calculated from nomogram in Smith (1955)

**Moderate work: add 1.55 L to basic value.

2. Rate of Total Body Sweating

The pre-period data for rate of total body sweating are summarized in Table III. 85. Paired values on rate of sweating during the several periods for the men on the different nutrient combinations are given in Table III. 86. In order to evaluate these data, we first made a study of sweat rates among the FRA subjects.

Complete data were available for 11 of the 12 originally assigned to this regimen. It was felt that if trends or correlations were present among the data of this small group, we would better be able to manage the large mass of observations on the other 88 men. A plot of dry bulb temperature vs. mean sweating rate (which was assumed to be equal to the weight loss during the march) revealed a low correlation coefficient (+0.37, P = 10%). The wide scatter of points suggested that individual variability was lowering the significance of the correlation. We suspected that body weight might be one variable causing this scattering.

Rate of Sweating and Body Weight. A plot of body weight vs. sweating

rate, for days on which the effective temperature exceeded 80°F., indicated a correlation coefficient of +0.41 which was significant at the 10% level. This association suggested a direct relationship between body weight and sweat loss. A similar correlation has been reported by Adolph (1947). He found that sweating rate was also correlated with body surface area. However, in the present subjects there was essentially a linear relationship between rate of sweating and body weight, and no greater variation than 5% in the range 50-100 kg. A similar analysis was made of the rate of sweating in P II of the EXP subjects (the 88 men destined to go on restricted food and water in the experimental periods) with results shown in Table III. 87 and Figure III. 36. Significant correlations were obtained in all flights between total rate of sweating and body weight.

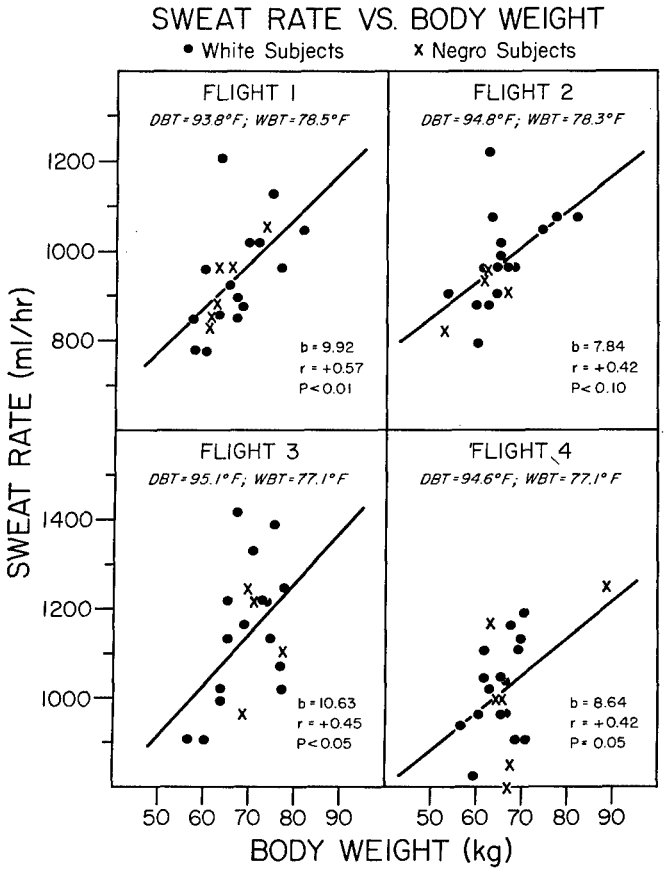


FIGURE III. 36. RATE OF TOTAL BODY SWEATING VS. BODY WEIGHT FOR WHITE AND NEGRO SUBJECTS.

In view of this relationship, all of the total rates of sweating were corrected to correspond with a standard 65-kg man. In the case of the FRA's, actual body weights for each period were used. In the case of the experimental subjects, the corrected sweat rate (C.S.R.) was calculated for each of the five

tests using the subject's pre-period weight. It was assumed, we think reasonably, that loss of body tissue from undernutrition would not change the number or activity of the eccrine sweat glands. Pre-period data for C.S.R. are in Table III. 88, and for all periods in Table III. 89. The data of Table III. 89 are summarized in Table III. 90.

Corrected Sweat Rate vs. Ambient Temperature and Indices of Heat Stress. When the corrected sweat rates for the FRA's were plotted against ambient dry-bulb temperature, wet-bulb temperature, and effective temperature, linear trends of C.S.R. on temperature were evident (Figures III. 37 and III. 38). Regression lines and correlation coefficients were calculated for D.B.T., W.B.T., E.T., and P.4.S.R. In these calculations mean data were used; i.e., mean C.S.R.'s for the FRA subjects in each flight and mean C.S.R.'s for the EXP subjects in each flight (Table IV. 91). For the FRA's all five periods were used in the statistical analysis; for the EXP's the experimental periods were omitted, for at this time the subjects were on many different diets and were not considered "normal."

The statistical data are summarized in Table III. 91. High correlations are evident in each instance. Both for FRA and EXP subjects the lowest correlate was W.B.T. These data indicate that in order to evaluate the effect of the experimental regimens we must compare the observed C.S.R.'s with an expected value of the C.S.R. The expected values were calculated from the "dry-bulb temperature" regression equations. This parameter was used because later work on the heat tolerance of these subjects revealed that an index of Ladell (1951) was linearly related to dry-bulb temperature but curvilinearly related to effective temperature.

Effect of Nutrient Regimen on C.S.R. Inspection of Table III. 92 and Figure III. 38 indicates a uniform decrease in the mean C.S.R. for the EXP subjects in the experimental period. Since the dry bulb temperature was constant from P II to EXP I for Flights 2 and 4 we can apply the "t" test to measure the significance of the differences of the means. For both flights the probability that the differences were significant was less than 0.001.

When mean predicted sweat rates were calculated from the appropriate regression equations and compared with observed sweat rates, the differences shown in Table III. 93 resulted. Each is highly significant. The flights on limited water tended to show greater decreases than those on unlimited water but that trend is not significant. The only conclusion justified is that some aspect of the experimental period caused the sweat rate to decrease among all subjects. Since the FRA's do not show comparable decreases or differences from predicted C.S.R. the nutrient regimens must be involved.

When we examine the sweat rate deviations (observed C.S.R. minus C.S.R. predicted from regression equation) for the subjects on the several regimens (Figures III. 39 and III. 40), it becomes evident that all of them sweat at a slower rate in the experimental period. Thus the C.S.R. does not discriminate significantly among nutrient regimens or between levels of water intake or work load. We are left with the possibility that some factor common to all EXP subjects provoked the reduced C.S.R. This factor may have been general

dehydration, a supposition strongly suggested by results of determination of total body water. Such results will be of great significance, for it is still a moot point whether or not rate of sweating is diminished by dehydration (Adolph, 1947).

The C.S.R. of the Negro. Before proceeding further with the analysis of heat tolerance and nutrient regimen, we must consider the problem of whether or not the Negro sweats at a different rate than the white subject. Our data have been carefully scrutinized on this point. The results (Table III. 94 and Figure III. 36) indicate that as a group the Negro subjects do not sweat at a significant different rate from the white subjects. There are individual Negroes, however, who do sweat at very low rates: two EXP subjects in Flight 4 and four FRA subjects. Because an equal number of white subjects sweat at comparably low rates we do not feel justified in differentiating between these two racial types in our interpretation of data involving rates of sweating.

TABLE III. 85

PRE-PERIOD DATA ON RATE OF TOTAL BODY SWEATING
(l/hr)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.60	0.17	27.9	21	0.94	0.11	11.4
2	21	0.56	0.08	15.3	20	0.97	0.10	10.0
3	21	0.66	0.10	14.7	20	1.15	0.14	12.6
4	21	0.66	0.19	29.4	22	1.02	0.12	11.7
FRA	12	0.67	0.16	24.4	11	1.14	0.18	15.8

TABLE III. 86

RATE OF TOTAL BODY SWEATING
(ml/hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	713	933	878	728	841	646	1162	726	850	816
	L	591	943	758	718	728	361	1007	666	850	832
0/100/0	U	587	829	807	652	709	524	964	666	836	779
1000	L	577	992	751	709	581	663	964	779	851	865
0/100/0	U	672	1116	875	793	851	638	993	765	921	861
2000	L	830	978	836	822	794	821	964	808	1021	992
2/20/78	U	548	907	879	765	765	695	1183	794	1077	936
1000	L	586	1021	779	871	751	635	1105	709	765	1105
2/20/78	U	644	964	949	---	---	673	1197	950	978	793
2000	L	500	964	837	793	666	632	907	539	737	709
15/52/33	U	638	781	1007	808	879	794	1289	793	978	751
1000	L	467	952	822	---	---	605	978	667	822	837
15/52/33	U	497	850	822	765	---	709	1163	765	935	879
2000	L	425	893	737	652	737	677	1091	836	1531	822
15/52/33	U	468	851	978	695	695	666	1261	905	1063	978
3000	L	496	921	779	652	565	836	1148	---	----	---
30/0/70	U	343	943	965	723	836	567	992	624	709	709
1000	L	649	1148	709	652	595	923	921	666	836	879
30/0/70	U	750	993	893	851	836	723	1162	865	993	935
2000	L	617	907	839	723	737	735	1091	822	992	936
FRA		669	1141	994	954	828	669	1141	994	954	828

TABLE III. 87

CORRELATION BETWEEN BODY WEIGHT AND SWEAT RATE: EXP SUBJECTS IN PRE II

Flight	Slope (ml/kg)	r	P
1	9.92	+0.52	0.01
2	7.84	+0.42	0.10
3	10.63	+0.45	0.05
4	8.64	+0.42	=0.05

TABLE III. 88

PRE-PERIOD DATA ON CORRECTED SWEAT RATE (L/hr)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.58	0.14	23.9	21	0.93	0.10	10.3
2	21	0.57	0.10	16.4	19	0.97	0.10	10.7
3	21	0.62	0.08	12.8	20	1.07	0.25	23.2
4	21	0.65	0.22	34.2	22	1.00	0.11	11.2
FRA	11	0.60	0.16	26.9	11	1.01	0.16	15.9

TABLE III. 89

CORRECTED SWEAT RATE HARD WORK
(ml/hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	686	903	769	708	807	598	1083	675	795	760
	L	628	988	797	716	733	366	1005	664	848	836
0/100/0	U	611	864	835	627	682	554	1016	703	858	824
1000	L	646	995	816	837	640	652	956	772	844	854
0/100/0	U	650	1085	846	774	821	568	890	575	826	780
2000	L	792	916	786	774	742	812	956	707	942	916
2/20/78	U	541	894	866	761	761	652	1114	726	984	856
1000	L	607	1057	808	902	777	642	1118	716	772	1073
2/20/78	U	615	930	915	---	---	567	1040	872	896	730
2000	L	499	964	834	792	663	585	928	554	713	686
15/52/33	U	556	749	924	742	820	740	1202	740	911	700
1000	L	478	970	879	---	---	610	986	672	826	844
15/52/33	U	552	943	912	866	---	612	1005	662	807	759
2000	L	438	924	727	643	727	674	1081	830	1526	816
15/52/33	U	494	916	1031	732	732	581	1100	789	927	854
3000	L	506	940	898	666	622	708	974	---	---	---
30/0/70	U	328	923	874	707	762	577	1010	635	722	722
1000	L	590	1064	743	743	624	979	960	690	860	890
30/0/70	U	675	882	790	758	742	762	1220	908	1044	986
2000	L	660	935	869	746	762	708	1052	759	916	864
FRA	U	484	899	875	681	650	718	1140	796	1025	874
	L	544	980	982	844	722	646	998	854	838	812

TABLE III. 90

MEAN CORRECTED SWEAT RATE
(ml/hr)

Flight	P I M±s.d.	P II M±s.d.	EXP I M±s.d.	REC I M±s.d.	REC II M±s.d.
			FRA Subjects*		
1	484	899	875	681	650
2	544	980	982	844	722
3	718	1140	796	1025	874
4	646	998	854	838	812
			EXP Subjects		
1	581±139	931± 96	871±114	732±106	775±125
2	568± 93	974±104	824± 74	757± 86	704± 95
3	622± 80	1072±249	736±108	867±468	792±330
4	469±222	1002+112	709±112	919±247	770±412

*s.d. not calculated; three subjects in Flights 1, 3, and 4; two in Flight 2.

TABLE III. 91

CORRELATION BETWEEN CORRECTED SWEAT RATE
AND INDICES OF HEAT STRESS

Index	b*	r	S y.x.	P
	FRA Subjects (All Periods)			
Dry Bulb	23.82	+0.81	± 95	<0.001
Wet Bulb	20.96	+0.71	±115	<0.001
Effective	26.07	+0.80	± 97	<0.001
"P.4.S.R."**	325.83	+0.84	± 88	<0.001
	EXP Subjects (Pre- and Recovery Periods)			
Index	b*	r	Sy.x.	P
Dry Bulb	22.30	+0.85	± 80	<0.001
Wet Bulb	21.04	+0.82	± 85	<0.001
Effective	25.83	+0.89	± 68	<0.001
"P.4.S.R."**	304.54	+0.87	± 73	<0.001

*b = slope in regression equation Y = a + 6x

**"P.4.S.R." = Predicted Four-Hour Sweat Rate.

TABLE III. 92

MEAN PREDICTED SWEAT RATES (C.S.R.)
(ml/hr)

Flight	P I	P II	EXP	R I	R II
		A. EXP Subjects* Period			
1	613	911	961	720	753
2	597	934	936	787	633
3	653	940	878	827	969
4	711	929	923	822	916
		B. FRA Subjects** Period			
1	596	915	967	710	746
2	579	939	941	782	617
3	639	946	879	824	977
4	701	934	927	820	920

*C.S.R. = 22.30(D.B.T.)-1180.28

**C.S.R. = 23.82(D.B.T.)-1319.42.

TABLE III. 93

COMPARISON OF OBSERVED AND PREDICTED MEAN CORRECTED SWEAT RATES FOR EXP SUBJECTS IN EXPERIMENTAL PERIOD

Flight	Corrected Sweat Rate		Difference
	Observed	Predicted	
1	871	967	- 96
2	824	941	-117
3	736	879	-143
4	709	927	-206

TABLE III. 94

HEAT ACCLIMATIZATION TEST: COMPARATIVE PRE-PERIOD DATA ON CORRECTED SWEAT LOSS AMONG WHITE AND NEGRO SUBJECTS
(L/hr)

Flight	P I		P II	
	White	Negro	White	Negro
1	0.59 (16)*	0.56 (6)	0.93 (15)	0.94 (6)
2	0.56 (16)	0.58 (5)	0.98 (16)	0.98 (4)
3	0.62 (17)	0.62 (4)	1.08 (16)	1.04 (4)
4	0.66 (15)	0.61 (6)	1.02 (16)	0.95 (6)
FRA	0.64 (7)	0.53 (4)	1.08 (7)	0.88 (4)

*Numbers in parentheses indicate number of subjects.

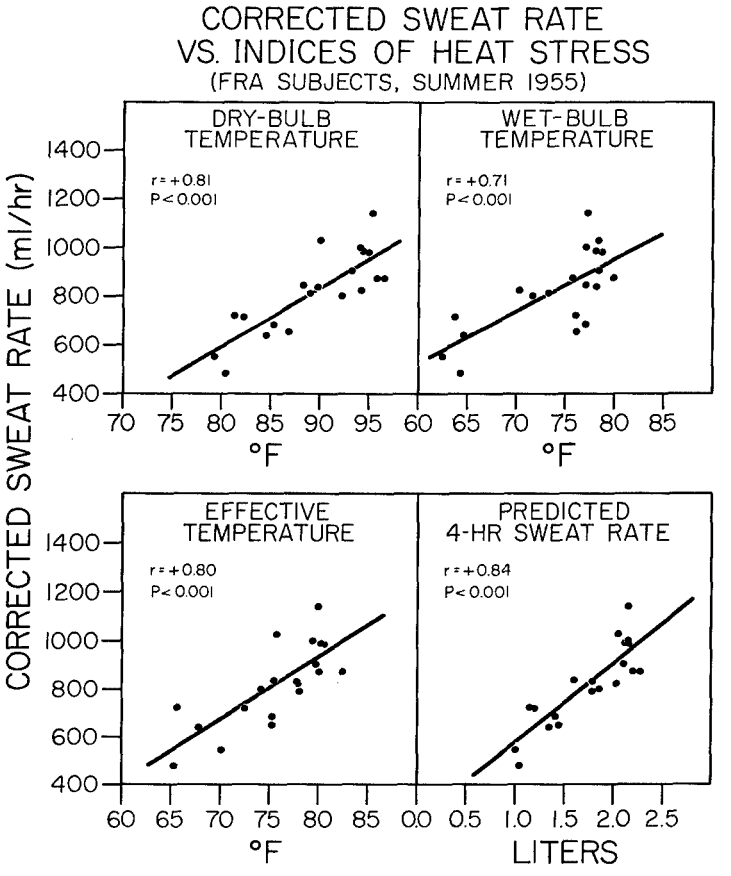


FIGURE III. 37. CORRECTED SWEAT RATE VS. INDICES OF HEAT STRESS: FRA SUBJECTS.

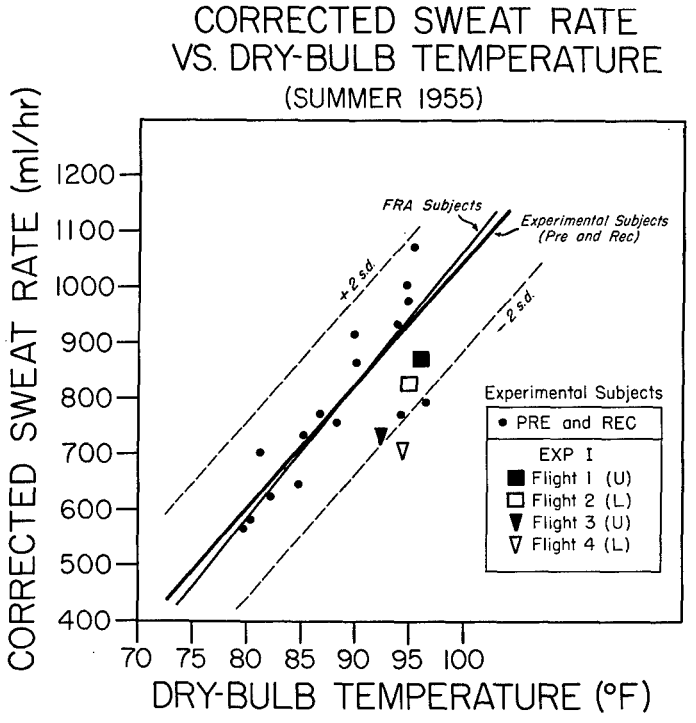


FIGURE III. 38. CORRECTED SWEAT RATE VS. DRY-BULB TEMPERATURE: ALL SUBJECTS.

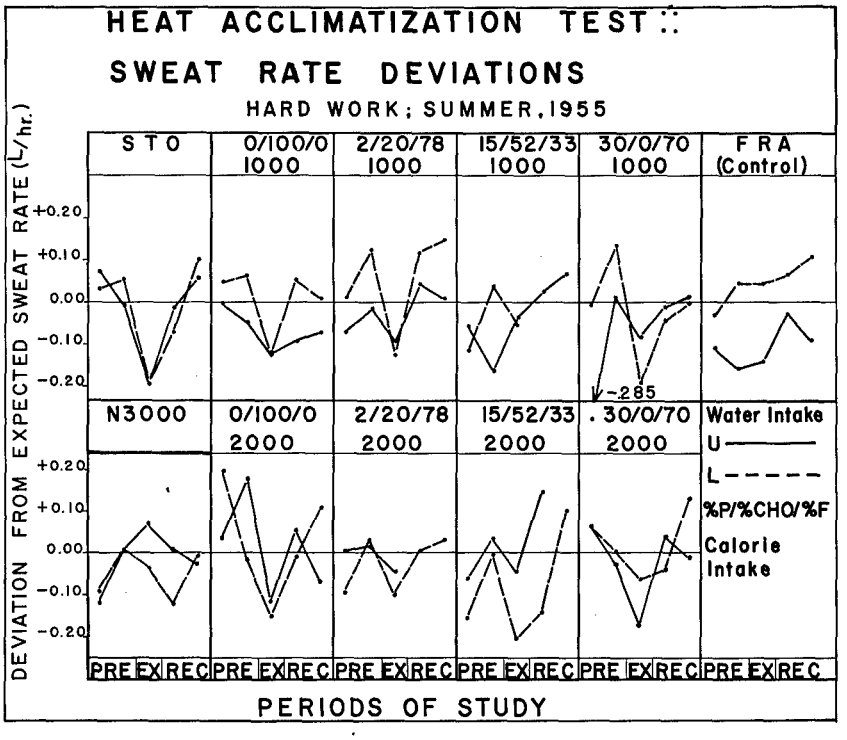


FIGURE III. 39. SWEAT RATE DEVIATIONS: HARD WORK.

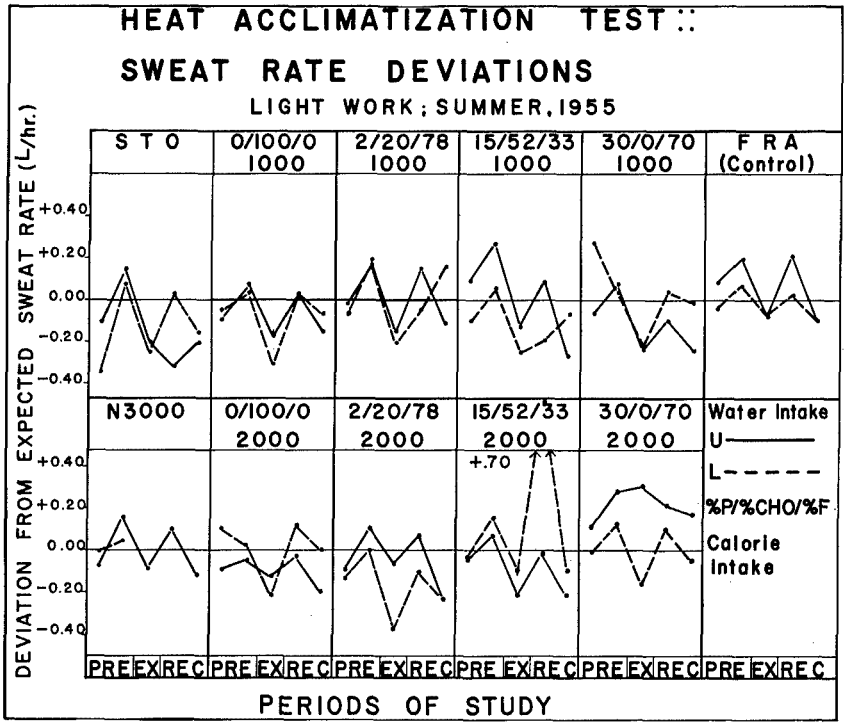


FIGURE III. 40. SWEAT RATE DEVIATIONS: LIGHT WORK.

3. Rectal Temperature

Both exposure to heat and performance of muscular exercise will cause an elevation of the rectal temperature. As a man becomes adapted to these stresses, the same degree of heat or the same amount of work cause less of a rise of rectal temperature. It follows then that if the experimental regimens had any deleterious effects on our subjects, we should find an increase in rectal temperature rather than a fall.

Prior to performing the paced march, and immediately afterwards, the rectal temperature of each subject was measured with a Leeds and Northrup rectal thermocouple inserted to a depth of 5 cm and held in place until a stable potentiometer reading was obtained. The potentiometer was calibrated each week prior to the heat acclimatization test. Table III. 95 contains pre-period data for initial and final rectal temperatures and increment of rectal temperature during the march. These data reveal a high order of inter- and intragroup consistency. In order of magnitude, the resting rectal temperatures are comparable to values reported in the literature (Horvath, Menduke, and Piersol, 1950). Comparing pre-periods we find no significant trends for final rectal temperature. In the case of initial rectal temperature all five groups showed an increase, the differences being statistically significant for Flight 1 and the FRA subjects. The exercise-increment of rectal temperature was, as a consequence, less in P II than in P I, and the same groups had significantly different mean values.

Turning to variations in rectal temperature during five heat acclimatization tests, we find that the initial rectal temperature failed to reveal any striking trend (Table III. 96). There are no evident correlations with work load, water intake, nutrient mixture, or period. On the other hand, in the case of the final rectal temperature (Tables III. 97), there was a quite uniform drop in the experimental periods. Only six of the 40 values failed to decrease. No further change was evident in the recovery periods. Another interesting observation is that among the men in the hard work flights those on limited water and 15/52/33 1000, 2000, and 3000, and 30/0/70 1000 and 2000 had higher final rectal temperatures than paired controls on unlimited water during the test of the experimental period. The same phenomenon is evident among the men doing light work but here only for those on 15/52/33 2000 and 30/0/70 1000 and 2000. The common denominator in these cases is high solute load. This trend suggests that nutrient regimens with high osmotic demands (greater dehydration) were causing deterioration of homeothermic mechanisms.

More striking demonstration of this thermal deterioration may be found in data on exercise increment of rectal temperature (Table III. 98 and Figures III. 41 and III. 42). There is a uniform drop from P II to the experimental period for both Flights 1 and 3, which were on unlimited water. The limited water groups, however, showed an increase wherever the osmotic load was high (2/20/78 2000, 15/52/33 1000, 2000, and 3000, and 30/0/70 1000 and 2000).

In general the increments of rectal temperature decrease from P I to R II. This trend suggests acclimatization. A curious finding, however, is the tendency of the increments to increase slightly in R II. Thirteen of 38 paired means show this trend. One is tempted to suggest dysacclimatization due to six weeks of exposure to moist heat under rather trying circumstances.

We must mention one other intriguing observation which has up to now been incompletely studied. The observation concerns the final rectal temperature of the FRA subjects. Study of those data plotted against effective temperature brings out the fact that, with the exception of P II, the higher was the ambient temperature the lower was the final rectal temperature. When the P II (2-3 July) data are omitted from a calculation of the correlation coefficient, one obtains a "r" of -0.87 (P less than 0.001). We have interpreted this association as evidence of acclimatization. Whether the EXP subjects will show the same correlation, we are not yet prepared to state. The deviant P II data remain an enigma. One can hypothesize that these data are a manifestation of a response to hotter weather than the subjects had previously experienced or adapted to. The first five days of the testing period were relatively cool; thereafter it became hot and stayed that way. Researches by the group at Fort Knox point to an analogous process for men working under much hotter conditions than those encountered at Camp Atterbury (Horvath and Shelley, 1946).

The analysis to this point has suggested that the heat acclimatization test was, in fact, discriminatory. We have evidence that men on restricted water and nutrient mixtures demanding high renal osmotic work had difficulty maintaining thermal balance during a standard period of work. We might anticipate that the thermal dysfuntion would also be evident in sweating rates. The

normal physiological adjustment to heat is a development of an ability to maintain thermal balance. This process is achieved by an onset of sweating at a lower and lower rectal temperature. To inquire whether or not this phenomenon was operating in our subjects we next proceeded with a study of the relation of the sweat rate to the rectal temperature.

TABLE III. 95

PRE-PERIOD DATA ON HEAT ACCLIMATIZATION TEST:
FINAL AND INITIAL RECTAL TEMPERATURES;
AND RISE IN RECTAL TEMPERATURE
(^{o}F)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
			Final Rectal Temperature					
1	22	101.4	0.2	0.2	21	101.3	0.6	0.6
2	21	101.1	0.9	0.9	20	101.4	0.4	0.4
3	21	101.3	1.1	1.1	20	101.5	0.5	0.5
4	21	101.4	0.9	0.9	22	101.5	0.8	0.8
FRA	12	101.1	0.4	0.4	11	101.4	1.1	1.1
			Initial Rectal Temperature					
1*	22	98.9	0.7	0.8	21	99.5	0.2	0.2
2	21	98.9	1.2	1.2	20	99.5	0.4	0.4
3	21	98.9	0.7	0.7	20	99.5	0.4	0.4
4	21	99.2	1.1	1.1	22	99.5	0.4	0.4
FRA**	12	99.0	0.4	0.4	11	99.7	0.5	0.5
			Rise in Rectal Temperature					
1*	22	2.5	0.6	24.0	21	1.7	0.5	28.6
2	21	2.2	0.8	36.3	20	1.8	0.7	38.8
3	21	2.3	0.7	30.4	20	1.9	0.7	36.8
4	21	2.2	0.7	31.8	22	2.0	0.6	30.0
FRA	12	2.1	0.5	23.8	11	1.7	0.3	17.6

"t" test on P I vs. P II
*P less than 0.001
**P less than 0.005

TABLE III. 96

INITIAL RECTAL TEMPERATURE
(°F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	98.4	99.7	99.6	99.6	99.6	98.9	99.8	99.3	99.6	99.5
	L	99.2	99.6	98.8	99.4	99.3	98.9	99.7	98.5	99.2	99.2
0/100/0	U	98.6	99.8	99.8	99.5	99.2	98.2	99.6	99.4	99.5	99.2
1000	L	98.6	99.7	98.8	99.2	99.0	99.6	99.5	98.5	99.6	99.0
0/100/0	U	99.9	99.5	99.5	99.5	99.2	99.1	99.4	99.2	99.5	99.4
2000	L	99.6	99.4	99.0	99.5	99.0	99.4	99.7	98.5	99.8	99.1
2/20/78	U	99.4	99.6	98.7	99.5	99.0	99.6	99.4	98.5	98.7	99.1
1000	L	97.2	99.0	98.6	99.6	99.1	99.5	99.5	98.5	100.0	99.5
2/20/78	U	98.8	98.8	99.2	----	----	98.7	99.2	99.2	99.2	99.4
2000	L	98.9	99.4	98.5	99.4	99.4	99.6	99.2	98.8	99.5	99.0
15/52/33	U	98.2	99.6	99.2	99.4	99.4	99.0	99.6	99.0	99.5	99.1
1000	L	99.6	99.8	99.1	----	----	99.1	99.0	99.0	99.1	99.2
15/52/33	U	98.9	99.7	99.4	99.7	----	98.9	99.1	99.2	99.4	99.2
2000	L	98.8	99.3	99.5	99.4	99.3	99.6	100.0	99.1	99.2	99.0
15/52/33	U	99.3	99.8	99.4	99.6	99.1	98.5	99.6	98.5	99.0	99.0
3000	L	98.8	98.8	98.7	99.4	99.2	98.9	99.4	----	----	----
30/0/70	U	99.1	99.5	99.2	99.4	99.5	98.5	99.0	99.0	99.0	99.2
1000	L	99.5	99.6	99.6	99.4	99.1	99.5	99.8	98.4	99.9	99.1
30/0/70	U	98.8	99.6	99.0	99.8	99.2	99.4	99.4	98.8	99.0	99.0
2000	L	98.0	99.4	98.6	99.4	99.2	99.2	99.7	98.5	99.5	99.0
FRA		99.0	99.7	99.1	99.3	99.2	99.0	99.7	99.1	99.3	99.2

TABLE III. 97

FINAL RECTAL TEMPERATURE
(^{o}F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	101.4	101.4	101.4	100.7	100.7	101.6	101.4	100.8	100.6	100.6
	L	101.2	101.6	100.6	100.9	100.8	101.7	101.5	100.1	100.8	100.1
0/100/0	U	101.2	101.4	100.7	100.6	100.9	101.0	101.8	100.8	100.6	100.2
1000	L	100.7	101.4	100.2	100.6	100.6	101.2	101.6	100.5	100.7	100.0
0/100/0	U	101.8	100.4	100.6	100.5	100.8	100.8	101.0	100.5	100.6	100.9
2000	L	101.3	101.6	100.5	100.6	100.6	101.8	101.8	100.4	100.8	100.1
2/20/78	U	101.4	101.8	100.4	100.6	100.6	101.4	101.2	100.0	101.0	100.0
1000	L	100.6	101.8	100.4	100.7	101.0	101.5	101.4	100.4	100.7	100.3
2/20/78	U	101.4	101.2	100.4	-----	-----	101.4	101.4	100.5	100.6	100.2
2000	L	101.1	101.0	100.8	100.6	100.6	101.4	101.4	100.2	100.8	100.4
15/52/33	U	101.4	101.4	100.5	100.9	100.6	101.4	101.4	100.2	100.6	100.4
1000	L	101.4	101.3	101.0	-----	-----	101.4	101.4	100.4	100.8	100.2
15/52/33	U	101.2	101.4	100.4	100.3	-----	101.4	101.9	100.2	101.1	100.4
2000	L	101.9	101.0	100.7	100.6	100.7	101.2	101.0	101.4	100.6	100.0
15/52/33	U	100.7	101.4	100.8	100.6	100.8	101.6	101.8	100.8	101.0	100.5
3000	L	101.2	101.4	101.0	100.5	100.6	101.1	101.6	-----	-----	-----
30/0/70	U	101.4	101.0	100.4	100.4	100.8	100.5	100.8	100.5	100.4	100.4
1000	L	101.2	101.2	101.7	100.5	100.5	101.0	101.4	101.0	100.8	100.1
30/0/70	U	101.4	101.6	100.6	100.6	100.8	101.0	101.8	100.0	101.0	100.2
2000	L	101.2	101.4	100.7	100.8	100.6	101.8	101.8	101.1	101.2	100.0
FRA		101.1	101.4	100.4	100.5	100.4	101.1	101.4	100.4	100.5	100.4

TABLE III. 98

RECTAL TEMPERATURE RISE
(^{o}F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	3.0	1.9	1.8	1.0	1.2	2.6	1.3	1.5	1.1	1.2
	L	2.0	2.0	1.8	1.4	1.8	2.7	1.9	1.8	1.4	0.9
0/100/0	U	2.6	1.6	1.4	1.1	1.4	2.7	2.2	1.4	1.0	1.1
1000	L	1.6	1.7	1.4	1.4	1.6	2.5	2.2	2.0	1.1	1.0
0/100/0	U	1.9	1.0	1.2	1.0	1.6	1.7	1.6	1.8	1.2	1.0
2000	L	1.7	2.2	1.5	1.2	1.6	2.4	2.0	1.8	1.0	1.0
2/20/78	U	2.5	2.2	1.6	1.1	1.6	1.8	1.8	1.5	2.3	0.9
1000	L	3.4	2.8	1.9	1.2	1.9	2.0	1.8	1.8	0.6	0.8
2/20/78	U	2.6	2.3	1.2	---	---	2.6	2.2	1.2	2.0	0.9
2000	L	2.2	1.6	2.4	1.1	1.2	1.8	2.2	1.5	1.3	1.4
15/52/33	U	3.1	1.7	1.2	1.6	1.2	2.4	1.8	1.2	1.2	1.2
1000	L	1.8	1.4	1.9	---	---	2.2	2.4	1.5	1.2	1.0
15/52/33	U	2.4	1.6	1.0	1.6	---	2.6	2.8	2.0	1.6	1.2
2000	L	3.2	1.6	2.2	1.2	1.4	1.6	1.1	1.4	1.4	1.0
15/52/33	U	1.9	1.6	1.4	1.0	1.6	2.7	2.2	2.2	2.0	1.5
3000	L	2.4	1.6	2.3	1.0	1.5	2.2	2.2	---	---	---
30/0/70	U	2.4	1.5	1.2	1.0	1.3	2.0	1.8	1.5	1.4	1.2
1000	L	1.7	1.5	1.6	1.1	1.4	1.6	2.1	2.6	0.8	1.0
30/0/70	U	2.2	2.0	1.6	0.7	1.6	1.6	2.5	1.2	2.0	1.1
2000	L	2.8	1.6	2.0	1.5	1.4	2.6	2.1	2.6	1.7	1.0
FRA		2.1	1.7	1.3	1.2	1.2	2.1	1.7	1.3	1.2	1.2

FIGURE III. 41. RECTAL TEMPERATURE INCREMENT: HARD WORK.

FIGURE III. 42. RECTAL TEMPERATURE INCREMENT: LIGHT WORK

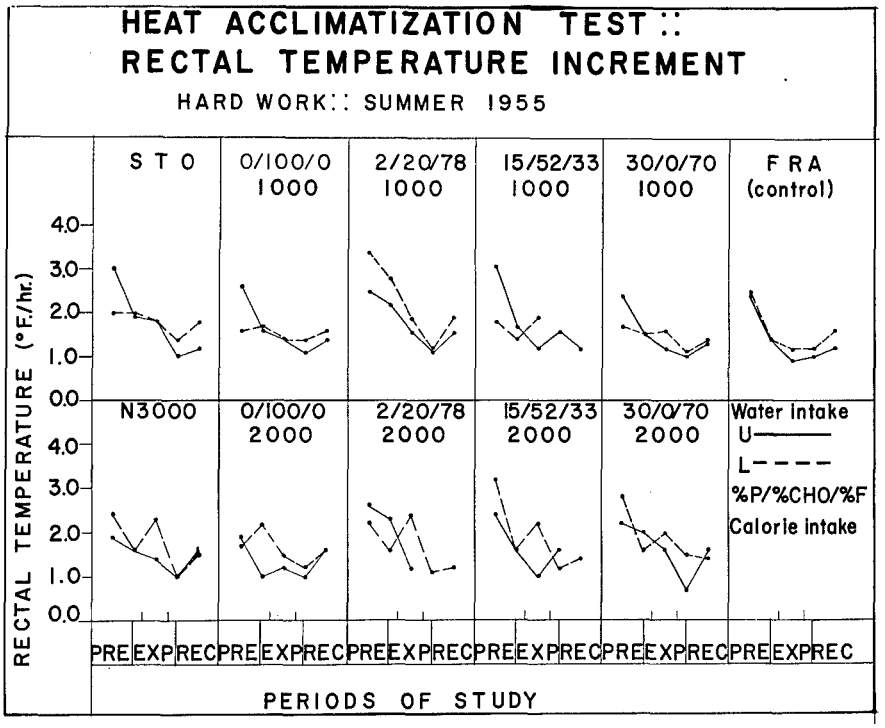


FIGURE III. 41.

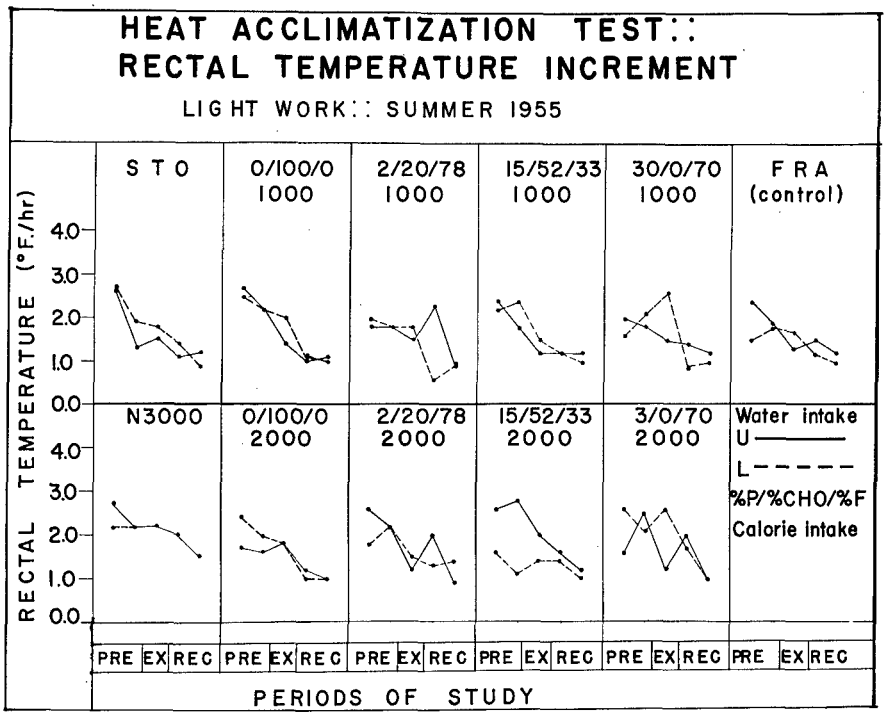


FIGURE III. 42.

4. An Index of Acclimatization

Since the corrected sweat rates and rectal temperature displayed trends which suggested functional deterioration on certain nutrient regimens, we sought to correlate the trends in order to gain insight into the phenomenon. Because of its simplicity and its bioclimatologic reasonableness, we adopted Ladell's (1951) index of acclimatization. This index is based on the premise that, after acclimatization, standard work can be performed more efficiently. This is, in part, a manifestation of increased rate of sweating at given rectal and ambient temperatures. Thus, more sweat is secreted per degree-rise in rectal temperature. The threshold for sweating is lowered. Indices of acclimatization (A.I.) were calculated for each man according to the formula:

$$\text{A.I.} = \frac{\text{Corrected Sweat Rate (ml/hr)}}{\text{Rise in Rectal Temperature (°F/hr)}}$$

This index is not exactly the same as that of Ladell. He corrected the sweat rates of his subjects not only for body weight but also for surface area. We did not for reasons discussed above. His sweat rates and rectal temperature increments were for 80 minutes of standard work. Our data are for 60 minutes of standard work. The physiological basis for our index, however, is identical and changes in the index have the same meaning as they would have under Ladell's original conditions.

The basic data on the acclimatization index have been assembled in Tables III. 99 and III. 100. The former gives the pre-period means together with appropriate measures of variance, the latter the paired means for the five heat-acclimatization tests. Since ambient environment may have influenced the several data, we first studied that point and then scrutinized the residual variation for an influence of nutrient regimen.

Acclimatization Index vs. Ambient Temperature and Indices of Heat Stress. The effect of the D.B.T., W.B.T., E.T., and P.4.S.R. on the acclimatization index was investigated statistically by the same procedures employed in analyzing the corrected sweat rates (c.f., Table III. 91 and accompanying text). The mean indices for the FRA and EXP subjects are given in Table III. 101. The correlation data are detailed in Table III. 102. It is evident again that a high degree of association exists between the A.I. and ambient weather. The correlation between D.B.T. and A.I. is the highest for the EXP subjects while that between E.T. and A.I. is the highest for FRA subjects. The significant fact, however, is that the coefficients are uniformly lower for these indices and A.I. than for the same weather parameters and C.S.R. (c.f., Table III. 91).

The reason for these low correlations becomes evident when we examine Figure III. 43 wherein the mean acclimatization indices for the FRA subjects (Table III. 100) have been plotted against D.B.T., W.B.T., E.T., and P.4.S.R. The values for the five periods have been given different symbols. In each of the four plots, the deviant points are those for P II. In that period, the increments of rectal temperature increased over P I. Just prior to the test of P II, the weather suddenly became very hot. The drop in A.I. represents a re-acclimatization of the subjects to the increased warmth. Horvath and Shelley

(1946) and Eichna et al. (1945) report that when subjects acclimatized to a moderately hot environment are exposed to much hotter environment, they have to re-acclimatize. Their ability to regulate body temperature during work deteriorates until they have made the necessary homeostatic readjustments. That our men were generally successful in reacclimatizing is shown by the fact that their A.I.'s assume a linear relation to the indices of heat stress in subsequent periods. The major exception is one flight (FRA's of Flight 4) in EXP I. We surmise that they required a longer period of readjustment because they were on KP duty in a hot moist mess hall washing dishes. Study of the data for EXP subjects in a similar manner suggests that the same process was operating among them.

Effect of Experimental Nutrient Regimen on Acclimatization Index. Inspection of Table III. 100 and Figure III. 44 brings out a most interesting fact. The acclimatization indices for men on unlimited water changed very little, while the indices for men on restricted water decreased. Since the dry bulb temperatures were comparable in P II and EXP I for tests of Flights 2 and 4, we can apply the "t" test to measure the significance of the difference of the means. In the case of Flight 2 "t" was significant at the 2.5% level; for Flight 4, "t" was significant at the 10% level. These results are highly suggestive and indicate that the index was discriminatory. The magnitude of the differences can perhaps be more readily appreciated when we compare the observed A.I.'s with those predicted from the regression equation A.I. = 23.63 (D.B.T.) - 1549.88 (Tables III. 103 and III. 104).

The residual variation of A.I. after correcting for influence of D.B.T. for the subjects on different experimental regimens have been graphed in Figures III. 45 and III. 46. Study of these figures brings out two patterns. In the experimental period men on limited water exhibited a decrease in the A.I.; those on unlimited water an increase. The patterns tend to contrast more sharply among men on high osmotic intake than among men on low. In fact, for the men on limited water and hard work, all showed a decrease except those on 0/100/0 1000 and 2000 and 2/20/78 1000. For the men on limited water and light work only those on 2/20/78 2000 and 15/52/33 1000 failed to exhibit a decrease in A.I. Men on the diets with high osmotic loads exhibited far greater decreases than those on the low solute loads (c.f., ST 0 and 0/100/0 vs. 30/0/70). These facts suggest that men subsisted on limited water did not deteriorate appreciably if their nutrient regimen was low in osmotically active material (Table III. 62). On the other hand, when the diet was a high osmotic regimen, the A.I. consistently decreased suggesting deterioration of heat tolerance (Table III. 105). These observations support the inferences drawn earlier regarding the increment of rectal temperature during work.

Comment. Another fact may be inferred from study of Figures III. 45 and III. 46. Limitation of water provoked a deterioration in heat tolerance. The deterioration, however, endured only so long as the men subsisted on the particular experimental regimen. When the subjects began "recovery" the acclimatization indices returned to expected values. Indeed in most cases, the A.I. rose above pre-period values. The deterioration caused by the simulated survival experience did not interfere with the process of acclimatization. It may be

concluded then that the mechanisms of acclimatization are independent of nutrient mixture. In the face of restricted water, heat tolerance will diminish. Once the water deficit is restored, the subject will clearly manifest the acclimatization which has accrued during the period of dehydration. In a later section we shall present evidence that the deleterious effects of water restriction were manifest not only physiologically but also by development of striking clinical dysfunction.

TABLE III. 99.

PRE-PERIOD DATA ON ACCLIMATIZATION INDEX
($L/^{o}F$)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.24	0.07	31.1	21	0.60	0.29	49.0
2	21	0.27	0.11	40.3	20	0.56	0.16	28.9
3	21	0.29	0.10	34.5	20	0.66	0.37	56.4
4	21	0.33	0.17	51.7	22	0.53	0.18	34.0
FRA	11	0.29	0.12	39.6	11	0.63	0.12	19.0

TABLE III. 100

ACCLIMATIZATION INDEX
(ml/°F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	235	539	430	709	688	235	1017	514	882	688
	L	365	497	464	500	400	153	524	372	679	907
0/100/0	U	239	543	587	570	401	216	503	613	818	749
1000	L	310	585	610	628	400	262	444	386	766	854
0/100/0	U	342	1273	753	774	500	338	578	428	780	743
2000	L	504	418	530	672	466	342	471	372	942	916
2/20/78	U	216	418	522	692	476	374	696	484	428	951
1000	L	178	334	424	782	410	328	606	388	1251	1446
2/20/78	U	237	417	741	---	---	196	433	843	502	995
2000	L	227	638	368	724	534	450	433	444	548	490
15/52/33	U	180	623	803	474	706	336	678	662	841	562
1000	L	271	910	463	---	---	278	412	506	724	844
15/52/33	U	262	572	1089	541	---	253	370	826	526	685
2000	L	146	570	330	536	519	434	1019	749	1137	816
15/52/33	U	266	596	782	417	444	216	510	357	464	569
3000	L	218	626	397	636	433	330	432	---	---	---
30/0/70	U	152	638	749	626	604	288	561	423	516	602
1000	L	350	706	572	675	446	656	482	284	943	888
30/0/70	U	306	430	489	1082	478	480	522	1226	574	944
2000	L	232	510	424	582	565	304	517	292	584	864
FRA	U	204	633	945	662	548	297	602	624	681	820
	L	217	708	874	706	477	429	588	476	785	1138

TABLE III. 101

MEAN ACCLIMATIZATION INDEX
(ml/°F)

Flight	P I M±s.d.	P II M±s.d.	EXP I M±s.d.	R I M±s.d.	R II M±s.d.
		FRA Subjects*			
1	204	633	945	662	548
2	217	708	874	706	477
3	297	602	624	681	820
4	429	588	476	785	1138
		EXP Subjects			
1	242± 75	597±292	682±283	713±191	560±144
2	278±112	565±163	459± 99	633±123	458± 68
3	290±100	655±369	634±404	684±312	738±222
4	330±170	533±181	429±201	849±257	918±269

*S.d. not calculated; three subjects in Flights 1, 3, and 4; two in Flight 2.

TABLE III. 102

CORRELATION BETWEEN ACCLIMATIZATION INDICES AND INDICES OF HEAT STRESS

Index	b*	r	Syx	P
	FRA Subjects (All Periods)			
Dry Bulb	30.38	+0.74	±154	<0.001
Wet Bulb	30.22	+0.73	±157	<0.001
Effective	36.12	+0.79	±141	<0.001
"P.4.S.R."**	407.48	+0.31	±218	<0.200
	EXP Subjects (Pre- and Recovery Periods)			
Dry Bulb	23.63	+0.73	±113	<0.001
Wet Bulb	17.63	+0.56	±151	<0.025
Effective	21.14	+0.59	±147	<0.020
"P.4.S.R."**	285.00	+0.66	±137	<0.010

*b = scope in regression equation Y = a+bX

**"P.4.S.R" = Predicted Four-Hour Sweat Rate

TABLE III. 103

PREDICTED ACCLIMATIZATION INDICES
(ml/°F)

A. EXP Subjects*

Flight	Period P I	P II	EXP	R I	R II
1	350	667	719	463	499
2	333	690	693	534	371
3	393	697	631	577	728
4	454	686	678	572	671

B. FRA Subjects**

Flight	P I	P II	EXP	R I	R II
1	338	745	812	483	529
2	316	775	778	575	365
3	392	784	699	629	824
4	471	769	760	623	751

*A.I. = 23.63(D.B.T.)-1549.88
**A.I. = 30.38(D.B.T.)-2104.92

TABLE III. 104

COMPARISON OF OBSERVED AND PREDICTED SWEAT RATES FOR EXP SUBJECTS IN EXPERIMENTAL PERIOD

Flight	Acclimatization Index Observed	Predicted	Difference
1	682	719	-37
2	459	693	-234
3	634	631	+3
4	429	678	-249

TABLE III. 105

EFFECT OF SOLUTE LOAD* ON ACCLIMATIZATION INDEX OF MEN ON RESTRICTED INTAKE OF WATER

	Acclimatization Index					
	Low Solute Load			High Solute Load		
Flight	P II	EXP I	% Change	P II	EXP I	% Change
2	473	515	+9	597	424	-15
4	431	381	-12	705	471	-33

*"Low solute load" regimens: 0/100/0 1000 and 2000. "High solute load" regimens: 15/52/33 2000 and 3000 and 30/0/70 1000 and 2000.

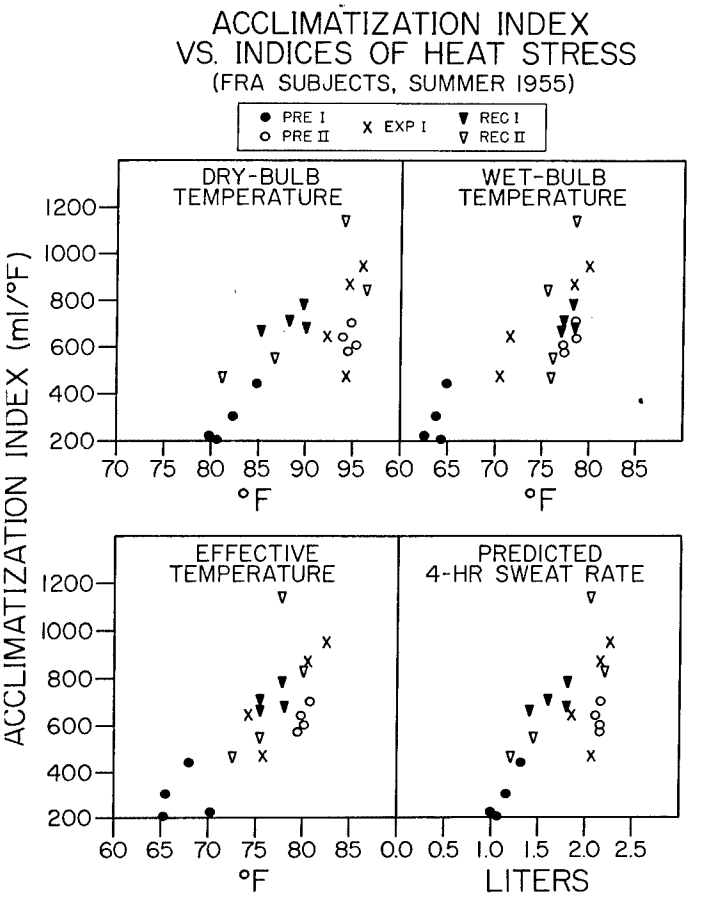


FIGURE III. 43. ACCLIMATIZATION INDEX VS. INDICES OF HEAT STRESS: FRA SUBJECTS.

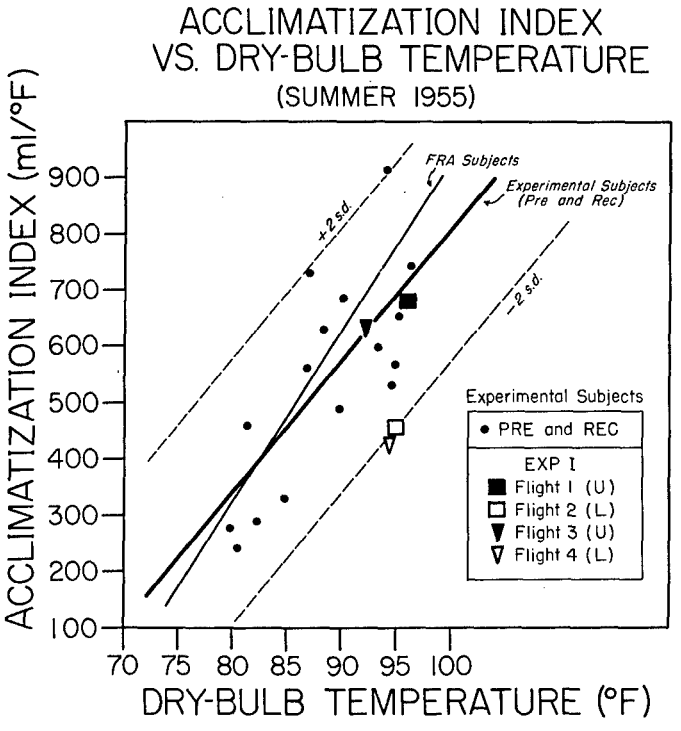


FIGURE III. 44. ACCLIMATIZATION INDEX VS. DRY-BULB TEMPERATURE: ALL SUBJECTS.

FIGURE III. 45. HEAT ACCLIMATIZATATION TEST. ACCLI-MATIZATION INDEX DEVIATIONS: HARD WORK.

FIGURE III. 46. HEAT ACCLIMATIZATION TEST, ACCLI-MATIZATION INDEX DEVIATIONS: LIGHT WORK.

HEAT ACCLIMATIZATION TEST : : : : :
ACCLIMATIZATION INDEX DEVIATIONS

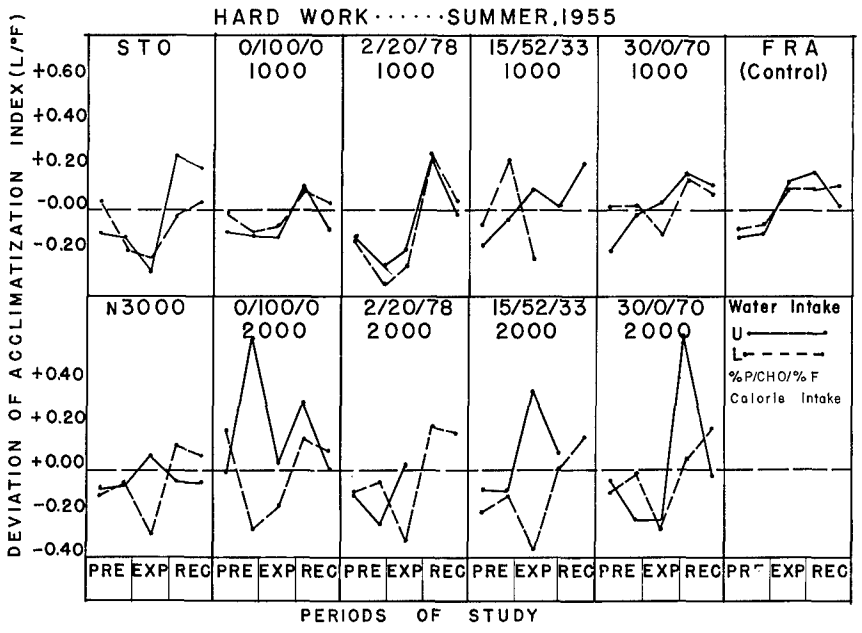


FIGURE III. 45.

HEAT ACCLIMATIZATION TEST : : : : :
ACCLIMATIZATION INDEX DEVIATIONS

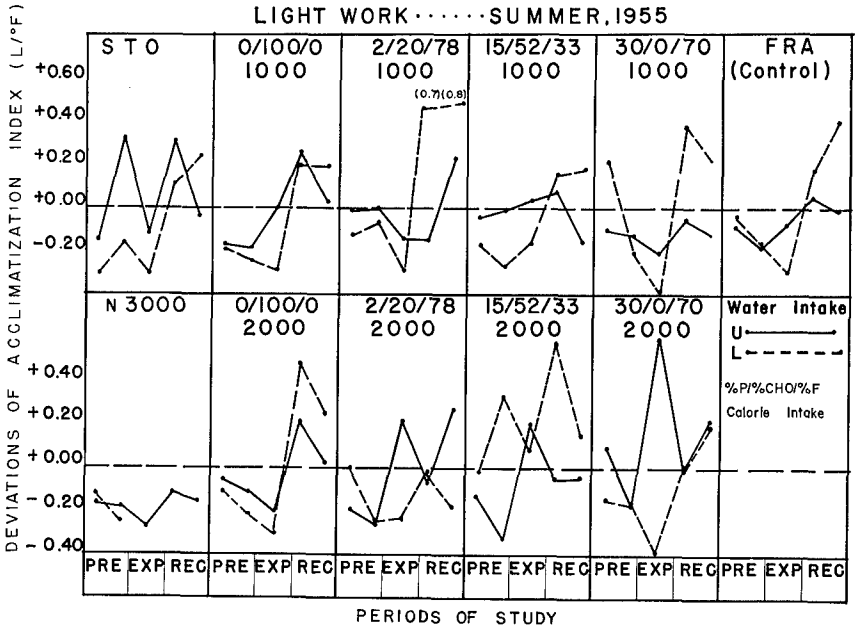


FIGURE III. 46.

5. Pulse Rate

The pulse rate was measured with the subject reclining just before the start of the paced march and again immediately at the end of the march. The pre-period data on initial pulse rate, final pulse rate, and work increment of pulse rate are given in Table III. 106. The initial pulse rates ranged from 76 to 85. The values exceeded resting pulse rates which will be presented later in a section on Cardiovascular Function. They are about what might be expected under the circumstances of this test. The variance was reasonable and there were no significant differences from P I to P II.

The final pulse rates ranged from 97 to 127. All means increased from P I to P II; in the cases of Flight 3 and the FRA's the increase was significant. The increase was not unexpected in the light of evidence that heat tolerance decreased from P I to P II with the onset of hot weather. The variance of the final pulse rate was of the same order of magnitude as the initial pulse rate.

The increment of pulse rate ranged from 12 to 20. Four of five groups exhibited a greater work increment in P II than in P I. The upward trend, however, was, in no case, significant, primarily because the variance was relatively great.

Initial Pulse Rate and Regimen. The pulse rates for the subjects are summarized according to diet and period in Table III. 107. In general, the initial pulse rate was lower in the experimental period than in the pre-period. Among the hard work groups, a decrease was noted among all regimens except 0/100/0 1000 U, 0/100/0 2000 U, 2/20/78 2000 U, and 30/0/70 1000 L. Among the light work groups the exceptions were 0/100/0 2000 L and 30/0/70 1000 U and L. No significant trends are evident when different levels of caloric intake, different diets, and different water intakes are compared. It is surprising that the bradycardia of caloric restriction was not evident. We suggest that under the conditions of this test, emotional factors tended to obscure that reaction.

Final Pulse Rate and Regimen. Data on final pulse rate are detailed in Table III. 108 and graphically presented in Figures III. 47 and III. 48. Examination of these data indicates that the march was not especially taxing. Pulse rates seldom exceeded 140. The regimens which did provoke high pulse rates were, for the hard work men (Figure III. 47): 2/20/78 1000, 15/52/33 1000, and 30/0/70 1000 and 2000. In 3 of the four instances, it was the limited water regimen which was the important element. Among the men doing light work (Figure III. 48), it was primarily 30/0/70 1000 and 2000 which was associated with high final pulse rates. Among these men, however, the cardiac acceleration was not as pronounced as among the men doing hard work. The outstanding trend is that the meat bar provoked a reduced cardiovascular efficiency. Greater effort was required to accomplish the moderately difficult task of the paced march.

Now it has been observed (Eichna et al., 1945) that pulse rate and rectal temperature do not consistently correlate with physical performance in heat. Among our men on meat bar, however, there was a good parallel. These men, especially when water was limited, sustained high rectal temperatures, high final pulse rates, and marked deterioration of physical performance (See Clinical

Reactions below). Among other men, however, a high pulse rate did not correlate with physical performance. We thus agree that pulse rate after work in heat is not an independently reliable index of performance or state of acclimatization.

In general, pulse rates of the recovery period were not remarkable. Men who had exhibited high rates in the experimental period had lower values in recovery. Men on ST 0 (Hard Work) and 0/100/0 2000 (Light Work) were the only ones exhibiting high rates in recovery.

The increment of pulse rate (Table III. 109) varied in much the same manner as the final pulse rate. These data will not be discussed in detail.

Influence of Ambient Weather on Pulse Rate and Rectal Temperature. Using only data for FRA subjects, an analysis was made of the correlation between pulse rate and D.B.T. and between rectal temperature and D.B.T. (Figure III. 49). Neither final pulse rate nor increment of pulse rate was correlated with the D.B.T. On the other hand, there was a striking correlation between D.B.T. and rectal temperature. In general, the higher the ambient temperature, the lower the final rectal temperature and the smaller the increment of rectal temperature during work. The deviant points in either case are for P II. We conclude that this striking relation is a manifestation of acclimatization to heat. The deviant points represent the reaction of re-acclimatization already alluded to. To our knowledge, this demonstration of acclimatization is unique. Studies in climatic chambers have not revealed such a finding so strikingly, principally because in such work the ambient temperature is fixed.

TABLE III. 106

PRE-PERIOD DATA: FINAL AND INITIAL PULSE RATES AND RISE IN PULSE RATE
(beats/min)

Flight	P I N	P I M	P I s.d.	P I C.V.	P II N	P II M	P II s.d.	P II C.V.
				Final Pulse Rate				
1	22	112	16	14.3	21	116	18	15.5
2	21	97	16	16.5	20	107	15	14.0
3*	21	110	12	10.9	20	124	16	12.9
4	21	106	14	13.2	22	109	15	13.8
FRA*	12	103	14	14.0	10	118	19	16.5
				Initial Pulse Rate				
1	22	83	12	14.6	21	85	15	17.3
2	21	76	9	11.4	20	81	13	15.5
3	21	82	11	12.9	20	84	10	11.8
4	21	80	9	11.9	22	78	8	10.7
FRA	12	78	9	11.1	11	85	6	7.4
				Rise in Pulse Rate				
1	22	30	17	55.5	21	32	12	38.8
2	21	21	12	57.1	20	27	14	54.3
3	21	29	12	43.1	20	40	15	36.2
4	21	27	13	47.7	22	32	17	54.7
FRA	12	25	17	71.7	10	34	20	58.8

"t" test on P I vs. P II

*P less than 0.001

TABLE III. 107

PULSE RATE BEFORE EXERCISE
(beats/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	78	82	63	79	93	79	84	60	90	93
	L	76	82	64	81	89	72	77	56	85	89
0/100/0	U	92	87	92	86	96	85	86	64	94	84
1000	L	82	104	61	78	99	71	74	63	81	84
0/100/0	U	74	76	87	86	80	82	84	69	82	100
2000	L	73	63	65	71	82	91	78	85	86	100
2/20/78	U	83	84	63	94	72	73	82	68	92	72
1000	L	77	99	65	84	94	81	79	77	89	79
2/20/78	U	100	80	84	--	--	85	82	72	100	77
2000	L	83	78	70	86	82	81	75	65	82	82
15/52/33	U	87	86	63	90	90	75	83	63	85	80
1000	L	67	76	68	--	--	80	87	74	94	92
15/52/33	U	75	84	65	72	--	87	88	74	89	89
2000	L	79	72	62	76	76	89	81	74	72	87
15/52/33	U	88	92	82	88	82	95	92	81	103	94
3000	L	81	88	70	80	79	70	70	--	--	--
30/0/70	U	71	87	72	90	82	72	84	56	100	92
1000	L	75	66	76	84	76	90	83	70	101	96
30/0/70	U	81	96	67	82	79	82	75	95	102	89
2000	L	69	78	68	76	84	81	74	84	104	96
FRA		78	85	80	86	79	78	85	80	86	79

TABLE III. 108

PULSE RATE AFTER EXERCISE
(beats/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	118	126	139	115	117	118	132	129	117	126
	L	104	115	140	163	128	108	107	115	116	127
0/100/0	U	128	121	119	130	126	109	113	126	122	111
1000	L	114	120	112	119	116	112	98	111	118	107
0/100/0	U	95	100	111	114	121	101	114	107	122	114
2000	L	88	96	117	105	113	123	122	126	124	146
2/20/78	U	100	107	112	110	112	112	127	118	120	124
1000	L	91	114	145	133	104	98	111	105	111	117
2/20/78	U	110	110	93	---	---	107	121	113	128	115
2000	L	98	122	122	113	106	93	109	109	112	118
15/52/33	U	109	102	143	121	137	101	113	110	126	113
1000	L	89	94	98	---	---	107	100	109	97	121
15/52/33	U	108	113	115	100	---	111	122	96	113	118
2000	L	100	103	86	108	88	116	121	107	101	117
15/52/33	U	133	113	133	128	122	109	127	119	131	130
3000	L	107	99	94	95	105	88	113	---	---	---
30/0/70	U	113	108	112	128	113	110	124	144	120	122
1000	L	88	106	155	124	132	106	117	135	115	130
30/0/70	U	104	124	112	108	111	113	135	122	137	120
2000	L	87	102	158	100	102	108	99	128	90	120
FRA	U	93	101	103	105	102	114	139	127	127	120
	L	105	117	104	98	104	98	111	114	105	102

TABLE III. 109

RISE IN PULSE RATE
(beats/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	40	43	76	36	24	38	48	70	28	34
	L	28	32	76	82	39	35	30	56	31	37
0/100/0	U	36	39	27	44	30	24	27	72	23	27
1000	L	32	16	51	41	17	46	24	48	37	23
0/100/0	U	26	24	24	28	49	19	30	38	40	14
2000	L	16	23	52	34	31	32	44	26	38	46
2/20/78	U	17	23	49	16	40	44	45	50	28	52
1000	L	14	15	80	49	10	17	32	23	22	38
2/20/78	U	10	30	9	--	--	22	39	41	28	38
2000	L	15	44	52	27	24	12	34	44	40	36
15/52/33	U	22	47	70	31	47	26	30	48	41	33
1000	L	22	18	30	--	--	27	13	35	3	29
15/52/33	U	38	29	50	28	--	24	34	22	24	29
2000	L	21	31	24	32	12	27	40	33	29	30
15/52/33	U	45	21	56	40	40	14	35	38	28	36
3000	L	26	13	24	15	26	18	43	--	--	--
30/0/70	U	32	21	40	38	31	38	40	88	20	30
1000	L	13	40	79	40	56	16	39	65	19	34
30/0/70	U	23	28	45	26	32	31	60	27	35	31
2000	L	18	24	90	24	18	27	25	44	-14	24
FRA	U	13	16	21	23	20	29	55	51	38	46
	L	37	31	30	16	19	20	32	27	17	33

FIGURE III. 47. FINAL PULSE RATE: HARD WORK.

FIGURE III. 48. FINAL PULSE RATE: LIGHT WORK.

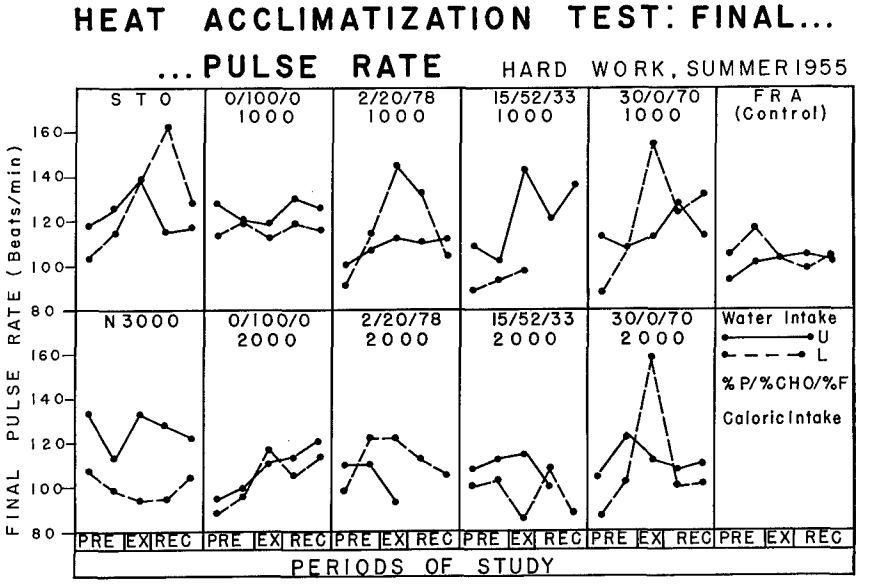


FIGURE III. 47.

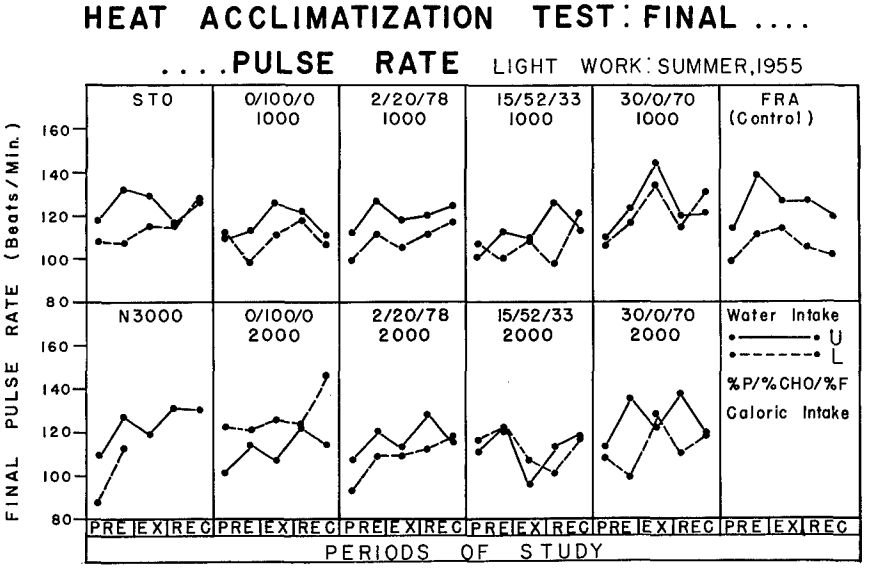


FIGURE III. 48.

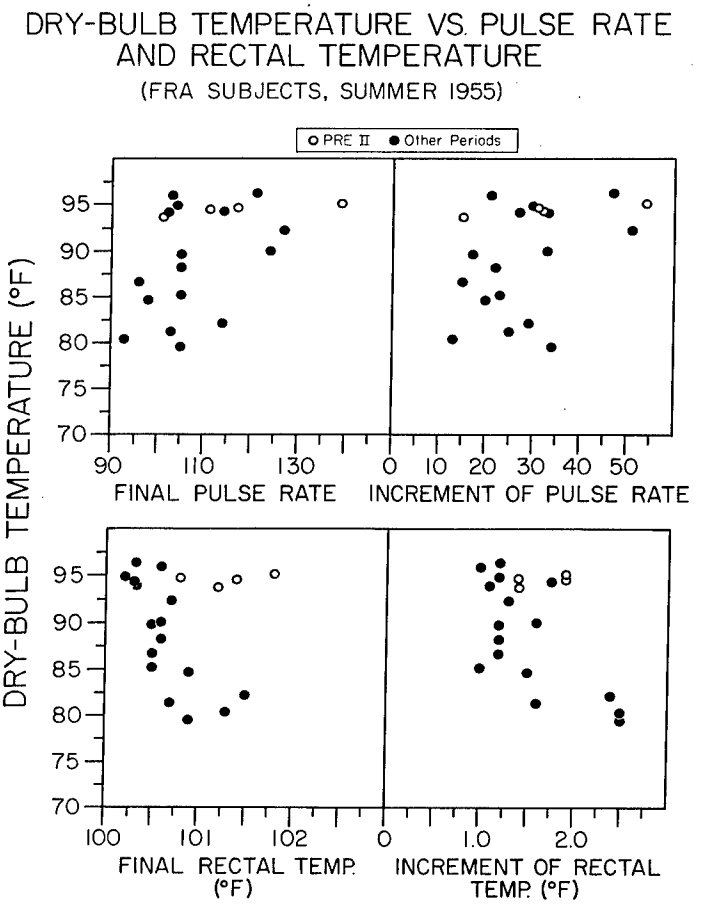


FIGURE III. 49. DRY-BULB TEMPERATURE VS. PULSE RATE AND RECTAL TEMPERATURE: FRA SUBJECTS.

6. Skin Temperature

The temperature of the skin surface was measured at two sites on two occasions during the heat acclimatization test: (1) before and after the test and (2) under the glove and on uncovered skin of upper arm ipsilateral with the "glove" temperature. We shall first present data on the skin temperature under the glove. This temperature was assumed to be representative of the thermal conditions within the impermeable barrier and was used for study of effect of skin temperature on volume and composition of glove sweat.

Skin Temperature under Glove. Pre-period data on final and initial skin temperature and the increment under the glove are summarized in Table III. 110. The standard deviation was of the order of 1.0°F. All group means of initial temperature increased significantly from P I to P II. The final skin temperature

behaved similarly. The final temperature increased more than the initial, for in all cases the increment of skin temperature during the march was greater in P II than in P I. In three of the five groups the increase was highly significant by the "t" test. This upward trend of skin temperature was correlated with the increase in environmental temperature from P I to P II.

Regimen and skin temperature under glove: Data on initial, final, and increment in skin temperature under the glove are given in Tables III. 111, III. 112, and III. 113 for the several phases of the summer test. Examine first the data on initial skin temperature. For the men doing hard work, during the experimental period, men on limited water had higher temperatures under the glove than men on unlimited water in all cases except 0/100/0 1000 and 15/52/33 2000. No such trend is evident in the pre-periods, a fact which tends to rule out individual variability. The trend is particularly significant since the weather was hotter during the test of Flight 1 than of Flight 2 (Table III. 84). In the case of Flight 2, the weather of P II was very similar to that for EXP I. Thus, we can compare paired means with control values. Again it is noted that skin temperature increased in many instances, especially among the high solute regimens 15/52/33 3000 and 30/0/70 1000 and 2000. Among men on unlimited water (Flight 1) such an increase is not evident even though the weather was warmer in EXP I than in P II (Table III. 84).

For the men doing light work these trends are not so clear cut. Comparing values in EXP I we note that the temperature measured on skin of men on limited water was higher than among men on unlimited in seven of nine comparisons; exceptions are 2/20/78 1000 and 30/0/70 2000. Here, however, the ambient temperature was higher during the test of Flight 4 than during the test of Flight 3. The weather of P II and EXP I was similar for P II and EXP I and when skin temperatures are compared, all men exhibit lower values in EXP I than in P II. The data for the light work groups do not support the data for the hard work groups.

When a similar analysis is made for the final skin temperature under the glove, we fail to find any convincing trends in relation to water, work, or nutrient regimen (Table III. 112). The paired means exhibit much less variability from regimen to regimen presumably because the march tended to bring the men into a more uniform condition than they were prior to the march. The effect of weather is clearly evident for highest skin temperatures tended to appear in P II and EXP I---the periods of hottest weather. Finally, we find that the rise in temperature under the glove does not discriminate among work, water, or nutrient mixture (Table III. 113). Weather again was the major variable, for the largest increments coincide generally with the warmest weather.

Skin Temperature of Upper Arm. Pre-period data on skin temperatures of the upper arm are given in Table III. 114. Because the thermistor thermometer had been calibrated for the range 90° to 110°F, we were unable to measure accurately values that fell below 90°F. We found that sweating frequently caused the skin temperature to fall below this level. In P I, when the weather was relatively cool, most of the initial temperatures were above 90°F. The average was close to 93.0°F. In contrast, most of the final skin temperatures were below 90°F

due to evaporation of sweat. The weather became hot in P II. No values below 90°F were observed. The initial skin temperature averaged close to 94.7°F. The final skin temperatures again were lower in three cases but unchanged in two.

Regimen and Skin Temperature of Upper Arm: Data on initial skin temperature during the five tests are detailed in Table III. 115. The major variable was the ambient weather. No consistent trends are evident in relation to work, water, or nutrient combination.

The final upper arm skin temperatures are detailed in Table III. 116. Again weather was the major determinant of the variations. Water, work, and nutrient combination cannot be regularly correlated with any of the variations.

Ambient Temperature and Skin Temperature. These analyses have pointed to ambient weather as the most significant factor causing the variations in skin temperature noted in the preceding tables. A statistical study was made of the final "glove" temperature for the FRA subjects (Figure III. 51). The final skin temperatures of these men were significantly correlated with the ambient D.B.T. ($r = +0.91$; P less than 0.001). There was no relationship between final rectal temperature and final glove temperature (Figure III. 51).

TABLE III. 110

PRE-PERIOD DATA ON SKIN TEMPERATURES
UNDER GLOVE: FINAL, INITIAL, RISE
(^{o}F)

Flight	P I N	P I M	P I s.d.	P I C.V.	P II N	P II M	P II s.d.	P II C.V.
		Final Temperature Under Glove						
1*	22	95.1	1.0	1.0	21	98.8	0.6	0.6
2*	21	95.3	0.8	0.9	20	98.8	0.3	0.3
3*	21	96.5	0.9	0.9	20	99.2	0.3	0.3
4*	21	96.0	0.8	0.8	22	99.2	0.4	0.4
FRA*	12	95.9	1.3	1.3	11	99.1	0.7	0.7
		Initial Temperature Under Glove						
1*	22	92.4	1.2	1.3	21	95.5	1.0	1.0
2*	21	93.4	0.9	1.0	20	95.3	0.8	0.8
3*	21	92.8	1.0	1.0	20	94.9	1.0	1.0
4*	21	93.2	1.1	1.1	22	95.5	0.7	0.7
FRA*	12	94.3	1.0	1.0	11	96.0	0.6	0.6
		Temperature Rise Under Glove						
1	22	2.7	1.5	55.5	21	3.4	1.1	32.3
2*	21	2.0	1.1	57.9	20	3.5	0.9	25.7
3	21	3.7	1.2	31.6	20	4.2	1.1	25.6
4**	21	2.7	1.1	40.7	22	3.7	1.0	27.0
FRA*	12	1.7	0.7	41.2	11	2.9	1.0	34.4

"t" test on P I vs. P II
*P less than 0.001
**P less than 0.005

TABLE III. 111

INITIAL SKIN TEMPERATURE UNDER GLOVE
(°F)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	92.6	95.1	94.4	94.0	94.0	92.7	94.4	92.2	93.4	93.9
	L	94.0	94.7	94.9	93.7	94.9	94.1	95.5	92.8	95.6	95.7
0/100/0	U	92.0	95.6	96.5	95.0	95.7	92.6	95.4	93.8	95.0	94.2
1000	L	92.8	95.2	95.2	93.9	95.5	92.8	95.4	94.4	94.8	94.4
0/100/0	U	92.4	95.0	94.8	95.0	93.4	91.7	94.0	92.2	92.7	94.6
2000	L	93.4	95.5	96.0	94.6	94.7	93.3	95.2	95.1	94.5	94.0
2/20/78	U	92.4	94.9	92.6	92.8	96.3	93.4	95.2	93.4	94.7	94.9
1000	L	93.6	95.8	95.2	94.8	96.4	93.8	94.8	92.4	96.0	95.2
2/20/78	U	93.1	95.1	94.9	----	----	92.7	93.6	91.4	93.5	93.6
2000	L	94.8	96.1	95.4	95.0	96.4	93.1	95.8	92.7	94.6	94.2
15/52/33	U	92.6	95.8	93.6	95.3	94.2	91.6	96.4	92.5	94.3	94.0
1000	L	92.6	95.2	95.9	----	----	92.8	95.5	93.4	95.3	93.8
15/52/33	U	91.8	96.4	96.3	97.0	----	93.6	95.4	93.0	95.3	95.0
2000	L	92.8	96.2	96.3	94.4	96.6	93.5	96.0	93.8	95.0	96.0
15/52/33	U	92.7	95.6	95.2	95.0	95.4	94.0	95.0	94.0	94.3	94.6
3000	L	93.0	95.2	96.0	95.2	94.7	93.2	95.4	----	----	----
30/0/70	U	94.6	96.1	94.6	95.4	95.2	93.6	95.2	93.3	95.0	95.2
1000	L	93.0	94.8	97.2	95.3	96.0	93.1	94.7	93.4	94.8	93.7
30/0/70	U	91.6	95.4	94.5	94.2	94.0	92.8	95.2	93.7	94.2	94.0
2000	L	93.2	94.8	95.6	94.4	95.5	92.0	95.6	93.5	94.8	94.6
FRA		94.3	96.0	95.2	95.0	95.1	94.3	96.0	95.2	95.0	95.1

TABLE III. 112

FINAL SKIN TEMPERATURE UNDER GLOVE
($^{\circ}$F)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	95.2	99.1	98.5	97.3	97.1	97.2	99.1	97.5	98.2	97.5
	L	95.3	99.0	98.5	97.9	96.2	95.7	99.6	98.2	98.0	97.7
0/100/0	U	94.0	99.2	98.3	95.7	96.2	96.4	99.0	97.0	98.2	96.9
1000	L	95.2	99.0	98.0	97.8	95.8	96.0	99.3	98.4	97.5	97.6
0/100/0	U	95.4	98.6	98.4	96.9	97.2	96.4	98.8	97.1	98.0	97.2
2000	L	95.6	98.4	98.0	96.7	96.4	96.4	99.6	98.2	97.7	98.1
2/20/78	U	95.0	98.8	98.2	97.4	98.1	96.4	99.2	96.8	98.1	97.8
1000	L	96.2	99.0	99.2	97.4	97.2	96.2	98.9	97.6	96.9	98.1
2/20/78	U	95.2	98.4	97.9	----	----	96.0	99.2	94.8	99.0	97.7
2000	L	97.2	99.2	99.2	96.9	97.2	95.6	99.2	97.8	98.2	98.0
15/52/33	U	96.1	99.0	98.2	97.2	97.4	95.6	99.2	97.0	98.4	96.9
1000	L	94.2	98.6	99.1	----	----	95.2	98.9	98.0	96.6	97.6
15/52/33	U	93.8	98.4	98.6	97.0	----	96.6	99.1	97.7	98.3	97.4
2000	L	94.2	98.5	98.5	97.0	96.8	96.7	97.8	98.0	96.8	97.8
15/52/33	U	95.6	99.4	99.0	96.6	96.5	96.2	99.2	97.6	97.3	97.3
3000	L	94.3	98.4	99.0	95.8	95.2	96.1	99.4	----	----	----
30/0/70	U	94.9	98.9	98.2	96.9	96.8	97.0	99.0	97.0	98.1	97.6
1000	L	95.6	98.7	99.9	97.4	96.0	96.5	99.3	98.1	97.6	97.8
30/0/70	U	94.8	98.7	98.2	97.0	97.8	96.7	99.8	97.8	98.4	98.2
2000	L	95.3	99.0	99.9	97.2	95.9	95.4	99.2	98.2	97.7	98.2
FRA		95.9	99.1	98.3	97.1	97.4	95.9	99.1	98.3	97.1	97.2

TABLE III. 113

RISE IN TEMPERATURE UNDER GLOVE
(^{o}F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	2.6	4.0	4.1	3.3	3.1	4.4	4.6	5.3	4.7	3.5
	L	1.3	3.8	3.6	4.2	1.3	1.6	3.7	5.4	2.4	2.0
0/100/0	U	2.0	3.6	1.8	0.7	0.5	3.8	3.6	3.2	3.2	2.7
1000	L	2.4	3.8	2.8	3.9	0.3	3.3	4.0	4.0	3.6	3.2
0/100/0	U	3.0	3.6	3.6	2.0	3.7	4.8	4.8	4.9	5.4	2.6
2000	L	2.2	2.8	2.1	2.0	1.6	3.1	4.4	3.1	3.2	4.1
2/20/78	U	2.6	4.0	5.6	4.6	1.8	3.1	3.9	3.4	3.5	2.9
1000	L	2.7	3.2	4.0	2.6	1.5	2.3	4.1	5.2	0.8	3.0
2/20/78	U	2.0	3.3	3.0	---	---	3.4	5.5	3.2	5.6	4.0
2000	L	2.5	3.1	3.8	1.8	0.8	2.5	3.4	5.0	3.6	3.8
15/52/33	U	3.6	3.2	4.5	2.4	3.2	4.0	2.8	4.5	4.1	3.0
1000	L	1.6	3.4	3.2	---	---	2.4	3.4	4.6	1.3	3.8
15/52/33	U	2.0	2.0	2.3	1.6	---	2.9	3.7	4.8	3.0	2.4
2000	L	1.5	2.3	2.2	2.6	0.2	3.2	1.8	4.3	1.8	1.8
15/52/33	U	3.0	3.8	3.8	1.6	1.1	2.2	4.3	3.6	3.0	2.8
3000	L	1.3	3.2	3.0	0.6	0.6	3.0	4.0	---	---	---
30/0/70	U	3.3	2.9	3.6	1.4	1.5	3.4	3.8	3.7	3.1	2.4
1000	L	2.6	3.8	2.6	2.1	1.6	3.2	4.6	4.7	2.8	4.1
30/0/70	U	3.3	3.3	3.7	2.8	3.8	4.0	4.6	4.0	4.2	4.2
2000	L	2.0	4.2	4.3	2.8	0.4	3.5	3.6	4.7	2.9	3.6
FRA		1.6	2.9	3.3	2.1	2.3	1.6	2.9	3.3	2.1	2.3

TABLE III. 114

PRE-PERIOD DATA ON SKIN TEMPERATURE OF UPPER ARM
(^{o}F)

Skin Temperature	P I Groups of Subjects 1	2	3	4	FRA	P II Groups of Subjects 1	2	3	4	FRA
Number of subjects having final skin temperature below 90^{o}F	--	19	19	21	7	0	0	0	0	0
Number of subjects having final skin temperature above 90^{o}F	--	2	2	0	2	21	20	20	22	11
Mean skin temperature above 90^{o}F	--	90.2	90.6	--	93.6	93.2	93.2	94.4	93.8	94.6
Number of subjects having initial skin temperature below 90^{o}F	--	1	0	1	0	0	0	0	0	0
Number of subjects having initial skin temperature above 90^{o}F	--	20	21	20	9	21	20	20	22	11
Mean skin temperature above 90^{o}F	--	92.7	93.5	93.1	93.0	94.7	94.7	94.3	94.8	94.7

TABLE III. 115

INITIAL SKIN TEMPERATURE OF UPPER ARM
(90°F)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	----	93.8	96.2	91.4	91.3[1]	93.3	94.8	94.8	91.7	92.6[1]
	L	92.4	94.8	95.2	92.5	93.1	93.4	95.0	94.8	94.2	92.9
0/100/0	U	----	95.3	95.9	93.0	90.0	92.7[1]	93.4	93.4	93.3	93.2
1000	L	92.9	94.5	94.8	93.2	94.5	93.7[1]	94.8	94.6	93.0	94.2
0/100/0	U	----	94.6	96.0	93.1	92.0[1]	93.2	93.8	93.2	91.7	92.6
2000	L	90.7	94.6	95.4	92.7	93.7	91.8	94.4	93.2	92.6	92.8
2/20/78	U	----	94.3	94.8	90.0	91.7	93.8	95.2	93.0	93.5	93.0
1000	L	92.2	94.4	94.8	94.0	94.6	93.6	94.6	93.6	93.4	94.4
2/20/78	U	----	94.4	94.7	----	----	93.2	91.6	92.1	93.3	93.2
2000	L	94.0	95.1	94.2	94.0	94.2	93.6	94.8	94.0	92.2	92.5
15/52/33	U	----	94.4	93.5	92.0	91.4	94.0	94.8	92.3	92.8	92.1
1000	L	93.0	95.0	95.3	----	----	92.8	94.0	93.9	92.6	93.1
15/52/33	U	----	96.2	94.7	91.9	----	94.4	94.8	93.4	92.4	93.6
2000	L	93.6	96.0	95.3	95.0	95.6	94.0	95.0	94.9	93.7	93.5
15/52/33	U	----	95.2	94.6	91.2	93.0	93.4	93.9	94.0	93.0	93.0
3000	L	93.0	94.6	94.9	93.2	94.3	91.8	95.2	----	----	----
30/0/70	U	----	95.4	94.8	91.9	91.8	93.0	93.8	92.8	92.7	93.7
1000	L	91.5[1]	94.2	96.2	94.1	93.2	92.9	94.8	94.1	92.3	93.0
30/0/70	U	----	93.8	95.2	91.0[1]	90.5[1]	94.0	94.9	92.9	94.0	93.0
2000	L	92.0	94.0	95.0	94.3	95.2	93.6	95.4	95.0	93.9	92.2
FRA		93.0	94.7	94.2	93.1	93.3	93.0	94.7	94.2	93.1	93.3

[1]Superscripts refer to occurrence of values less than 90°F.

TABLE III. 116

FINAL SKIN TEMPERATURE OF UPPER ARM
(90°F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	----	92.2	95.1	92.1	92.2	90.0	94.2	90.0	94.4	91.6
	L	90.0	93.0	93.6^{1}	94.7^{1}	90.0	90.0	93.6	93.4^{2}	93.0	92.8^{2}
0/100/0	U	----	92.7	93.7	90.0	90.0	90.0	93.4	91.6^{1}	95.5^{1}	93.6
1000	L	90.0	91.0	93.2	92.2	90.0	90.0	95.7	92.0	92.7	92.2
0/100/0	U	----	94.2	94.9	90.0	96.2^{1}	91.2^{1}	94.7	90.0	93.0	90.9^{1}
2000	L	90.0	92.4	92.9	92.2	90.0	90.0	93.1	91.0^{1}	90.0	91.2
2/20/78	U	----	92.7	94.9	90.0	90.0	90.0	94.9	94.8	94.5	91.2
1000	L	90.0	92.8	94.0	92.4	93.1^{1}	90.0	95.0	94.6^{1}	92.4	92.0
2/20/78	U	----	91.0	94.0	----	----	90.0	94.0	90.0	95.8	94.2^{1}
2000	L	90.0	94.2	94.5	91.8	90.0	90.0	94.5	91.4	90.0	94.5
15/52/33	U	----	94.4	94.4	92.5	93.4	90.0	93.6	90.0	94.8	90.6
1000	L	90.0	92.3	92.0	----	----	90.0	92.7	90.2^{1}	92.2^{1}	92.1
15/52/33	U	----	92.8	91.8	92.8	----	90.0	94.8	90.0	92.2	92.2^{1}
2000	L	90.0	94.2	94.2	90.8	90.0	90.0	93.2	92.4^{1}	93.3^{1}	94.0
15/52/33	U	----	94.2	95.4	91.9	92.1	90.0	94.3	92.8^{1}	93.5^{1}	92.6
3000	L	90.0	94.2	95.0	90.0	90.0	90.0	94.8	----	----	----
30/0/70	U	----	94.6	95.2	94.4^{1}	91.7^{1}	90.0	94.5	90.0	94.2	91.3
1000	L	90.0	94.4	94.0	90.6	90.0	90.0	92.0	92.9^{1}	92.0^{1}	93.3
30/0/70	U	----	94.9	94.2	93.4	93.2	90.0	96.0	93.1	95.4	93.3
2000	L	90.0	92.0	94.5	92.6	90.0	90.0	93.3	90.0	91.0	91.6
FRA		93.6^{7}	94.6	93.6^{3}	92.6^{4}	92.6^{1}	93.6^{7}	94.6	93.6^{3}	92.6^{4}	92.6^{1}

Superscripts refer to occurrence of values less than 90°F.

7. Volume of Glove Sweat

Elbow length gloves were worn on each arm by the marching subjects. At the end of the march, the sweat from both arms was pooled, the volume was measured, and the rate of sweating calculated as ml/hr. This sweat was collected for chemical studies which will be reported in detail in Section 8 (below).

Pre-period data on volume of glove sweat are given in Table III. 117. Within periods the means were surprisingly uniform. There was wide individual variability, but nevertheless several subjects were found who consistently excreted low glove volumes (Table III. 118) and again others consistently produced high volumes (Table III. 119). The reasons for these differences are not readily apparent. Two factors which come to mind are skin temperature and race. Among the "small volume" men (Table III. 118), one/third were Negroes. The expected frequency is one quarter, but it is doubtful that this difference is significant. It is of interest that there were no Negroes among the large volume men (Table III. 119). The sample is small and other data do not support an inference that Negroes sweat less than white persons. The final skin temperatures under the glove were also not helpful. Men with "small volumes" had, on the average, consistently lower skin temperatures.

Mean Skin Temperature, °F

Sweat Volume	P I	P II	EXP I	REC I	REC II
Small	95.5	98.9	98.2	97.3	97.0
Large	96.0	99.2	98.4	97.6	97.6

The differences, however, would not account for the contrasting volumes measured for the two groups.

Regimen and Glove Volume of Sweat. The paired means for the volumes of glove sweat excreted during the five marches are given in Table III. 120. No detailed study of the volume per se has been made. Examination of the table indicates that, in general, the "glove" volumes decrease in EXP I just as did the rate of total body sweating. Nutrient mixture, work, and water were less significant than ambient weather.

Total Body Sweat Loss vs. Glove Sweat Volume. To study whether or not the fluctuations in glove sweat did, in fact, parallel changes in rate of total body sweating, a correlation was made between total body sweat and glove sweat (Figure III. 50), with data from the FRA subjects. A highly significant association was found. All but three of the 57 points fell within ± two standard deviations. This fact demonstrates that glove volumes varied in the same fashion as did rate of total body sweating.

Ambient Weather and Glove Sweat Volume. Final skin temperature under the glove varied directly with ambient D.B.T. (Figure III. 51) but not with final rectal temperature. The glove sweat volume correlated positively and significantly with the final skin temperature under the glove and the increment of

skin temperature under the glove (Figure III. 51). We can conclude then that the major factor causing variations in rate of sweating from period to period was the weather. The ambient environment directly affected the microenvironment within the impermeable barrier and thus the rate at which the eccrine glands elaborated sweat. We have already shown that similar correlations exist for rate of total body sweating and ambient weather. The consistency of the relations between total body sweating and glove sweating will simplify our analysis of data on the chemical composition of the glove sweat.

TABLE III. 117

PRE-PERIOD DATA ON GLOVE SWEAT VOLUME
(ml/hr)

	P I		P II	
Flight	Mean	Range	Mean	Range
1	28	4-118	38	11-87
2	22	5- 41	32	4-78
3	24	5- 59	48	16-99
4	24	6- 42	36	3-65
FRA	29	3- 78	58	27-113

TABLE III. 118

MEN WITH SMALL GLOVE VOLUMES OF SWEAT*
(ml/hr)

Subject No.	Color	P I	P II	EXP I	REC I	REC II
13	W	4	12	12	--	--
14	N	5	11	22	10	5
17	W	8	--	21	10	20
18	W	7	27	11	8	21
41	W	8	11	--	--	23
42	N	6	4	5	11	7
44	W	5	13	28	17	15
45	W	9	33	11	15	21
61	W	5	17	5	17	6
63	W	8	16	15	16	26
68	N	6	3	1	4	--
79	W	8	6	5	12	24
92	W	3	34	39	12	14

*Glove less than 10 ml/hr in P I.

TABLE III. 119

MEN WITH LARGE GLOVE VOLUMES OF SWEAT*
(ml/hr)

Subject No.	Color	P I	P II	EXP I	REC I	REC II
3	W	118	33	27	24	18
4	W	52	48	32	30	16
8	W	52	87	61	45	70
47	W	59	99	40	76	70
56	W	54	94	69	98	95
97	W	78	113	79	74	87
100	W	54	72	92	82	66

*Glove volume greater than 50 ml/hr in P I.

TABLE III. 120

GLOVE SWEAT VOLUME
(ml/hr)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	60	43	33	23	20	26	51	27	36	39
	L	21	36	21	23	27	14	30	16	26	29
0/100/0	U	22	58	54	25	20	22	44	33	46	52
1000	L	21	29	12	18	20	30	44	26	39	36
0/100/0	U	34	50	44	35	56	16	42	32	44	45
2000	L	41	35	24	26	34	33	43	35	39	61
2/20/78	U	5	12	17	10	5	22	52	36	72	53
1000	L	29	50	43	36	38	17	9	12	16	20
2/20/78	U	18	23	27	--	--	46	66	31	30	36
2000	L	22	28	26	40	26	16	19	16	24	17
15/52/33	U	7	27	16	9	20	15	33	20	30	24
1000	L	20	48	47	--	--	16	20	10	24	26
15/52/33	U	24	43	38	48	--	14	22	15	26	23
2000	L	7	8	5	11	7	33	56	40	50	50
15/52/33	U	13	20	24	17	28	28	52	42	43	46
3000	L	8	12	20	16	16	27	44	--	--	--
30/0/70	U	36	56	50	24	40	14	52	17	23	33
1000	L	26	44	40	30	24	33	55	28	48	42
30/0/70	U	30	36	34	40	40	38	73	54	74	68
2000	L	33	39	30	42	40	28	42	31	61	45
FRA		29	58	54	48	44	29	58	54	48	44

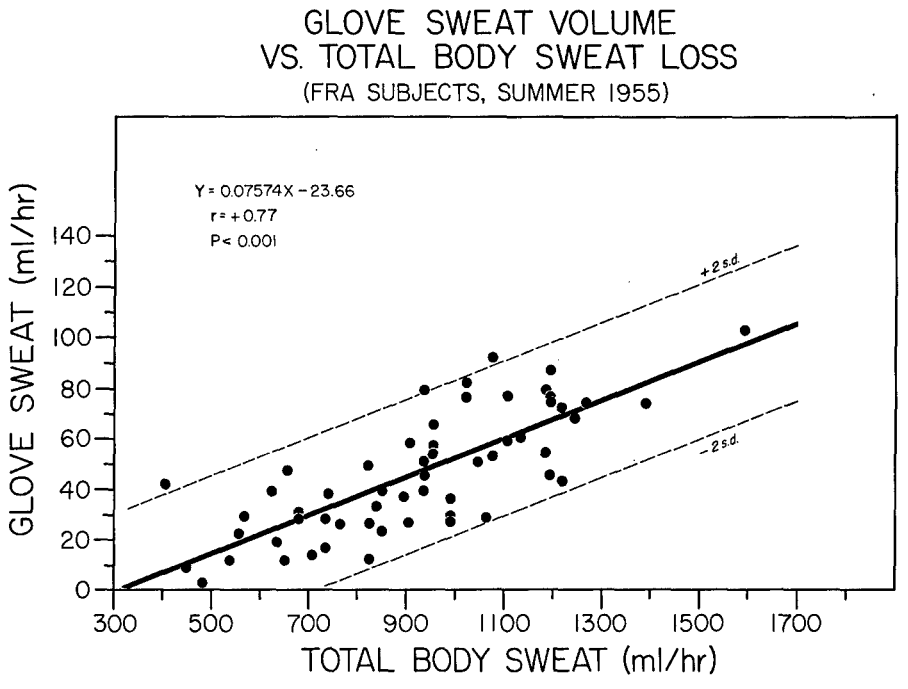


FIGURE III. 50. GLOVE SWEAT VOLUME VS. TOTAL BODY SWEAT LOSS: FRA SUBJECTS.

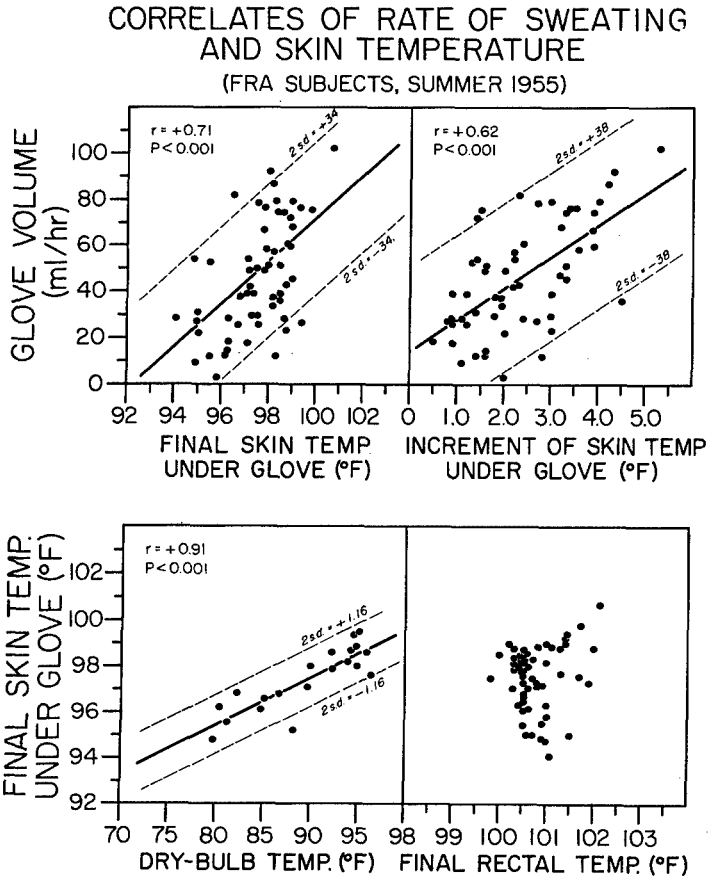


FIGURE III. 51. CORRELATES OF RATE OF SWEATING AND SKIN TEMPERATURE: FRA SUBJECTS.

8. Chemical Studies of Sweat

a. Qualitative Analysis of Sweat

Glove sweat was collected from all subjects participating in all five heat acclimatization tests. These specimens of sweat were subjected to the following qualitative examinations: albumin, glucose, urobilinogen, reaction, ketone bodies.

Albumin. The specimens were tested for albumin with sulfosalicylic acid. All of the specimens were negative. A curious phenomenon, however, was observed. A number of the specimens developed a red color after the sulfosalicylic acid had been added. This red color was also observed in some specimens when exercise and post-exercise urinary specimens were similarly analyzed. A study was made of this phenomenon (Table III. 121). The red color was observed far more frequently in sweat than in urine. Ten specimens contained the red color in PRE II. The red color then persisted in the specimens of sweat collected during the remainder of the study. The red color did not appear in the exercise and post-exercise urine until the recovery period, and even then the frequency was lower among the urines than among the sweats. The appearance of the red color was not restricted to the same subjects on all occasions. When the red coloration developed in urinary specimens there was no correlation with the sweat collected from the same subjects. We have no idea what chemical substance or groups of substances was responsible for this color reaction. It is possible that the subjects' responses to exposure to heat had something to do with the appearance of this substance in the body. During the PRE I the weather was cool; the red color was seen in neither urine nor sweat. In PRE II the weather became hot and continued hot for the remainder of the study; the red color was then observed in every test.

Glucose. All specimens were negative when tested with Clinitest Tablets.

Urobilinogen. All specimens were negative.

Reaction. The pH was measured with Hydrion Papers. All of the specimens fell within the range 4.5 to 5.5.

Ketone Bodies. The specimens of glove sweat were tested for the presence of ketone bodies by means of the Rothera reaction. A wide variety of colors was observed (Tables III. 122, III. 123, III. 124, and III. 125): blue, green, yellow, pink, purple, blue-green, blue-purple, and yellow-green. Only three specimens failed to develop any color at all. The intensity of these colors ranged all the way from +1 to +4. This intriguing display of colors poses a very intriguing analytical problem, for the chemical compounds which might cause these colors are various. The purple color was undoubtedly caused by the presence of acetoacetic acid and acetone, and the blue color by pyruvic acid. Previous experiments with this reaction have indicated that ethylacetoacetate will cause a yellow color when tested by the Rothera reaction (Sargent and McArthur, 1953). What compounds are responsible for the green and pink colors are unknown. Since it is doubtful that ethylacetoacetate occurs in sweat, the compound causing the yellow color is also unknown. Finally the cause for the mixed colors is equally enigmatic.

The only striking trend that can be discerned in these data concerns the presence or absence of ketone bodies. We would expect these substances to be present only during the experimental period when some subjects were subsisting on ketogenic metabolic mixtures, such as starvation and the high fat diets. Inspection of Tables III. 122, III. 123, III. 124, and III. 125, however, discloses that ketone bodies were not uniformly present in the sweat collected from men on ketogenic regimens. This curious absence of ketone bodies in the sweat has been scrutinized in the following manner. Two tables have been prepared. In Table III. 126 we list all the subjects who exhibited +3 or +4 reactions in urine collected during the heat acclimatization test but who did not excrete sweat which yielded a purple color when tested by the Rothera reaction. With one exception, all those subjects were on ketogenic regimens. The one exception was Subject 52 who was subsisting on 0/100/0 2000. In Table III. 127 we list all the subjects whose exercise urine was strongly positive by the Rothera reaction and whose sweat yielded a purple color when tested by this same reaction.

Two facts stand out when these tables are compared: (1) The vast majority of subjects whose sweats yielded a purple color were starving men. (2) Men whose sweat did not contain purple color excreted a slightly larger volume of sweat than did men whose sweat gave a purple reaction. This difference was significant by the "t" test at the 5% level and was not influenced by the fact that the ambient temperature at the time these men were tested was not uniform. We see in Table III. 128 that when subjects tested at similar times are compared, the differences in sweat volume persist. No man in Flight 1 secreted sweat which tested purple. Among the men in Flights 2, 3, and 4 the volumes of the purple-reacting sweat were 14, 4, and 4 ml per hour smaller, respectively, than the non-purple-reacting specimens of sweat. While these differences in rates of sweating may be significant statistically, we are of the opinion that increasing the volume of sweat by 9 ml will not change a +3 reaction to a negative reaction. The results rather suggest that ketone bodies are threshold substances and that only when their blood level reaches a certain point will they appear in the secretion of the eccrine sweat glands. This inference is supported by the fact that the vast majority of subjects secreting purple-reacting sweat were starving. This hypothesis will be investigated further when we have completed a quantitative study of the concentrations of ketone bodies in sweat and serum.

TABLE III. 121

DATA ON RED COLOR REACTION OF SWEAT AND URINE WHEN TESTED WITH SULFOSALICYLIC ACID

Period	Frequency Sweat	Frequency Urine*	Subject Code No. Sweat	Subject Code No. Urine*
P I	0	0	----	----
P II	10	0	13,14,16,51,61, 63,79,80,82,83	----
EXP I	14	0	13,18,23,28,33, 43,48,51,63,66, 82,83,84,99	----
R I	7	4	28,42,43,44,45, 63,79	4,6,14,23
R II	19	6	1,2,11,12,18,21, 23,25,26,28,33, 34,35,43,44,66, 67,80,83	1,26,28,40, 52,60

*Exercise and post-exercise urine.

TABLE III. 122

ROTHERA REACTION ON SWEAT: FLIGHT 1
(0 to +4)

Experimental Regimen	PRE I	PRE II	EXP I	REC I	REC II
ST 0	1B,1B,2B,4B	2G,2G,2G,3G	2BG,3BG,3BG	4B,3BG,4BG	3G,2BG,3BG
0/100/0 1000	3B,4B	2G,3G	2BG,2BG	3BG	1BG
0/100/0 2000	4B,4B	2G,2G	3BG,Y	3BG,3BG	2BG,2BG
2/20/78 1000	1B,3B	3G,4G	1BG,2BG	4BG	---
2/20/78 2000	2B,3B	3G,4G	3BG,3BG	---	---
15/52/33 1000	1B,1B	2G	3BG,3BG	4B,3BG	2G,2BG
15/52/33 2000	1B,4B	2G,2G	3BG,3BG	3BG	---
15/52/33 3000	1B,2B	2G,3G	3B,3B	2BG,3BG	2BG,2G
30/0/70 1000	1B,2B	1G,1G	Y,Y	3BG,3BG	2G,3BG
30/0/70 2000	1B,2B	2G,2G	3BG,3BG	1BG,3B	3G,2BG
FRA	1B,2B,2B	1G,2G,2G	3G,3B,2BG	4B,2BG,3BG	2G,3B,1BG, 1BG,2BG

B = blue, G = green, Y = yellow, BG = blue green.

TABLE III. 123

ROTHERA REACTION ON SWEAT: FLIGHT 2
(0 to +4)

Experimental Regimen	PRE I	PRE II	EXP I	REC I	REC II
ST 0	3B,3B,4B,4B	1G,2G,2G,3G	3P,3BP,3BP,3BG	3BG,3BG,3BG	3B,3BG,3BG
0/100/0 1000	2B,3B	4G	2B,2BG	3G,4B	3Y,3B
0/100/0 2000	4B	2G,3G	3B,3B	3BG,3BG	3G,3BG
2/20/78 1000	4B,4B	1G,2G	3B,3B	3B,3BG	4G,3BG
2/20/78 2000	2B,3B	2G,3G	YG,3B	1G,3BG	2G
15/52/33 1000	2B,4B	2G	3B	---	---
15/52/33 2000	3B,3B	4G,4G	YG	3BG	---
15/52/33 3000	1B,2B	1G,3G	3B,3B	3BG,3BG	2BG,3B
30/0/70 1000	1B,4B	2G,3G	2B,2B	3BG	3B
30/0/70 2000	2B,4B	2G,3G	3B,3B	3BG,3BG	3G,3BG
FRA	0,1B,1B	1G,1G	2BG,3B	2BG,1BG,3BG, 2G	1G,3G,3G, 2BG,2BG

B = blue, G = green, Y = yellow, BG = blue green, P = purple, BP = blue purple, YG = yellow green.

TABLE III. 124

ROTHERA REACTION ON SWEAT: FLIGHT 3
(0 to +4)

Experimental Regimen	PRE I	PRE II	EXP I	REC I	REC II
ST 0	1B,2B,2B,4B, 4B	2G,3G,3G, 3G,3G	2BP,3BP,2P 3P,2 Pink	2BG,2BG,2BG, 1G,2G	3B,2G,3G, 2BG,2BG
0/100/0 1000	3B,3B	3G,3G	2B,3B,3B	2BG,3BG	2G,2BG
0/100/0 2000	1B,4B	3G,4G	3B,2BG	1BG,2BG	1G,2BG
2/20/78 1000	2B,2B	2G	3B	1BG	2G
2/20/78 2000	1B	1G	1B	1BG,4B	2BG,3G
15/52/33 1000	3B,4B	3G,4G	1BG,3BG	3B,1BG	2BG,3BG
15/52/33 2000	3B,3B	4G,4G	2B,3B	4B,1BG	3BG,3BG
15/52/33 3000	4B,4B	1G,2G	3B,1BG	4B,2BG	3G,3G
30/0/70 1000	2B	2G	2P	2BG	1G
30/0/70 2000	3B,4B	2G,2G	2B,3B	2BG,2BG	2BG,2BG
FRA	1B,2B,4B	1G,2G,4G	1B,3B,2BG	1BG,2BG,2BG	2BG,2G,2G

B = blue, G = green, BG = blue green, P = purple, BP = blue purple.

TABLE III. 125

ROTHERA REACTION ON SWEAT: FLIGHT 4
(0 to +4)

Experimental Regimen	PRE I	PRE II	EXP I	REC I	REC II
ST 0	1B,1B,2B,4B	3G,3G,4G,4G	1P,3P,3BP	2B,1BG,2BG	2G,2BG,2BG
0/100/0 1000	3B,3B	2G,2G	2B,3B	1BG,3BG	1G,3BG
0/100/0 2000	1B,4B	2G,3G	2B	2BG	2BG
2/20/78 1000	2B,4B	4G,4G	Y	4B,4BG	2BG,3BG
2/20/78 2000	3B	3G,4B	2B,2B	3B	3BG
15/52/33 1000	2B,2B	1G,4G	0,0	3B,4B	2BG,3BG
15/52/33 2000	2B,2B	2G,3G	0,2B	2B,4B	2G,3G
15/52/33 3000	1B,3B	2G,2G	---	---	---
30/0/70 1000	2B,2B	3G,3G	3B,2BG	1BG,4B	1G,2G
30/0/70 2000	2B,4B	3G,4B	3B	4BG	3G
FRA	1B,2B,3B	1G,2G,2G	1B,3B,3B	2BG,2BG,3BG	2G,2G,3G

B = blue, G = green, Y = yellow, BG = blue green, P = purple, BP = blue purple.

TABLE III. 126

CORRELATION BETWEEN URINARY AND SWEAT EXCRETION OF KETONE BODIES: SUBJECTS WITH "ROTHERA--NEGATIVE" SWEAT

Nutrient Regimen*	Subject Code No.	Urine Rothera	Sweat Rothera	Sweat Volume
ST O	3	4	3BG	27
ST O	4	4	2BG	32
B-1	9	4	Y	63
B-1	10	4	Y	37
B-2	11	4	3BG	31
B-2	12	3	3BG	37
C-1	13	4	1BG	12
C-1	14	3	2BG	22
ST O	26	4	3BG	26
B-1	31	4	2B	51
B-1	32	4	2B	30
B-2	34	4	3B	30
C-1	35	4	3B	29
ST O	46	4	2BG	29
ST O	48	4	2 Pink	20
A-2	52	4	2BG	41
B-1	75	4	3B	30
B-1	76	4	2BG	25
C-2	81	4	2B	17
				31±11

*A = 0/100/0; B = 30/0/70; C = 2/20/78; 1 = 1000; 2 = 2000.

TABLE III. 127

CORRELATION BETWEEN URINARY AND SWEAT EXCRETION OF KETONE BODIES: SUBJECTS WITH "ROTHERA--POSITIVE" SWEAT

Nutrient Regimen*	Subject Code No.	Urine Rothera	Sweat Rothera	Sweat Volume
ST O	23	4	3BP	21
ST O	24	4	3P	18
ST O	25	4	3BP	19
ST O	45	4	3BP	11
ST O	47	4	3P	40
B-1	53	4	2P	17
ST O	54	4	2P	35
ST O	67	4	3P	25
ST O	69	3	1P	15
ST O	70	4	3BP	21
			Mean =	22±8

*B = 30/0/70; 1 = 1000.

TABLE III. 128

SWEAT VOLUMES FROM SUBJECTS IN TABLES III. 126 AND III. 127 COMPARED AT EQUAL AMBIENT TEMPERATURES

Flight	Sweat Volume (ml/hr) No Purple Color	Purple Color
1	33	--
2	33	19
3	30	26
4	24	20
Grand Means*	33±11	22±8

"t" = 2.09; P = 5%, when "t" = 2.052

b. Morphologic Examination of Sweat

Formed elements were sought for microscopically in each specimen of sweat, according to techniques universally used for urine. The details of these examinations will be found in tabular form in Appendix II. There was one important observation, a negative finding, so to speak. In no specimen of the approximately 500 was there found a cast. Some of the clinical dermatologists who have interested themselves in dermal reactions to heat have desscribed Schiff-positive casts in the duct of the eccrine sweat gland (Sargent and Slutsky, 1957). These casts have been implicated as responsible for miliaria rubra. Our microscopic data indicate that cast-like formed elements do not appear in the sweat of healthy young men. Whether or not these casts are excreted by individuals with miliaria rubra has not been reported. The histological studies of Dobson and Lobitz (Sargent and Slutsky, 1957) suggest that the casts probably cannot be excreted; their elimination is blocked by a keratin plug which forms in the sweat duct pore.

An interesting and totally mysterious finding in many specimens was the presence of orthorhombic crystals which were blue. These occurred without any apparent consistency, unrelated to individual subject or any of the experimental variables. The only information obtained on them during the field test was that they were insoluble in dilute (0.1N) NaOH and NH_4OH but were soluble in excess dilute NaOH. Since the crystals were always present in sweat and only infrequently present in appropriate "glove blanks" (distilled water placed in glove and carried by one subject during each march), we postulate that they are either a product of the skin or of the eccrine sweat gland. These crystals should be identifiable by the application of standard organic micromethods, but we have not attempted as yet to do so.

In all specimens there occurred, as would be expected, cellular debris, especially squamous epithelial cells, and a few white cells. No red cells were ever seen. The occurrence of these formed elements was not correlated with any of our experimental variables.

In brief, morphologic examination of the sweat was unrewarding from the standpoint of survival rations. However, it did raise at least one very interesting problem for future study: the occurrence of blue crystals.

c. Quantitative Analysis of Sweat

Introduction. By many environmental physiologists it has been argued that the only important function of sweat is to maintain body temperature within normal limits. In other words, primary importance has been attributed to one physical property of sweat, its high heat of vaporization. This rather limited approach must be rejected by the nutritional physiologist for two general reasons, each of which is important in the present study, and either of which would justify the involved and detailed chemical study which is reported in this section. In the first place, daily nutrient losses in the sweat may approach or even far exceed those from either the renal or the gastrointestinal routes, a point which has been emphasized in the section on nutrient balances (III. B). Second, there is a kind of reciprocal relationship between renal and dermal regulations of water, electrolyte and osmotic excretions such that the sweat glands might be said to compete with the kidney, or at least to take over progressively some of the functions of the kidney as rate of sweating increases. A clear discussion of this relationship will be found in the Ph. D. thesis of Lichton (1954). In the present general study, the chemistry of sweat is of utmost importance for the reason that our subjects were sweating profusely much of the time.

Our material is voluminous, so that some of the documentation will be reserved for the appendices. At this point, we shall present first the general conclusions to be reached from a study of the individual cations, anions, and unionized molecules of the sweat. Next we shall focus on the remarkably interesting fact that in a majority of samples of sweat the total osmolarity cannot be accounted for in terms of presently known constituents. This fact leads to a future search for a substance, or substances, present in amounts quantitatively equivalent to as much as 25% of the total osmotic activity of the sweat. Finally, we shall present some of the correlations between sweat chemistry and concomitant physiological measurements such as rate of sweating and skin temperature.

Cations in Sweat. Sodium: In PRE I, sweat sodium averaged about 37 mEq/L (Table III. 129); individual variations were large. In PRE II, the sweat sodium of the controls decreased very slightly; that of all four flights increased sharply.

During the experimental period the sweat sodium concentration showed but little change in the control groups (Table III. 130; Figures III. 52 and III. 53). However, in the four flights there was a strong tendency for the sweat sodium concentration to diminish to values even below those of PRE I. Only in the diet of highest NaCl content, 2/20/78 2000, was there in all subjects an increase. No other clear correlations seem to exist with work, dietary intake, or water restriction.

In REC I, sweat sodium concentration generally increased above EXP. In

REC II, in hard work flights it was variably increased or decreased, but in light work flights it decreased in all subjects, including controls, to values below those of PRE I.

Potassium: In PRE I, sweat potassium averaged approximately 12 mEq/L (Table III. 129). The FRA subjects excreted in their sweat somewhat less potassium than did the subjects on the 5-in-1 ration. In general the variability of sweat potassium from period to period was much less than in the cases of sodium (Table III. 131; Figures III. 54 and III. 55). The variability, however, was generally greater for men on limited water than for men on unlimited water. In contrast to the subjects on experimental regimens or 5-in-1 rations, the ones subsisting on Field Ration A showed much less alteration in sweat potassium from week to week. Study of the data fails to reveal any constant correlation with work output or nutritional regimens. Limitation of water, however, in addition to increasing period to period variability was also correlated with a higher sweat potassium. Men on limited water and 0/100/0 1000 and 2000 hard work and light work, 2/20/78 1000 and 2000 hard work and light work, 15/52/33 1000 and 2000 hard work, 15/52/33 2000 light work, 30/0/70 2000 hard work, and 30/0/70 1000 and 2000 light work all showed greater sweat potassium concentration than in the pre-period. In recovery, no striking correlations could be detected with previous regimens.

Ammonia: In the pre-period, sweat ammonia concentration was consistent from flight to flight, and tended to increase slightly in PRE II, except in Flight 3 and among the controls (Table III. 129C). In the experimental period, sweat ammonia remained quite constant in the controls, but tended to increase in all experimental groups (Table III 132; Figures III. 56 and III. 57). In relation to regimen, one consistent change occurred: in the diets of highest protein percentage, sweat ammonia increased sharply in EXP I, regardless of work load, calorie intake, or water intake. Limitation of water also had an effect. Including both hard work and light work, there are 19 paired comparisons; limitation of water was associated with a greater increase in sweat ammonia in 16 comparisons with unlimited water. The low nitrogen diets were associated with the least rises in EXP I.

In recovery, there was a decrease among most groups, in REC I, followed by an increase in REC II.

Hydrogen ion: As measured by our technique (pH paper) sweat pH was most remarkably constant in all groups, in all periods (Table III. 129 and III. 133). Its maximum range was 4.5 to 5.5. It tended to decrease slightly among all groups in EXP I and REC I. No correlations can be discerned with weather or any factor of the regimen.

Anions in Sweat. Chloride: Generally speaking, sweat chloride followed sweat sodium, but with somewhat smaller absolute changes (Tables III. 134 and III. 135; Figures III. 58 and III. 59). The striking features were the same as those for sodium. In PRE II, there was a general increase. In EXP, generally there was a substantial decrease, except in the diet of highest NaCl intake, 2/20/78 2000. In REC I, there was an increase, and in REC II there

was a decrease especially in the light work groups. No clear correlation appeared between sweat chloride and the variables: nutritional intake of chloride, rate of work, or water intake.

Lactic acid: In a physico-chemical sense, we must distinguish between the total acidity due to lactic acid (and other organic acids) and its ionic state. Being a weak acid, it dissociates according to the equation

$$\text{Lactic Acid} \rightleftharpoons H^+ + \text{Lactate}^-$$

Its dissociation constant is 1.38x10-4, or in other words, its pK is 3.86. This means that at pH 3.86, in a dilute aqueous solution, half the lactic acid would be undissociated and half dissociated. The total acid would contribute osmotically, whether dissociated or not; only the ions would contribute to ionic balance. Hence, in our discussion of lactic acid we shall consider both the total lactic acid and the lactate ions. In the pH range of our specimens (4.5-5.5) the total lactic acid would be dissociated as follows:

pH	% Dissociation	pH	% Dissociation
4.4	78	5.0	93
4.5	81	5.1	94.5
4.6	84	5.2	95.5
4.7	87	5.3	96.5
4.8	90	5.4	97
4.9	91.5	5.5	98

By percentage dissociation, we mean that percentage of the total lactic acid which is present as lactate ion. We realize that sweat is not a simple dilute aqueous solution of lactic acid, but a complex mixture. Hence, our assumptions may not be precisely correct. However, the dissociation and activity coefficients are not well worked out for any complex mixtures, and one must be content with assumptions such as we have made.

During pre-periods, sweat lactic acid was in the range reported by other investigators (Table III. 134B and C). In three of the four flights and among the FRA subjects it decreased in PRE II. During the experimental period there was a marked correlation with work load (Tables III. 136 and III. 137; Figures III. 60 and III. 61). There was an average increase among the hard work groups in 12 of 20 comparisons, and a decrease among the light work groups in 15 of 20 comparisons. In the light work groups there was also correlation with dehydration. Sweat lactate was lower in the L subjects in 8 of 9 comparisons. No other clear correlations existed with calorie level, nutrient ratio, or intake of individual nutrients.

In recovery, the relations of EXP were still operative in REC I. However, in REC II there was a strong tendency for sweat lactate to increase back to PRE I levels.

Other Nitrogenous Constituents of Sweat. Urea: In the pre-periods,

sweat urea tended to be somewhat lower among the FRA controls than among the flights (Table III. 138A). In PRE II, there was a small decrease among the FRA controls and Flight 3; and a small increase in Flights 1, 2, and 4. In the experimental period there were several correlations with regimen (Table III. 139; Figures III. 62 and III. 63). Regimens of highest protein percentage led to increases in sweat urea, especially in 30/0/70 1000 and 2000. There was also a correlation with limitation of water regardless of work load. Among 19 comparisons between U and L, the increase in sweat urea was greater in L in 15 cases.

In REC I there was almost invariably a decrease followed generally in REC II by an increase back to values well above those of PRE I.

Creatinine: This compound, quantitatively speaking, is present only in minute amounts as compared with urea. However, it may be of some importance in elucidating some of the factors related to clearance by the sweat gland.

Pre-period data for sweat creatinine are summarized in Table III. 138B. The mean values agree very well with those reported by Bass and Dobalian (1953). Those investigators found that the mean concentration of bag sweat collected from men exposed to 120°F was 0.176±0.070 mg/k00 ml. They emphasized that this mean value represents "true" creatinine. Their sweat had been analyzed by a method which employed Lloyd's reagent for adsorption and elution of creatinine from sweat. In our analyses we employed a similar procedure; in fact it was the same procedure as that which we had used for analysis of serum.

The pre-period data show some variation from group to group and all five groups secreted less creatinine in PRE II than in PRE I. It will be noted that in all groups there was a very wide individual variability in the creatinine concentration.

Data on the sweat creatinine concentration found in the glove sweat collected during five heat acclimatization tests are summarized in Table III. 140. In the case of the hard work subjects, there was a substantial increase in the serum creatinine concentration for all men except those on 15/52/33 1000, 15/52/33 2000, 15/52/33 3000 L, and the FRA's. The magnitude of the increase was apparently independent of limitation of water. In the following recovery periods there was a general tendency for the sweat creatinine to decrease. Only in the case of the FRA subjects who were controls for Flight 2 was there a substantial increase, and this occurred only in REC I.

Turning to the subjects who performed light work we find that the increase in sweat creatinine for EXP I occurred in all but two of the regimens. The subjects on 0/100/0 2000 U exhibited only a slight increase, and the FRA controls for Flight 3 exhibited a slight decrease. As in the case of the hard work groups, the sweat creatinine fell substantially in the recovery periods.

Sweat Osmolarity. It is a singular fact that practically no attention has been paid by investigators to the total osmotic activity of sweat. Only seven observers since 1880 have published data on the direct measurement of freezing point depression, or other measurements of the physical properties of sweat that are correlated with osmotic activity, and only a few specimens have been reported. By contrast, the renal physiologists have made important generalizations on kidney function by systematic studies of osmotic clearance, for which a voluminous literature exists. Thinking that a systematic study of sweat osmolarity might lead to important generalizations on osmotic regulation by the sweat gland, we have made a detailed study of the freezing point depression of sweat as related to regimen, to individual constituents of the sweat, and to the rate of sweating.

In the pre-periods the sweat osmolarity of the controls was about 110 mOsm/L, substantially lower than that of the flights (Table III. 138C), all of which averaged in the range 130-200 mOsm/L. The majority of the subjects increased in PRE II, but the controls did not increase.

A general chemical property of sweat is rather wide individual variations, and osmolarity is no exception (Table III. 141). Characteristically, some subjects are consistently high and some consistently low. Hence, changes in osmolarity are best discussed as deviations from the PRE I value (Figures III. 64 and III. 65). The controls showed but minor fluctuations from week to week; by contrast, the experimental subjects showed rather wide fluctuations.

In the experimental period, work load was not correlated with any consistent changes, but regimen was correlated with certain changes. In diets of highest osmotic intake associated with dehydration, sweat osmolarity tended to increase, as is seen in hard work 2/20/78 2000, 15/52/33 2000, and 30/0/70 2000, and in light work 2/20/78 1000 and 2000, 15/52/33 1000 and 2000, and 30/0/70 1000 and 2000. Unlimited water minimized these changes. In the pure carbohydrate regimens, 0/100/0 1000 and 2000, the osmolarity tended to increase with limited water, and to decrease with unlimited water.

In recovery, the tendency was a return to or below PRE I values. Exceptions were in previously dehydrated subjects whose EXP values had been very high. In some of these, the values did fall but not to PRE I values.

The two regimens which were somewhat anomalous were ST 0 and N 3000. In the former as well as the latter, changes were usually small, and the dehydrated subjects in EXP I behaved the opposite to the other experimental subjects. However, in REC I and REC II, the ST 0 and N 3000 subjects reverted to near PRE I values, just as did all other subjects.

Sweat osmolarity as a function of individual constituents: The previous workers who have discussed sweat osmolarity (e.g., Amatruda and Welt, 1953; Van Heyningen and Weiner, 1949) have assumed that the total osmolarity of sweat can be accounted for altogether by sodium, chloride and urea, which are present quantitatively in the largest amounts. Also they have assumed that these constituents are present in such constant proportions that one can

calculate the osmolarity knowing the amounts of sodium, chloride and urea. In our specimens, neither of these basically important assumptions is true, as can be demonstrated from Tables III. 142, III. 143, III. 144 and III. 145.

For most of our specimens we have quantitative direct measurements of freezing point (a correlate of total osmolarity); sodium; potassium; ammonia plus urea; chloride; and lactic acid. (Table III. 142A and B). The sums of these constituents in the pre-periods do not add up to the total osmolarity in a majority of specimens (Table III. 142C). The mean of osmolarity accounted for by the sum of the constituents was as low as 80% in Flight 2, PRE II, and only 94% at the highest in these pre-period specimens.

So far as the experimental periods and recovery periods are concerned, the same trends are present. Table III. 143 shows in absolute amounts the sum of the constituents sodium, potassium, ammonia plus urea, chloride, and lactic acid. In Table III. 144 will be found the absolute difference between measured total osmolarity and the sum of the constituents. Table III. 145 expresses the sum of the constituents as a percentage of the total measured osmolarity. In the experimental period, the controls tended to be lower than the experimental subjects in sum of constituents. In the low salt regimens, this sum tended to decrease, regardless of work load or water intake. In the high salt diets 2/20/78 2000 it increased. In recovery, there were fluctuations not clearly associated with previous regimen. In the light work groups, REC II was generally lower than REC I, but this was not so with the hard work groups. So far as concerned the difference between total osmolarity as measured by freezing point, and the sum of constituents, no clear correlations existed between regimen and this difference, either in experimental or recovery periods. In general, the controls showed relatively small discrepancies, whereas the experimental subject showed changes of substantial magnitude. For the most part, the total measured osmolarity was greater than the sum of the constituents. In other words, some substance or substances of considerable quantitative importance had not been measured.

The percentage importance of the difference between total measured osmolarity and the sum of the important constituents is listed by regimen in Table III. 145. This presentation is perhaps the clearest for scrutinizing the data. In the experimental period, the controls changed very little. Dehydration had a tendency to depress this percentage, seven of ten comparisons in hard work, nine of nine comparisons in light work. There was a tendency for general depression in the experimental period as compared with PRE II, 17 of 19 comparisons in hard work, but only seven of 20 comparisons in light work. No other clear correlations with regimen are evident. In recovery (REC I or REC II) the percentage increased to or above PRE I values in most cases.

A point of crucial importance is whether the freezing point depression of the complex mixture, which is sweat, is truly a measure of molality. An experiment on this point was run by Adams (1957) and reported in detail by him in Appendix II. A "synthetic sweat" was made from sodium, potassium, ammonia, chloride, lactic acid, and urea, to represent a very concentrated sweat. This was diluted serially with water in the range 0.50 mMols/kg to 0.05 mMols/kg. The molal freezing point depression was a constant throughout this range.

Hence, the freezing point method can be trusted with concentrated or dilute specimens of sweat to be a measure of true molality. Conclusive proof that this is so was offered by Adams (1957) when he diluted actual specimens of sweat from three subjects in the proportion 1:1, 1:2, and 1:4 with water. Regardless of dilution, the molality came out to be the same.

In short, we are looking for a substance, or substances, present in a majority of specimens, that may account for as much as 50% of the total osmolality, and may be quantitatively present in larger amounts than sodium, chloride, urea, or lactic acid. Previous workers have paid little or no attention to this substance, because they have not appreciated its importance or recognized its presence. We are inclined at present to the view that it may be beta hydroxybutyric acid or some related ketone. Our evidence rests on several disparate observations: (a) all specimens of sweat react blue with nitroprusside; (b) many specimens react pink with sulfosalicylic acid; (c) as will be shown in the next section below, there is a consistent ionic deficit, in the sense that the sum of the cations exceeds the sum of the known anions in a large proportion of specimens.

Electrolytic Balance of Sweat. In any aqueous solution containing ionized molecules, electrolytic neutrality is maintained; the sum of the cations is electrolytically equivalent to the sum of the anions. In sweat, by far the most prevalent cations are sodium, potassium, and ammonia, and the most prevalent anions are chloride and lactate. We have considered the question of electrolytic balance in all of the specimens for which we have complete data.

In the pre-periods, the total cation content of the sweat of the controls decreased slightly from 49 mEq/L, but it increased substantially in the four flights. (Table III. 146A). The total anion concentration decreased among the controls, but increased among the flights (Table III. 146B). Electrolytic balance was achieved among the controls, but there was, especially in PRE II, a real deficit of anions in the flights. This finding suggests that an anion of some considerable quantitative importance is present in addition to chloride and lactate. Previous workers have not suggested any ion, such as pyruvate, which will account for this discrepancy satisfactorily.

In the experimental period, the cation concentration decreased in the regimens of low salt content, but increased in 2/20/78 2000 (Table III. 147). It changed but little among the controls. Similarly, the anion sum decreased among regimens of low salt content and increased in 2/20/78 2000 (Table III. 148). Among the controls, it changed very little in those of Flight 1, decreased among those for Flight 2, and increased for the other two sub-groups of controls. The difference between cations and anions was somewhat different in hard work and in light work (Table III. 149). In hard work, there was a general tendency for the ionic deficit to diminish in experimental period. In fact, the sum of the anions actually exceeded the sum of the cations in 6 of 20 experimental regimens. The contrary was true in light work, where the discrepancy became more pronounced in many cases, and cations always exceeded anions. No correlations could be detected with water intake, calories, or nutrient ratios.

In recovery, sweat cations tended to increase among light work groups, decreasing once more in REC II; the hard work groups showed no such tendency. A similar relationship between hard work and light work held in the case of anions, without regard to previous regimen. Ionic balance was very closely approximated in most hard work groups in REC I, with a tendency to considerable imbalance in REC II. Among the light work groups, such a tendency was not clear. The controls approximated balance closely.

In summary, we cannot in many of our specimens account for electrolytic balance in terms of those cations and anions which are known to be quantitatively most important in sweat. In a majority of cases, the imbalance is in the direction of more cations than anions. We should look, therefore, for some organic anion which has not received much attention in the previous literature on the chemistry of sweat.

Sweat Chemistry as Function of Rate of Sweating. Scatter-diagrams have been prepared of the relationship between rate of sweating (in the gloves) and the concentration of the several organic and inorganic constituents measured. We shall consider our observations and then briefly indicate the supporting or conflicting observations reported in the literature. In the majority of the several figures only data for PRE II and REC II have been used. In these periods the weather was equally warm. PRE I has been omitted because the weather was cool; EXP I, because of the possible influence of diet on sweat chemistry; and REC I, because it was a period of rapid metabolic readjustment.

Total Osmolarity: Sweat osmolarity decreased exponentially as the rate of sweating increased (Figures III. 66 and III. 68). Subject No. 97 was consistently aberrant but it is evident (Figure III. 66) that his sweat osmolarity is also exponentially related to rate of sweating. In the case of the FRA subjects (No. 97 omitted), the coefficient of correlation was -0.53. A similar correlation for EXP subjects was not calculated, and the relation between osmolarity and sweat rate was not explored further by additional curve-fitting procedures.

Potassium: The concentration of potassium in sweat declined as the rate of sweating increased. For the FRA subjects the decrease was linear (Figure III. 66). All but three points fall outside the one standard deviation zone. The two high points presumably represent the curvilinear relation which exists between potassium and rate of sweating when more data become available for low rates of sweating. Note that for the EXP subjects (Figure III. 68) when the sweat rate was less than 30 ml/hr, the potassium concentration rose rapidly. Assuming a linear relation for potassium in the case of the FRA subjects, the correlation coefficient was -0.87. Assuming an exponential relation for the EXP subjects, the coefficient was -0.73. Study of the later data suggest that probably a quadratic curvilinear regression line would fit the data better. More curve fitting was not undertaken since the basic intent of these studies was only to make a preliminary examination of the relation between solute concentration and rate of sweating.

In contrast to his behavior with respect to total osmolarity, Subject 97 did not deviate from the group in so far as potassium was concerned.

Sodium and chloride: The concentrations of these electrolytes bear no significant relationship to the rate of sweating (Figures III. 66 and III. 68). Subject 97 is again deviant and exhibits significantly elevated sweat sodium and chloride at high rates of sweating. Although the mean values for sodium and chloride differ for the two groups of subjects within each group the concentration of sodium is approximately equal to the concentration of chloride.

Urea and ammonia nitrogen: The concentrations of these nitrogenous compounds decreased with increased rates of sweating (Figures III. 67 and III. 69). For the FRA subjects, the decrease in urea nitrogen was linear. The correlation coefficient was -0.59. Since the ammonia was calculated as a constant percentage of the urea nitrogen, we have not calculated a correlation coefficient. It is evident that a coefficient of similar order of magnitude is probably present. Note that Subject 97 was not deviant from the group with respect to urea or ammonia nitrogen.

In the case of the EXP subjects, the decrease of urea and ammonia nitrogen with increase in rate of sweating was exponential. Assuming a logarithmic relation, the coefficient of correlation was -0.63. A quadratic regression again would probably have yielded a more satisfactory fit.

Creatinine: No correlation exists between the concentration of creatinine in sweat and the rate of sweating (Figure III. 67 and III. 69).

Lactate: There is a suggestion of an exponential decrease in lactate with increasing rates of sweating (Figures III. 67 and III. 69). Because of the high degree of scatter we do not feel that a significant correlation exists. We have not calculated such a coefficient. Subject 97, both for creatinine and lactate, is not significantly aberrant.

Sweat Chemistry as Function of Nutrient Intake. It has been stated that the chemical composition of sweat will reflect marked deviations in nutrient intake (Robinson and Robinson, 1954). With this idea as a working hypothesis, we examined our data for such an influence in the case of sodium, potassium, and nitrogen.

Sodium and potassium: No consistent effect of sodium and potassium intake was demonstrable. Sweat from men who had been on salt free diet (0/100/0) for four to five days was compared with sweat from men who had been on relatively high sodium or potassium diets. No significant differences were demonstrable.

Urea nitrogen: A clear influence was revealed for sweat urea nitrogen. Men who had been on nitrogen free diets (0/100/0) were compared with men on high nitrogen diets (30/0/70). In PRE II, there was no differences in the chemistry of the sweat of these two groups (Figure III. 70). We did not calculate a correlation coefficient for the sweat-serum relation since sweat

was collected in the afternoon and blood in the morning. The absolute level of the serum urea nitrogen was therefore not known for the period of the march. Note once again the high negative correlation ($4 = -0.66$, $p<0.01$) between sweat urea nitrogen and rate of sweating.

In EXP I, after the men had been on fixed intakes of either 0/100/0 or 30/0/70 for four or five days the sweat from the latter group contained significantly more urea nitrogen than that from the former (Figure III. 70). The x, y coordinates were 32.50 ml/hr and 27.12 mg/100 ml for men on 30/0/70. The standard deviation of the 0/100/0 curve was 4.28; for the 30/0/70 curve, 3.34. The two means, 20.31 and 27.12, were significantly different ($t = 4.65$, $P<0.001$). It is of interest to note that the men on 0/100/0 exhibited no drop in sweat urea nitrogen from PRE II. The men on 30/0/70, however, secreted sweat with much increased values of urea nitrogen. Presumably the nutrient effect was due particularly to the elevated serum urea nitrogen (Figure III. 70).

The effect of diet did not obscure the relation between urea nitrogen concentration and rate of sweating. For the men on 0/100/0 the correlation was -0.67 ($P<0.01$); for the men on 30/0/70, -0.73 ($P<0.01$). The slopes for the two regression lines were identical: -0.2588 and -0.2561, respectively.

A Generalizing Hypothesis Relating Sweat Chemistry and Rate of Sweating. Almost everyone who has ever worked systematically on the chemistry of sweat has tried to evolve a generalizing hypothesis to explain several puzzling phenomena. They include:

a) Sweat is rarely if ever hypertonic with respect to sodium, chloride, or urea.

b) Nevertheless, some substances are often present in sweat in much higher concentrations than in plasma, e.g., potassium, lactic acid.

c) Some substances that are present in plasma do not appear at all in sweat, e.g., inorganic phosphate.

d) With increased rate of sweating, some substances become more concentrated (e.g., sodium, chloride), and others more dilute (e.g., potassium, urea).

e) Sodium and chloride are present in equal concentrations.

Our own investigations have added to the above list two more puzzling phenomena:

f) total osmolarity declines with increased rate of sweating.

g) An as yet unindentified substance or substances are quantitatively important at low rates of sweating; but apparently disappears from the sweat at high rates of sweating.

Most workers in this field have accepted the fluctuations in concentration with rate of sweating as evidence of an active process in which the individual sweat gland produces a fluid which varies in concentration differently with different substances. Active or passive reabsorption of water and active secretion of solutes are usually necessary postulates. At this time we should like to propose a new hypothesis, which so far as curve fitting is concerned, is in concord with all the phenomena which appear to need explaining.

The new hypothesis is that the sweat glands produce two kinds of sweat. The composition of each is constant, but the relative rates of production of each are quite different. "Sweat A" is postulated to be like intracellular fluid, with low sodium and chloride, high potassium, nitrogenous components, and total osmolarity. "Sweat B" is postulated to be like extracellular fluid, with relatively high sodium and chloride, low or absent potassium, and nitrogenous constituents; and relatively low osmolarity. "Sweat A" is postulated to be predominant in rate of production at low sweat rates, and to increase slowly and linearly with increased total sweating. "Sweat B" is postulated to be absent at low rates of sweating, but to increase linearly in rate thereafter much more rapidly than "Sweat A". Finally, "Sweat A" is postulated to contain a high concentration of our unknown osmol, "Sweat B" none.

If we accept the above postulates, then for any given rate of total sweating, the concentration of any given solute in the total sweat will depend upon its concentration in "Sweat A" and in "Sweat B" and on the relative contribution made by each to the total sweat volume. Expressed in equation form:

> Concentration of Solute in Total Sweat = (Concentration in "Sweat A" x Fraction of Total Sweat Contributed by "Sweat A") + (Concentration in "Sweat B" x Fraction of Total Sweat Contributed by "Sweat B").

This equation has been explored with results illustrated in Figure III. 71. For this presentation "Sweat A" is assumed to have a total osmolarity of 250 mOsm/L, contributed by Na 25, K 25, NH_3 15, Cl 35, Lactic Acid 35, Urea 30, "unknown osmol" 95. "Sweat B" is assumed to have a total osmolarity of 120 mOsm/L, contributed by Na 50, K 0, NH_3 5, Cl 50, Lactic Acid 5, Urea 10 and "unknown osmol" 0. "Sweat A" is assumed to be the only sweat at 10 ml/hr or lower total volume, and to increase linearly to 20 at total volume 100 ml/hr. "Sweat B" is assumed to be absent up to total rates of 10 ml/hr, and to increase linearly thereafter to 80 at a total rate of 100 ml/hr. The consequences of these assumptions are:

a) Total sweat cannot become hypertonic with respect to sodium, chloride, or urea.

b) Some substances, e.g., lactic acid may be hypertonic by a process of active secretion.

c) Some substances, e.g., inorganic phosphate, do not appear at all in sweat by some unknown process.

d) With increased rate of sweating, sodium and chloride concentrations will increase, provided they are more concentrated in "Sweat B" than in "Sweat A". They could actually remain constant (as in our own present experiments) if the two sweats had equal concentration. Other substances, like potassium, urea, and ammonia will decrease with increased rate of sweating.

e) Total osmolarity will decrease with increased rate of sweating, provided "Sweat B" is more dilute than "Sweat A".

f) The "unknown osmol" will become of less and less significance in the total osmolarity with increased rates of sweating, because "Sweat B", which does not contain it, acts as a diluent of "Sweat A".

Reference back to our own data (Figures III. 66, III. 67, III. 68, and III. 69) will show that the present hypothesis produces curves which are quantitatively as well as qualitatively similar to the actual observed data. In particular, we draw attention to the shapes of the curves, such as that for potassium and urea there is a rapid increase at low rates of sweating, but at rates above 20 ml/hour, one could almost postulate a straight line. Our hypothesis demands this kind of curve, which is actually quadratic. Adumbrations of our hypothesis are to be found in the classic literature on sweat (Kuno, 1956). It is well established that some sweat glands, especially those of the palm of the hand and foot sweat at rates and with chemistry different from those of the general body. The former do not sweat profusely with exercise, whereas the latter do. If we extend this concept of Kuno to include the total body, we might expect to find a mixture of the two kinds of glands throughout the skin, but in various proportions.

Adams (1957) has made a special study of this whole problem, and his results are incorporated in full in Appendix II.

TABLE III. 129

PRE-PERIOD DATA ON CATIONS IN SWEAT: SODIUM, POTASSIUM, AMMONIA, HYDROGEN ION

Flight	N	P I Mean	Range	N	P II Mean	Range
			A. Sodium, mEq/L			
1	21	35	15-55	21	50	19-81
2	21	36	15-77	20	52	20-92
3	21	43	26-69	20	54	39-76
4	21	36	23-82	21	45	20-90
FRA	11	31	16-59	11	28	17-48
			B. Potassium, mEq/L			
1	21	11	4-20	21	10	6-22
2	21	13	7-19	20	14	6-26
3	21	12	4-26	20	11	7-19
4	21	12	7-19	21	14	7-29
FRA	11	9	5-11	11	8	6-12
			C. Ammonia, mEq/L			
1	21	7.6	3.3-11.9	21	9.0	4.4-13.3
2	22	8.8	5.9-13.2	20	10.7	6.6-16.7
3	19	8.4	4.3-13.2	20	7.2	5.0-11.1
4	20	9.4	5.6-13.7	21	10.3	6.0-16.7
FRA	10	7.5	4.7- 9.4	10	7.2	5.7- 9.9
			D. Hydrogen Ion, pH			
1	22	5.05	4.5-5.5	21	5.0	4.5-5.5
2	19	5.0	4.5-5.5	20	5.0	4.5-5.5
3	21	5.0	4.5-5.5	20	5.0	4.5-5.0
4	21	5.0	4.5-5.5	22	5.0	4.5-5.0
FRA	12	5.1	5.0-5.5	11	5.0	5.0-5.0

TABLE III. 130

SWEAT SODIUM
(mEq/ Na/L)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	32	53	34	38	42	47	49	19	57	45
	L	37	52	33	31	44	34	46	20	44	37
0/100/0	U	45	60	32	38	33	32	41	28	43	27
1000	L	28	35	30	31	35	32	43	33	45	29
0/100/0	U	18	33	17	21	17	38	53	28	39	26
2000	L	77	94	62	92	86	44	39	47	40	28
2/20/78	U	38	55	59	40	50	50	51	42	50	33
1000	L	55	62	52	72	68	34	70	57	52	32
2/20/78	U	24	36	45	--	--	39	53	57	68	38
2000	L	31	42	56	48	31	31	51	72	71	44
15/52/33	U	52	65	39	55	53	32	51	45	37	32
1000	L	15	20	17	--	--	24	29	36	27	18
15/52/33	U	24	41	18	28	--	56	76	49	86	47
2000	L	30	51	44	41	49	48	47	41	51	41
15/52/33	U	36	53	27	38	43	37	53	32	48	24
3000	L	32	65	37	45	35	30	33	--	--	--
30/0/70	U	42	57	25	37	32	33	51	32	33	19
1000	L	34	48	25	23	27	24	37	20	43	23
30/0/70	U	38	51	22	33	35	52	59	48	52	33
2000	L	40	44	33	37	41	58	64	51	90	73
FRA	U	30	28	29	19	18	46	40	36	43	28
	L	25	27	24	25	20	26	20	22	28	26

TABLE III. 131

SWEAT POTASSIUM
(mEq/L)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	7.6	9.2	10.0	8.8	8.2	10.4	9.6	14.2	9.5	8.6
	L	13.4	12.4	15.0	12.4	11.4	12.4	13.2	15.2	9.8	11.5
0/100/0	U	9.0	6.1	7.9	8.2	8.4	11.5	10.5	13.6	8.0	6.7
1000	L	13.2	15.5	16.0	16.0	17.8	8.0	11.4	13.7	8.5	9.9
0/100/0	U	10.7	10.2	10.8	8.3	9.2	16.0	12.5	11.8	8.4	7.7
2000	L	8.2	8.8	12.4	10.8	10.2	10.5	10.0	11.8	8.8	9.4
2/20/78	U	16.7	15.2	14.6	10.7	20.8	11.4	9.9	9.0	6.9	8.0
1000	L	12.6	10.2	9.8	10.6	14.2	15.8	24.6	17.4	12.8	13.2
2/20/78	U	15.5	16.9	14.4	----	----	7.2	7.4	12.6	16.8	13.6
2000	L	13.6	16.6	17.1	10.8	15.4	12.1	18.0	15.4	11.9	14.3
15/52/33	U	12.7	10.5	13.2	11.4	10.4	14.2	14.2	21.8	9.0	15.9
1000	L	14.6	8.4	12.6	----	----	13.2	19.9	16.0	13.2	11.8
15/52/33	U	10.8	8.8	10.8	7.5	----	19.5	15.6	19.3	13.2	16.4
2000	L	14.8	20.7	25.8	14.3	12.8	11.2	16.7	11.9	8.4	9.2
15/52/33	U	11.2	10.6	13.2	12.0	10.2	10.5	9.0	14.2	8.8	11.9
3000	L	14.2	22.4	15.4	12.3	12.6	12.0	12.2	----	----	----
30/0/70	U	8.0	7.0	9.8	10.3	11.2	10.5	7.2	14.3	7.7	6.9
1000	L	11.2	10.4	8.8	9.3	12.0	9.6	11.9	17.4	9.8	14.6
30/0/70	U	10.7	10.8	13.4	8.4	12.0	9.2	7.2	10.2	6.5	6.4
2000	L	7.8	9.2	17.2	10.0	11.8	14.0	13.2	17.6	8.6	10.9
FRA	U	7.4	8.5	8.1	9.6	10.3	7.9	7.5	6.1	7.1	6.9
	L	10.0	9.1	7.5	7.9	10.1	9.3	8.6	10.3	7.8	11.6

TABLE III. 132

SWEAT AMMONIA
(mEq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	5.0	8.5	10.0	7.2	8.5	9.2	7.8	11.3	9.4	10.0
	L	8.0	9.4	13.6	9.8	10.9	10.4	9.7	12.3	7.4	9.7
0/100/0	U	8.3	10.2	7.6	8.9	10.5	9.4	8.1	9.3	6.7	5.7
1000	L	9.7	12.6	14.4	12.8	13.7	7.6	8.0	12.7	6.0	9.0
0/100/0	U	6.9	8.8	7.7	6.7	9.9	10.1	7.8	9.2	6.5	6.7
2000	L	6.3	8.7	11.3	8.3	10.7	9.6	9.1	8.9	6.9	8.3
2/20/78	U	11.3	12.3	13.8	11.6	15.6	7.7	6.6	8.6	4.3	5.5
1000	L	8.0	9.0	9.0	7.6	12.3	9.4	14.6	15.3	11.6	10.3
2/20/78	U	9.1	10.2	10.2	----	----	4.6	5.5	6.1	9.0	7.7
2000	L	9.1	12.1	12.6	8.6	11.2	10.0	13.4	15.9	11.6	12.1
15/52/33	U	9.9	7.1	12.3	11.8	12.1	6.3	5.7	7.4	6.9	10.5
1000	L	8.6	7.4	11.1	----	----	10.1	11.6	14.0	12.0	13.2
15/52/33	U	6.6	8.1	9.0	6.6	----	9.4	8.1	13.7	9.5	9.4
2000	L	12.2	15.6	15.6	12.4	15.1	7.8	8.7	12.9	7.9	10.8
15/52/33	U	8.6	10.7	10.8	10.2	11.5	8.1	6.6	11.1	6.2	9.6
3000	L	11.6	14.7	14.4	10.8	11.3	9.9	9.2	----	----	----
30/0/70	U	4.1	5.2	10.0	11.8	9.6	8.0	7.7	13.8	7.3	6.4
1000	L	7.4	9.2	12.2	6.4	9.0	8.4	10.8	15.9	6.5	9.6
30/0/70	U	8.8	9.2	14.3	9.3	14.4	7.7	5.9	11.5	7.5	8.4
2000	L	6.6	8.7	15.9	8.3	7.4	8.4	9.1	16.7	6.3	9.9
FRA	U	8.4	7.0	8.4	9.7	9.3	7.4	7.3	5.5	6.6	6.3
	L	8.9	8.1	6.8	6.3	8.8	6.3	6.4	6.9	6.2	6.9
				Sum of FRA's			7.7	7.2	6.9	7.3	8.0

TABLE III. 133

SWEAT ACIDITY
(pH)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	5.0	5.0	4.7	4.7	5.0	4.9	5.0	4.7	4.6	4.7
	L	5.0	5.0	4.8	5.0	4.7	5.0	4.9	4.5	4.5	4.7
0/100/0	U	5.2	5.0	4.5	4.5	5.2	5.0	5.0	4.8	4.5	5.0
1000	L	5.0	5.0	4.5	4.5	5.0	5.0	5.0	4.5	4.5	4.8
0/100/0	U	5.2	5.0	4.5	4.5	4.5	5.0	5.0	4.5	4.5	5.0
2000	L	5.0	5.0	4.5	4.8	4.5	5.0	5.0	4.5	4.5	4.5
2/20/78	U	4.8	5.0	5.0	5.0	5.5	5.2	5.0	5.0	4.5	5.0
1000	L	5.0	5.0	5.0	5.0	4.5	5.0	5.0	5.0	5.0	5.2
2/20/78	U	5.0	5.0	4.5	---	---	5.0	5.0	5.0	4.5	4.8
2000	L	5.0	5.0	4.8	5.0	4.8	5.0	5.0	4.5	4.5	4.5
15/52/33	U	5.0	5.0	5.0	5.0	4.8	5.0	5.0	5.0	4.8	5.2
1000	L	5.0	5.0	4.5	---	---	5.0	5.0	4.5	4.5	4.8
15/52/33	U	5.2	5.0	4.5	5.0	---	4.8	5.0	4.8	4.8	4.5
2000	L	5.0	5.0	4.5	4.5	5.0	5.0	5.0	4.5	4.5	4.5
15/52/33	U	5.0	5.0	5.0	4.8	5.2	5.0	5.0	4.8	4.5	4.8
3000	L	5.0	5.2	4.8	4.8	4.8	5.2	5.0	---	---	---
30/0/70	U	5.0	5.2	5.0	4.5	4.8	5.0	5.0	5.0	4.5	5.0
1000	L	5.2	4.8	4.5	4.5	4.5	5.0	5.0	4.5	4.5	4.8
30/0/70	U	5.0	4.8	5.0	4.5	4.5	5.2	4.8	5.0	4.8	4.5
2000	L	4.8	5.0	4.5	4.5	4.8	4.8	4.8	4.5	5.0	5.0
FRA	U	5.2	5.0	4.8	4.5	4.7	5.0	5.0	5.0	4.7	4.7
	L	5.2	5.0	5.0	5.0	5.0	5.2	5.0	5.0	4.7	5.0

TABLE III. 134

PRE-PERIOD DATA ON ANIONS IN SWEAT: CHLORIDE, TOTAL LACTIC ACID, LACTATE ION

Flight	P I N	P I Mean	P I Range	P II N	P II Mean	P II Range
			A. Chloride, mEq/L			
1	21	31	15-54	21	42	19-56
2	21	32	14-73	20	43	16-84
3	21	35	22-54	20	46	31-66
4	21	31	13-66	21	39	16-74
FRA	11	25	14-66	11	28	13-45
			B. Total Lactic Acid, mEq/L			
1	22	22.3	6.0-33.3	21	22.0	8.7-33.9
2	21	19.0	5.2-33.9	19	12.0	5.0-33.9
3	21	22.7	9.4-33.5	20	19.4	6.7-33.9
4	21	21.8	14.6-30.9	20	25.3	16.7-33.9
FRA	11	20.8	8.1-31.2	11	14.2	9.1-25.6
			C. Lactate Ion, mEq/L			
1	22	20.1	5.4-30.0	21	19.8	7.8-30.5
2	21	17.1	4.7-30.5	19	10.8	4.5-30.5
3	21	20.4	8.5-30.2	20	17.5	6.0-30.5
4	21	19.6	13.1-27.8	20	22.8	15.0-30.5
FRA	11	18.7	7.3-28.1	11	12.8	8.2-23.0

TABLE III. 135

SWEAT CHLORIDE
(mEq Cl/L)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST O	U	28	45	27	39	39	38	43	33	55	42
	L	30	43	27	34	34	29	46	28	45	34
0/100/0	U	38	53	25	46	32	24	35	25	35	19
1000	L	22	28	24	32	20	24	38	33	43	27
0/100/0	U	17	24	13	25	17	29	44	19	38	26
2000	L	50	61	42	71	53	32	27	35	28	16
2/20/78	U	35	47	58	41	42	40	40	38	40	23
1000	L	46	53	48	71	65	35	58	58	45	39
2/20/78	U	23	29	47	--	--	38	49	56	33	42
2000	L	26	31	47	45	27	41	52	76	68	44
15/52/33	U	48	55	49	57	43	26	42	43	47	31
1000	L	14	16	19	--	--	17	22	35	24	17
15/52/33	U	22	33	25	31	--	50	64	41	79	45
2000	L	26	39	38	40	38	41	44	38	49	36
15/52/33	U	34	41	31	37	34	28	42	28	43	35
3000	L	37	62	42	53	37	24	32	--	--	--
30/0/70	U	35	53	24	38	30	23	45	26	31	19
1000	L	30	44	23	29	20	35	42	40	49	37
30/0/70	U	40	50	37	41	40	44	51	50	53	33
2000	L	34	37	31	39	37	48	53	51	80	70
FRA	U	22	29	26	17	19	35	37	35	42	28
	L	21	30	28	28	22	20	19	22	24	25

TABLE III. 136

SWEAT TOTAL LACTIC ACID
(mEq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST O	U	16.1	22.3	20.6	17.6	18.2	20.2	20.6	16.7	13.5	24.6
	L	24.5	9.6	21.0	23.9	16.6	20.7	24.9	19.2	13.1	8.9
0/100/0	U	23.8	18.8	18.9	13.3	16.1	17.4	17.4	27.6	19.3	14.0
1000	L	28.9	11.1	18.4	24.8	18.7	17.9	23.3	19.7	12.7	17.8
0/100/0	U	22.2	11.6	23.5	22.0	20.1	16.1	25.4	18.9	21.3	12.8
2000	L	25.5	8.4	30.0	25.4	16.0	23.5	21.8	3.8	8.2	15.2
2/20/78	U	33.4	33.9	25.0	27.1	29.3	28.3	19.5	15.0	14.0	24.8
1000	L	15.9	6.5	19.2	19.2	24.4	25.2	27.2	6.0	12.0	23.8
2/20/78	U	31.0	29.2	32.5	----	----	13.0	14.2	14.0	23.8	20.8
2000	L	23.0	12.0	29.8	13.1	25.8	23.0	33.8	5.7	12.4	12.4
15/52/33	U	19.4	32.9	28.4	18.2	22.4	25.2	28.7	14.0	16.4	33.0
1000	L	19.8	9.8	22.3	----	----	25.2	30.8	13.0	16.5	23.0
15/52/33	U	19.2	15.2	24.0	15.5	----	31.6	22.1	31.6	24.4	24.4
2000	L	9.2	16.6	33.9	12.9	17.6	19.8	23.0	14.6	16.6	12.8
15/52/33	U	17.2	9.0	28.4	25.6	20.3	31.0	9.7	29.4	27.4	16.6
3000	L	6.6	32.2	24.4	17.1	28.6	21.4	22.4	----	----	----
30/0/70	U	19.6	20.1	14.6	24.0	24.5	20.0	18.7	3.5	20.6	19.4
1000	L	24.2	9.2	19.0	16.8	20.4	18.4	21.7	3.3	9.5	14.5
30/0/70	U	27.6	27.1	25.0	22.8	24.8	21.8	13.6	17.3	14.4	19.2
2000	L	19.2	8.4	20.2	16.2	25.8	24.6	24.9	4.7	11.9	24.0
FRA	U	17.2	14.0	14.5	23.0	11.2	19.2	12.9	18.5	12.8	12.8
	L	25.6	21.5	17.2	9.6	14.2	20.1	10.9	22.3	19.1	12.7
Sum of FRA's		20.8	14.2	18.2	16.7	12.7					

TABLE III. 137

SWEAT LACTATE ION
(mEq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	15.0	20.7	17.9	15.3	16.9	18.5	19.2	14.5	11.3	21.4
	L	22.8	8.9	18.9	22.2	14.4	19.3	22.8	15.6	10.6	7.7
0/100/0	U	22.7	17.5	15.3	10.8	15.4	16.2	16.2	24.8	15.6	13.0
1000	L	26.9	10.3	16.0	21.6	17.4	16.6	21.7	16.0	10.3	16.0
0/100/0	U	21.2	10.8	19.0	17.8	16.3	15.0	23.6	15.3	17.3	11.9
2000	L	23.7	7.8	24.3	22.9	13.0	21.9	20.3	3.1	6.6	12.3
2/20/78	U	30.1	31.5	23.2	25.2	28.7	27.0	18.1	13.9	11.3	23.1
1000	L	14.8	6.0	17.9	17.9	19.8	23.4	25.3	5.6	11.2	22.7
2/20/78	U	28.8	27.2	26.3	----	----	12.1	13.2	13.0	19.3	18.7
2000	L	21.4	11.2	26.8	12.2	23.2	21.4	31.4	4.6	10.0	10.0
15/52/33	U	18.0	30.6	26.4	16.9	20.2	23.4	26.7	13.0	14.8	31.5
1000	L	18.4	9.1	18.1	----	----	23.4	28.6	10.5	13.4	20.7
15/52/33	U	18.3	14.1	19.4	14.4	----	28.4	20.6	28.4	22.0	19.8
2000	L	8.6	15.4	27.5	10.4	16.4	18.4	21.4	11.8	13.4	10.4
15/52/33	U	16.0	8.4	26.4	23.0	19.4	28.8	9.0	26.5	22.2	14.9
3000	L	6.1	30.8	22.0	15.4	25.7	20.4	20.8	----	----	----
30/0/70	U	18.2	19.2	13.6	19.4	22.0	18.6	17.4	3.3	16.7	18.0
1000	L	23.1	8.3	15.4	13.6	16.5	17.1	20.2	2.7	7.7	13.0
30/0/70	U	25.7	24.4	23.2	18.5	20.1	20.8	12.2	16.1	13.0	15.6
2000	L	17.3	7.8	16.8	13.4	23.2	22.1	22.4	3.8	11.1	22.3
FRA	U	16.4	13.0	13.0	18.6	9.7	17.9	12.0	17.2	11.1	11.1
	L	24.4	20.0	16.0	8.9	13.2	19.2	10.1	20.7	16.6	11.8

TABLE III. 138

PRE-PERIOD DATA ON UREA AND CREATININE IN SWEAT, AND TOTAL OSMOLARITY

Flight	P I N	P I Mean	P I Range	P II N	P II Mean	P II Range
			A. Urea, mMol/L			
1	21	15.2	6.6-23.8	21	18.0	8.8-26.6
2	22	17.6	11.8-26.4	20	21.4	13.2-33.4
3	19	16.8	8.6-26.4	20	14.4	10.0-22.2
4	20	18.8	11.2-27.4	21	20.6	12.0-33.4
FRA	10	15.0	9.4-18.8	10	14.4	11.4-19.8
			B. Creatinine, mg/100 ml			
1	21	0.38	0.14-0.78	21	0.25	0.07-0.60
2	21	0.33	0.20-0.59	20	0.28	0.06-0.80
3	21	0.29	0.12-0.61	20	0.18	0.03-0.38
4	21	0.26	0.10-0.59	21	0.23	0.04-0.76
FRA	11	0.30	0.10-0.54	11	0.13	0.00-0.40
			C. Total Osmolarity, mOsm/L			
1	21	131	51-267	21	173	85-263
2	22	155	87-223	20	198	96-293
3	21	166	98-304	20	165	125-272
4	21	142	86-264	20	179	125-374
FRA	10	116	86-166	11	105	77-138

TABLE III. 139

SWEAT UREA
(mMol/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	10.0	16.9	20.1	14.4	16.9	18.3	15.7	22.6	18.9	20.0
	L	16.0	18.8	27.2	19.5	21.8	20.8	19.3	24.6	14.7	19.4
0/100/0	U	16.6	20.4	15.2	17.7	21.0	18.9	16.3	18.5	13.5	11.5
1000	L	19.4	25.3	28.9	25.5	27.5	15.1	15.9	25.4	12.0	17.9
0/100/0	U	13.8	17.7	15.4	13.4	19.8	20.3	15.8	18.4	13.0	13.4
2000	L	12.6	17.4	22.6	16.6	21.5	19.3	18.2	17.7	13.7	16.6
2/20/78	U	22.6	24.6	27.5	23.1	31.2	15.4	13.3	17.1	8.6	11.0
1000	L	16.0	17.9	17.9	15.2	24.6	18.9	29.2	30.7	23.2	13.5
2/20/78	U	18.2	20.4	20.4	----	----	9.1	11.0	12.3	16.9	15.5
2000	L	18.3	24.3	25.2	17.1	21.9	20.0	26.9	31.8	21.1	24.2
15/52/33	U	19.8	14.3	24.6	22.6	23.2	12.6	11.5	14.9	13.7	21.0
1000	L	17.1	14.9	22.1	----	----	20.1	23.1	28.0	24.0	26.4
15/52/33	U	13.3	16.2	17.9	13.3	----	18.9	16.2	27.4	19.0	18.8
2000	L	24.3	31.2	31.2	24.9	30.1	15.7	17.4	25.7	15.8	21.6
15/52/33	U	17.1	21.5	21.5	20.4	22.9	16.3	13.2	22.1	12.4	19.5
3000	L	23.1	29.4	28.9	21.5	22.6	19.9	18.3	----	----	----
30/0/70	U	8.1	10.4	19.9	17.4	19.3	16.0	15.5	27.7	14.6	12.9
1000	L	14.9	18.5	24.3	12.9	18.0	16.7	21.5	31.8	12.9	19.3
30/0/70	U	17.6	18.5	28.6	18.5	28.9	15.4	11.8	22.9	14.9	16.9
2000	L	13.3	17.4	31.8	16.6	14.9	16.7	18.2	33.5	12.6	19.8
FRA	U	16.7	13.9	16.7	19.5	18.6	14.9	14.5	11.0	13.2	12.6
	L	18.6	16.2	13.5	12.6	17.5	12.5	12.9	13.9	12.4	13.7
Sum of FRA's		15.4	14.3	13.8	14.6	12.5					

TABLE III. 140

SWEAT CREATININE
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	0.24	0.15	0.37	0.39	0.26	0.33	0.15	0.41	0.27	0.44
	L	0.34	0.29	0.33	0.37	0.31	0.31	0.15	0.37	0.14	0.22
0/100/0	U	0.30	0.12	0.26	0.18	0.22	0.36	0.20	0.24	0.11	0.24
1000	L	0.29	0.08	0.48	0.28	0.28	0.10	0.08	0.37	0.11	0.40
0/100/0	U	0.27	0.24	0.29	0.16	0.21	0.29	0.24	0.26	0.18	0.20
2000	L	0.32	0.18	0.34	0.18	0.34	0.18	0.40	0.16	0.06	0.11
2/20/78	U	0.38	0.32	0.72	----	----	0.32	0.18	0.58	0.05	0.13
1000	L	0.42	0.23	0.22	0.28	0.26	0.29	0.26	0.40	0.52	0.23
2/20/78	U	0.54	0.45	0.56	----	----	0.14	0.18	0.31	0.04	0.34
2000	L	0.46	0.43	0.44	0.22	0.11	0.32	0.33	0.76	0.32	0.50
15/52/33	U	0.66	0.38	0.38	0.40	0.32	0.26	0.24	0.54	0.12	0.51
1000	L	0.26	0.20	0.16	----	----	0.27	0.24	1.05	0.37	0.34
15/52/33	U	0.34	0.21	0.15	0.04	----	0.30	0.27	0.82	0.52	0.37
2000	L	0.33	0.46	----	----	1.60	0.28	0.12	0.50	0.14	0.30
15/52/33	U	0.46	0.08	0.44	0.36	0.36	0.36	0.09	0.47	0.24	0.21
3000	L	0.38	0.45	0.44	0.17	0.38	0.44	0.33	----	----	----
30/0/70	U	0.31	0.18	0.42	0.30	0.35	0.26	0.06	0.34	0.17	0.14
1000	L	0.24	0.10	0.27	0.09	0.24	0.28	0.18	0.50	0.28	0.10
30/0/70	U	0.56	0.29	0.48	0.30	0.56	0.17	0.18	0.30	0.10	0.12
2000	L	0.24	0.22	0.70	0.17	0.28	0.40	0.29	0.95	0.02	0.42
FRA	U	0.39	0.20	0.17	0.22	0.31	0.27	0.23	0.22	0.43	0.29
	L	0.33	0.27	0.25	0.60	0.32	0.22	0.05	0.26	0.31	0.44

TABLE III. 141

TOTAL SWEAT OSMOLARITY
(mOsm/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	99	158	111	124	122	193	154	163	185	183
	L	141	181	168	157	143	143	188	161	157	148
0/100/0	U	120	168	102	140	126	162	142	138	135	108
1000	L	149	200	178	183	146	98	154	164	138	128
0/100/0	U	96	138	91	96	88	170	173	134	130	116
2000	L	206	200	185	211	168	154	139	128	145	128
2/20/78	U	236	239	270	191	278	162	154	153	159	111
1000	L	172	192	168	210	222	180	294	151	189	159
2/20/78	U	140	196	190	---	---	119	132	222	233	154
2000	L	145	194	230	158	178	142	210	286	214	194
15/52/33	U	148	195	212	199	173	150	184	246	154	166
1000	L	155	96	112	---	---	128	193	312	150	140
15/52/33	U	100	130	120	92	---	231	241	231	264	172
2000	L	186	284	307	183	236	142	162	188	156	158
15/52/33	U	150	184	158	164	142	144	158	160	146	115
3000	L	172	282	201	176	159	128	144	---	---	---
30/0/70	U	119	159	112	152	126	134	154	162	137	94
1000	L	134	166	120	104	115	104	142	190	136	107
30/0/70	U	152	188	149	132	162	147	156	140	146	118
2000	L	132	156	206	144	152	194	194	231	183	197
FRA	U	119	109	110	104	105	147	121	116	125	96
	L	117	105	93	94	101	104	85	113	96	131

TABLE III. 142

PRE-PERIOD DATA ON SWEAT OSMOLARITY
AS A FUNCTION OF INDIVIDUAL CONSTITUENTS

Flight	P I			P II		
	N	Mean	Range	N	Mean	Range
	A. Total Osmolarity by Freezing Point, mOsm/L					
1	22	135	51-267	21	173	85-263
2	21	155	87-223	20	198	96-293
3	21	166	98-304	20	165	125-282
4	21	141	86-264	22	188	131-374
FRA	12	122	86-166	11	105	77-138
	B. Sum of Na, K, NH_3, Cl, Lactic Acid, Urea, mOsm/L					
1	21	120	55-181	21	150	72-221
2	20	127	77-214	79	152	80-252
3	19	135	90-198	20	149	112-218
4	20	127	82-229	18	147	107-214
FRA	10	112	83-167	10	103	64-141
	C. Fraction of Total Osmolarity Accounted For By Sum of Constituents, %					
1	21	94	65-147	21	89	66-103
2	20	85	53-100	19	80	62- 99
3	19	88	62-105	20	92	78-106
4	20	93	67-111	19	90	79- 98
FRA	10	92	68-104	10	94	79-101

TABLE III. 143

ABSOLUTE SUM OF SWEAT CONSTITUENTS
(mOsm/L Na, K, NH_3, Cl, Lactic Acid, Urea)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST O	U	98	154	111	111	122	146	135	127	168	159
	L	101	146	136	134	142	130	162	127	134	128
0/100/0	U	140	168	107	125	114	113	148	122	136	88
1000	L	122	145	132	143	91	105	140	136	128	110
0/100/0	U	88	106	88	97	92	130	161	113	126	92
2000	L	203	177	182	202	176	140	123	87	125	110
2/20/78	U	158	162	200	87	104	156	153	142	145	106
1000	L	153	159	156	196	210	138	178	185	156	130
2/20/78	U	120	142	169	---	---	111	139	161	184	124
2000	L	121	136	187	144	133	137	174	196	196	162
15/52/33	U	162	176	166	177	164	115	153	143	130	144
1000	L	81	76	104	---	---	109	112	141	118	110
15/52/33	U	96	124	105	96	---	180	202	181	230	160
2000	L	115	171	181	137	157	143	150	144	148	130
15/52/33	U	130	145	130	142	163	131	120	136	144	102
3000	L	124	220	158	156	143	116	127	---	---	---
30/0/70	U	118	156	105	137	123	106	139	118	112	80
1000	L	117	139	112	98	106	103	135	119	120	92
30/0/70	U	138	161	134	128	150	152	146	149	148	117
2000	L	121	126	150	128	140	170	211	133	168	166
FRA	U	119	101	106	99	87	132	120	112	126	95
	L	108	104	88	81	85	93	78	91	96	94

TABLE III. 144

DIFFERENCE BETWEEN TOTAL OSMOLARITY AND SUM OF CONSTITUENTS
(Absolute m Osm/L)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	+ 1	+ 4	0	+13	0	+47	+19	+36	+13	+24
	L	+40	+35	+32	+23	+ 1	+15	+16	+34	+23	+20
0/100/0	U	-20	0	- 5	+15	+12	+49	- 6	+16	- 1	+20
1000	L	+27	+55	+46	+40	+55	- 7	+14	+28	+10	+18
0/100/0	U	+ 8	+22	+ 3	- 1	- 4	+40	+12	+21	+ 4	+24
2000	L	+ 3	+13	+ 3	+ 9	- 8	+14	+16	+41	+20	+18
2/20/78	U	+78	+77	+70	+104	+174	+ 6	+ 1	+11	+14	+ 5
1000	L	+19	+33	+12	+14	+12	+42	+36	- 34	+33	+29
2/20/78	U	+20	+54	+21	---	---	+ 8	- 7	- 2	+49	+30
2000	L	+24	+58	+43	+14	+45	+ 5	+36	+90	+18	+32
15/52/33	U	-14	+19	+46	+22	+ 9	+ 4	+33	+22	+24	+22
1000	L	+74	+20	+ 8	---	---	+19	+13	+171	+32	+30
15/52/33	U	+ 4	+ 6	+15	- 4	---	- 1	+39	+50	+34	+12
2000	L	+71	+122	+126	+46	+79	- 1	+12	+44	+ 8	+28
15/52/33	U	+17	+39	+28	+22	+10	+13	+38	+24	+ 2	+13
3000	L	+48	+62	+43	+20	+16	+12	+17	---	---	---
30/0/70	U	+ 1	- 2	+ 7	+15	+ 3	+18	+15	+44	+25	+14
1000	L	+17	+27	+ 8	+ 6	+ 9	+ 1	+ 7	+71	+16	+15
30/0/70	U	+14	+17	+15	+ 4	+12	- 5	+10	- 9	- 2	+ 1
2000	L	+11	+30	+56	+16	+12	+24	-17	-98	+15	+31
FRA	U	-21	+ 8	+ 4	+ 5	+18	+15	+ 1	+ 4	- 1	+ 1
	L	+ 9	- 1	+ 5	+13	+16	+11	+ 7	+22	0	+ 6

TABLE III. 145

SUM OF CONSTITUENTS AS % OF TOTAL OSMOLARITY
(% mOsm/L)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST O	U	101	97	100	91	97	81	94	80	90	88
	L	90	80	82	86	99	92	92	79	85	87
0/100/0	U	93	100	104	90	97	71	91	88	100	82
1000	L	84	72	76	82	88	104	90	82	92	86
0/100/0	U	93	78	98	100	104	78	95	86	98	79
2000	L	94	90	86	95	103	94	88	67	86	85
2/20/78	U	66	80	78	91	75	96	99	93	91	95
1000	L	90	83	94	93	94	81	84	76	84	82
2/20/78	U	90	76	94	--	--	94	106	102	85	82
2000	L	85	72	84	90	80	97	84	68	92	88
15/52/33	U	118	90	78	88	94	97	88	86	84	86
1000	L	93	80	93	--	--	86	89	46	79	78
15/52/33	U	96	96	88	102	--	101	84	79	89	94
2000	L	64	60	58	78	66	102	92	77	94	82
15/52/33	U	89	79	82	86	94	91	84	86	98	90
3000	L	73	78	80	86	90	91	88	--	--	--
30/0/70	U	99	99	94	90	102	88	98	73	84	98
1000	L	90	80	94	93	100	100	94	70	89	94
30/0/70	U	90	86	90	97	92	102	95	108	202	100
2000	L	91	80	74	88	90	88	94	57	92	84
FRA	U	98	93	96	96	84	88	98	95	101	98
	L	95	100	96	86	86	90	86	88	99	92

TABLE III. 146

PRE-PERIOD DATA ON IONIC BALANCE IN SWEAT:
SUM OF CATIONS, SUM OF ANIONS, AND DIFFERENCE

Flight	P I N	P I Mean	P I Range	P II N	P II Mean	P II Range
		A. Sum of Cations (Na, K, NH_3), m Eq/L				
1	21	53	24-83	21	70	33-109
2	20	58	32-91	19	76	35-113
3	19	63	47-92	20	71	59-102
4	20	57	40-111	18	66	51-102
FRA	10	49	37-78	10	45	30-61
		B. Sum of Anions (Chloride, Lactate) m Eq/L				
1	21	52	25-74	21	62	30-85
2	20	51	33-97	19	55	32-106
3	19	56	34-80	20	64	43-94
4	20	52	31-91	18	61	44-85
FRA	10	48	37-70	10	43	23-60
		C. Difference (Cation-Anions)				
1	21	+1	-9 to +10	21	+8	-13 to +30
2	20	+7	-6 to +29	19	+21	+ 7 to +40
3	19	+7	-12 to +26	20	+7	- 3 to +21
4	20	+5	-9 to +20	18	+6	- 2 to +17
FRA	10	+1	-11 to +10	10	+2	-11 to +25

TABLE III. 147

SUM OF SWEAT CATIONS
(m Eq/L, Na, K, NH_3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	44	70	48	48	53	68	65	55	76	70
	L	58	74	60	55	67	58	73	52	65	63
0/100/0	U	62	76	48	52	49	54	60	51	59	39
1000	L	50	74	60	60	62	47	62	58	60	47
0/100/0	U	36	52	36	37	36	64	76	51	54	40
2000	L	91	89	64	88	86	65	56	44	60	47
2/20/78	U	67	85	88	77	101	70	72	64	65	40
1000	L	76	82	71	90	94	59	83	79	76	55
2/20/78	U	48	63	69	--	--	51	65	74	88	54
2000	L	54	70	85	68	58	53	76	98	95	73
15/52/33	U	76	81	64	80	76	51	70	67	53	58
1000	L	32	35	41	--	--	46	44	66	52	43
15/52/33	U	42	58	38	39	--	79	100	81	108	72
2000	L	56	88	81	62	74	66	65	65	66	60
15/52/33	U	53	74	50	60	76	56	68	56	62	45
3000	L	58	102	67	68	60	52	54	--	--	--
30/0/70	U	54	74	46	57	48	54	69	60	56	36
1000	L	52	68	46	36	47	42	60	54	59	43
30/0/70	U	58	71	50	50	62	70	70	70	66	48
2000	L	54	62	65	56	62	80	102	63	82	71
FRA	U	50	44	46	38	38	62	55	48	57	42
	L	44	40	34	35	35	41	39	39	41	41

TABLE III. 148

SUM OF SWEAT ANIONS
(m Eq/L, Chloride, Lactate)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	43	66	40	49	50	58	61	47	68	67
	L	53	52	46	58	50	51	68	48	57	45
0/100/0	U	60	70	40	53	44	40	50	49	59	37
1000	L	50	45	39	52	38	41	60	49	54	42
0/100/0	U	38	36	32	43	33	44	68	40	54	38
2000	L	97	70	67	92	66	54	48	24	50	43
2/20/78	U	64	80	82	72	77	69	66	60	68	53
1000	L	61	59	66	88	86	58	68	59	55	54
2/20/78	U	52	56	73	—	—	50	62	74	74	53
2000	L	48	42	73	58	50	62	69	66	78	55
15/52/33	U	66	79	74	72	62	50	70	60	62	64
1000	L	37	25	37	—	—	40	43	46	38	37
15/52/33	U	40	48	45	42	—	80	85	68	101	64
2000	L	34	52	62	47	51	60	66	50	62	47
15/52/33	U	58	50	57	59	62	62	51	52	65	36
3000	L	43	87	58	63	58	44	52	—	—	—
30/0/70	U	54	72	38	58	52	45	64	31	55	40
1000	L	53	52	38	44	42	42	52	32	46	36
30/0/70	U	60	68	53	54	54	64	64	54	65	48
2000	L	51	46	48	52	60	68	85	36	72	71
FRA	U	54	44	43	41	31	55	50	54	55	41
	L	46	48	41	33	32	40	26	44	43	39

TABLE III. 149

SUM OF SWEAT CATIONS (m Eq/L) MINUS SUM OF SWEAT ANIONS (m Eq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	+ 1	+ 4	+ 8	- 1	+ 4	+11	+ 4	+ 9	+10	+ 3
	L	+ 6	+21	+14	- 4	+18	+ 9	+ 5	+ 5	+ 8	+18
0/100/0	U	+ 2	+ 7	+ 8	- 1	+ 5	+14	+ 9	+ 2	0	+ 2
1000	L	+ 1	+29	+20	+ 8	+24	+ 6	+ 2	+ 9	+ 6	+ 5
0/100/0	U	- 2	+16	+ 4	- 6	+ 3	+20	+ 8	+11	0	+ 2
2000	L	- 6	+20	- 3	- 4	+20	+10	+ 8	+20	+10	+ 4
2/20/78	U	+ 2	+ 6	+ 7	+ 5	+24	0	+ 6	+ 4	- 3	-13
1000	L	+14	+22	+ 5	+ 2	+ 9	0	+15	+20	+20	+ 2
2/20/78	U	- 3	+ 7	- 4	---	---	+ 1	+ 3	0	+14	0
2000	L	+ 7	+29	+12	+12	+ 7	- 9	+ 7	+31	+13	+18
15/52/33	U	+10	+ 2	-10	+ 8	+14	+ 1	0	+ 7	- 9	- 6
1000	L	- 5	+10	+ 4	---	---	+ 6	+ 1	+20	+15	+ 6
15/52/33	U	+ 1	+ 8	- 8	- 3	---	- 1	+14	+13	+ 7	+ 8
2000	L	+22	+36	+19	+15	+23	+ 7	0	+16	+ 4	+13
15/52/33	U	- 5	+24	- 8	0	+14	- 6	+18	+ 4	- 3	+10
3000	L	+14	+15	+ 8	+ 6	+ 2	+ 7	+ 2	---	---	---
30/0/70	U	+ 1	+ 2	+ 8	- 1	- 3	+10	+ 5	+29	0	- 4
1000	L	0	+16	+ 9	- 8	+ 5	0	+ 8	+22	+12	+ 8
30/0/70	U	- 2	+ 4	- 3	- 4	+ 8	+ 6	+ 7	+16	+ 2	0
2000	L	+ 3	+16	+18	+ 4	+ 2	+12	+17	+27	+10	0
FRA	U	- 4	0	+ 3	- 3	+ 7	+ 7	+ 5	- 6	+ 2	+ 1
	L	- 2	- 8	- 8	+ 2	+ 3	+ 1	+12	- 5	- 1	+ 2

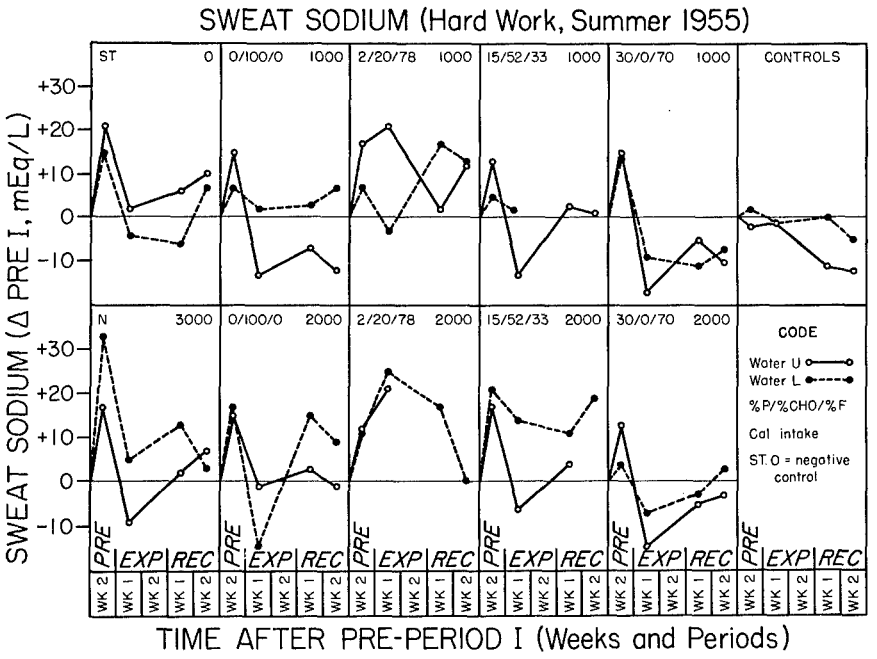


FIGURE III. 52. SWEAT SODIUM: HARD WORK.

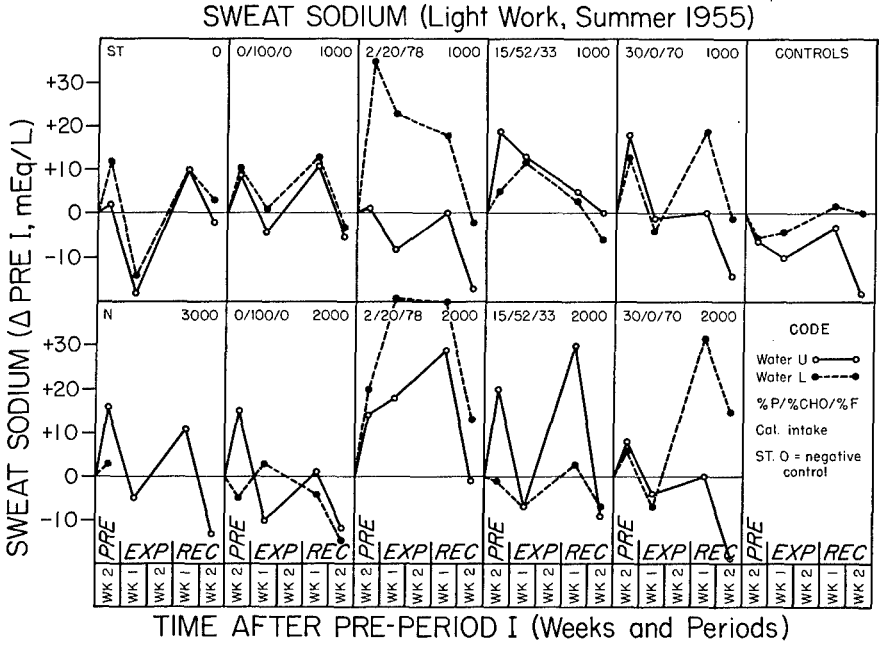


FIGURE III. 53. SWEAT SODIUM: LIGHT WORK

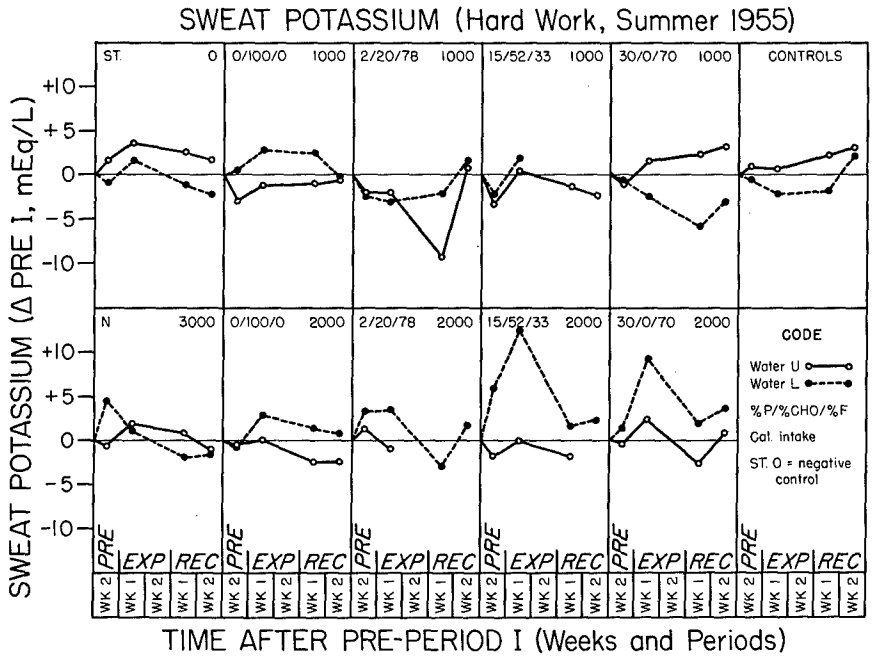


FIGURE III. 54. SWEAT POTASSIUM: HARD WORK.

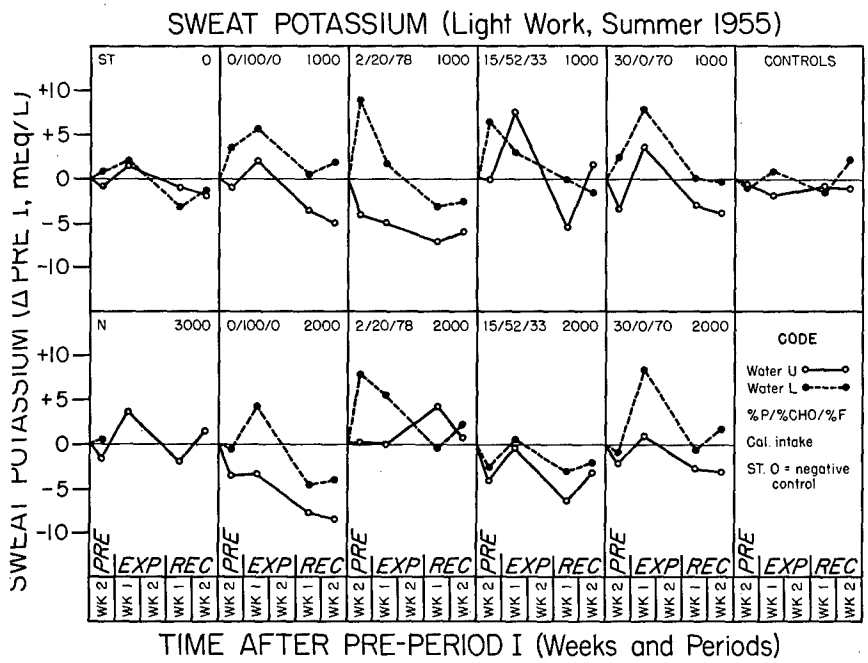


FIGURE III. 55. SWEAT POTASSIUM: LIGHT WORK.

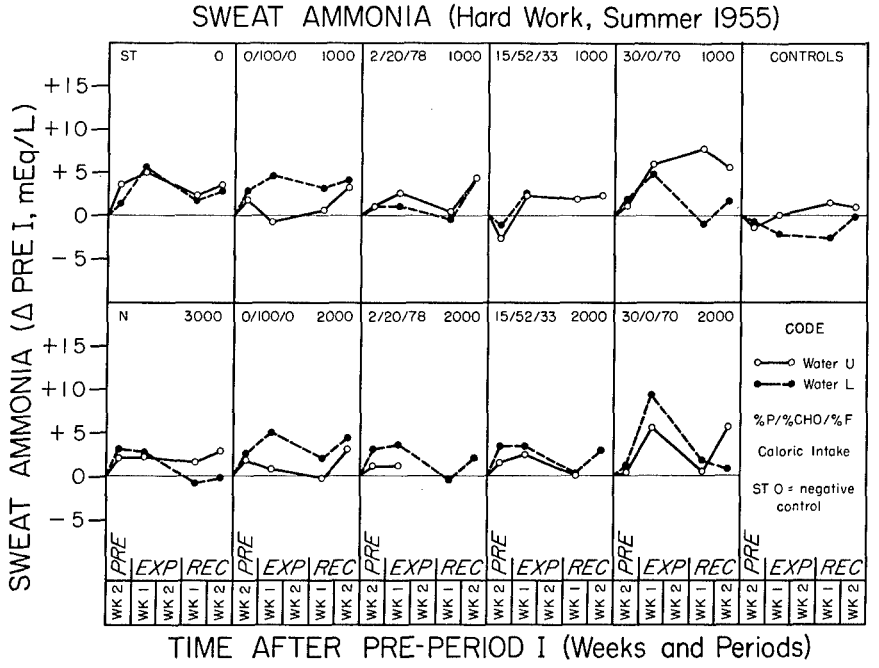


FIGURE III. 56. SWEAT AMMONIA: HARD WORK.

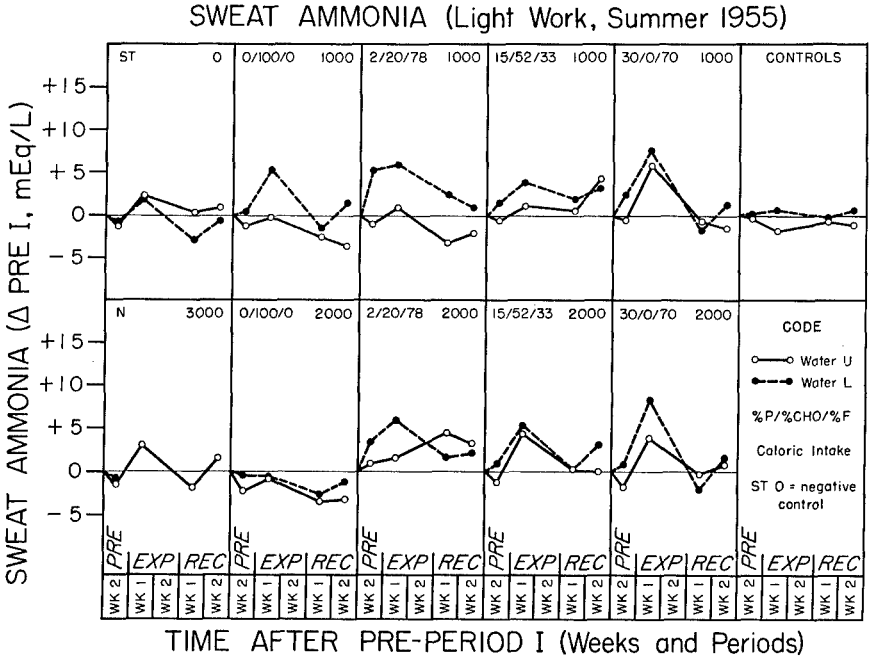


FIGURE III. 57. SWEAT AMMONIA: LIGHT WORK.

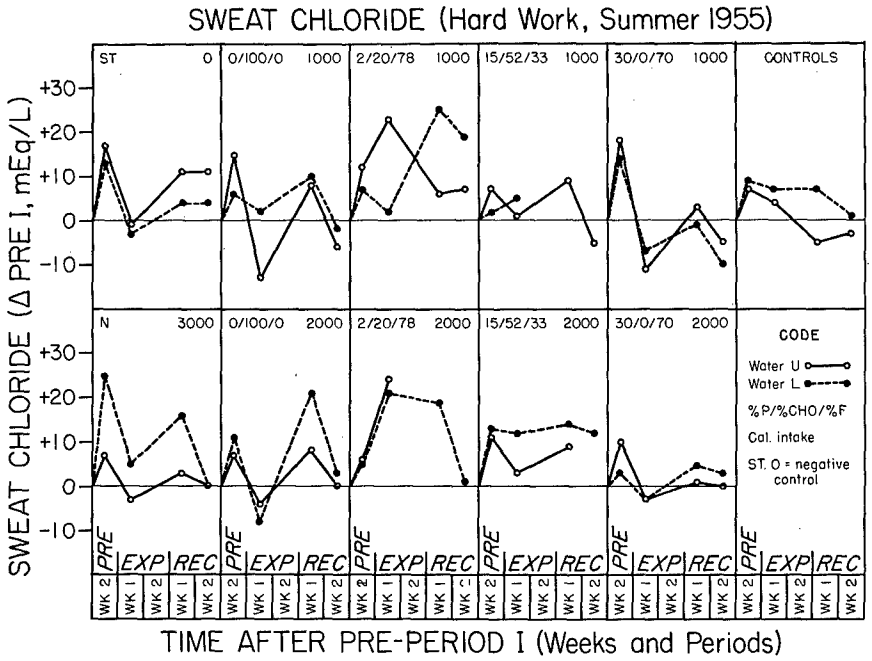


FIGURE III. 58. SWEAT CHLORIDE: HARD WORK.

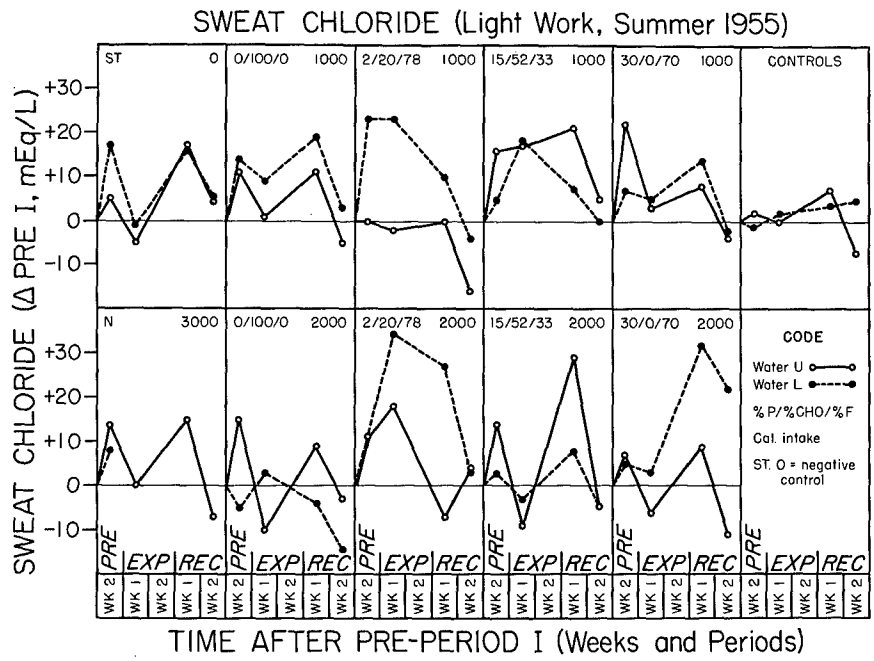


FIGURE III. 59. SWEAT CHLORIDE: LIGHT WORK.

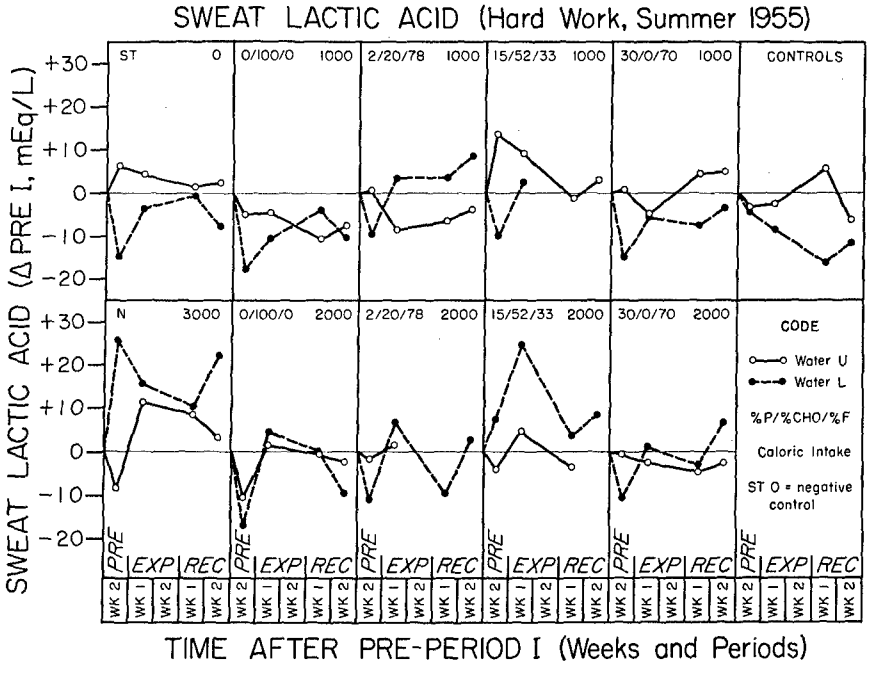


FIGURE III. 60. SWEAT LACTIC ACID: HARD WORK.

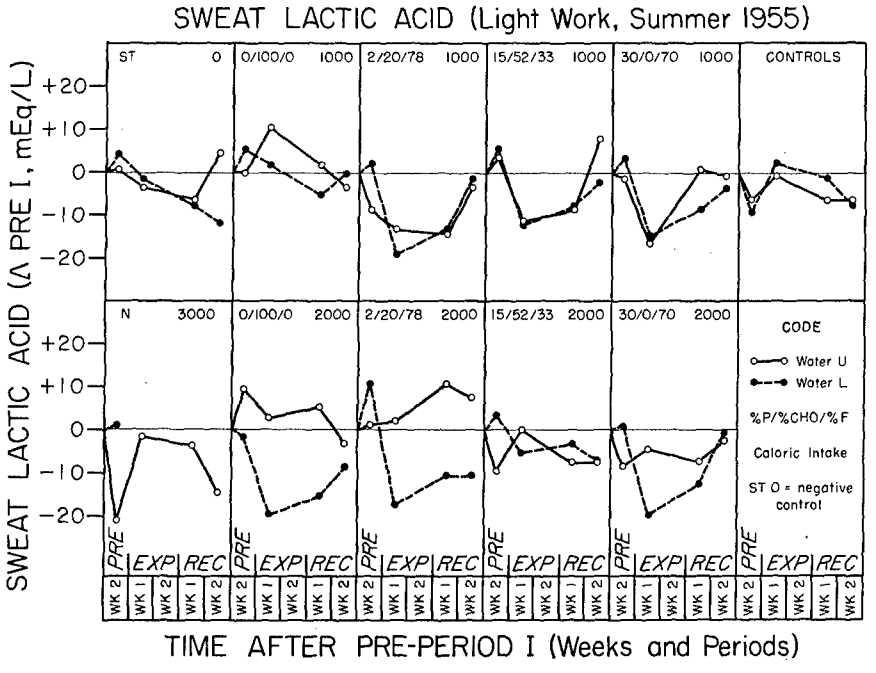


FIGURE III. 61. SWEAT LACTIC ACID: LIGHT WORK.

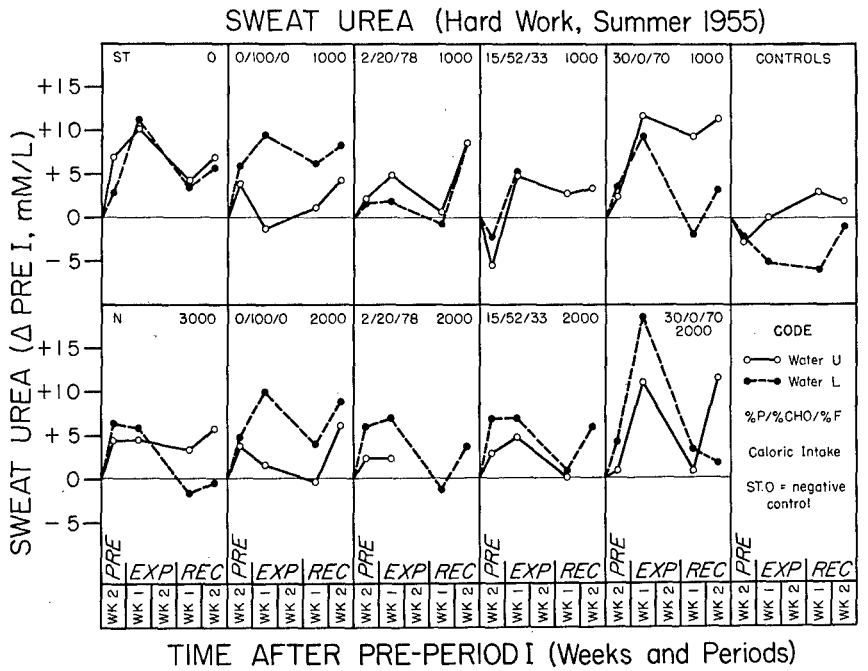


FIGURE III. 62. SWEAT UREA: HARD WORK.

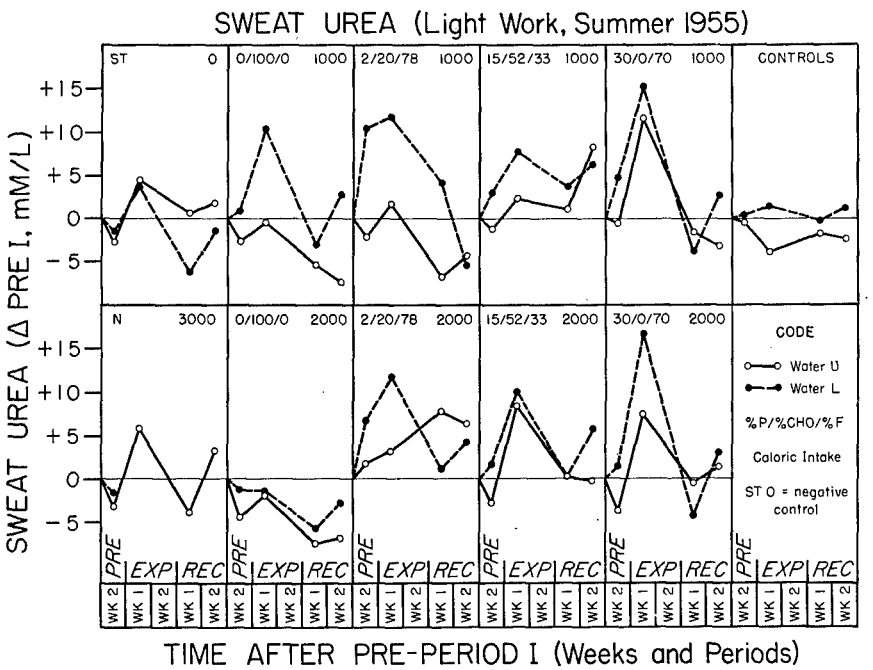


FIGURE III. 63. SWEAT UREA: LIGHT WORK.

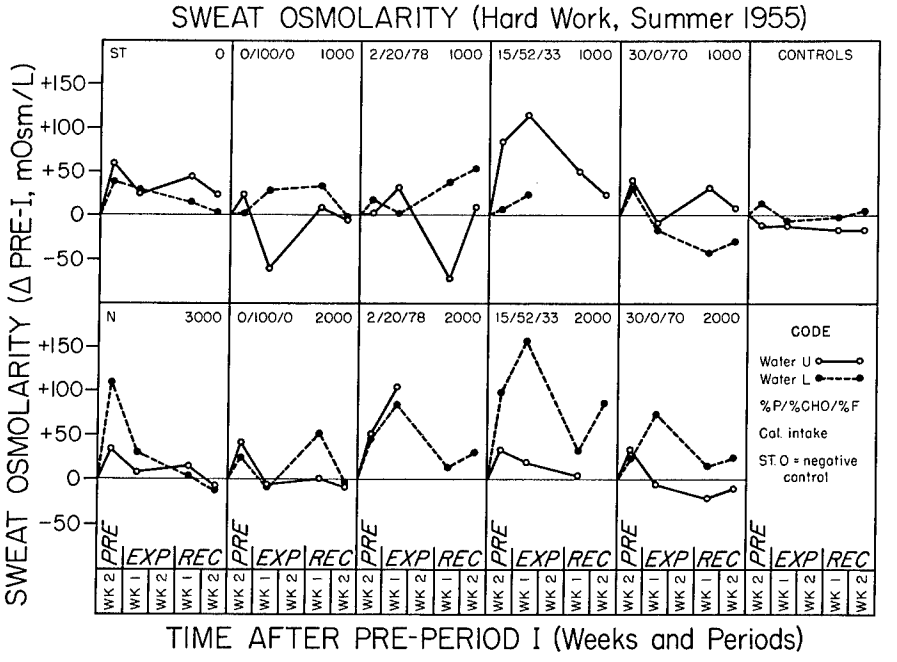


FIGURE III. 64. SWEAT OSMOLARITY: HARD WORK.

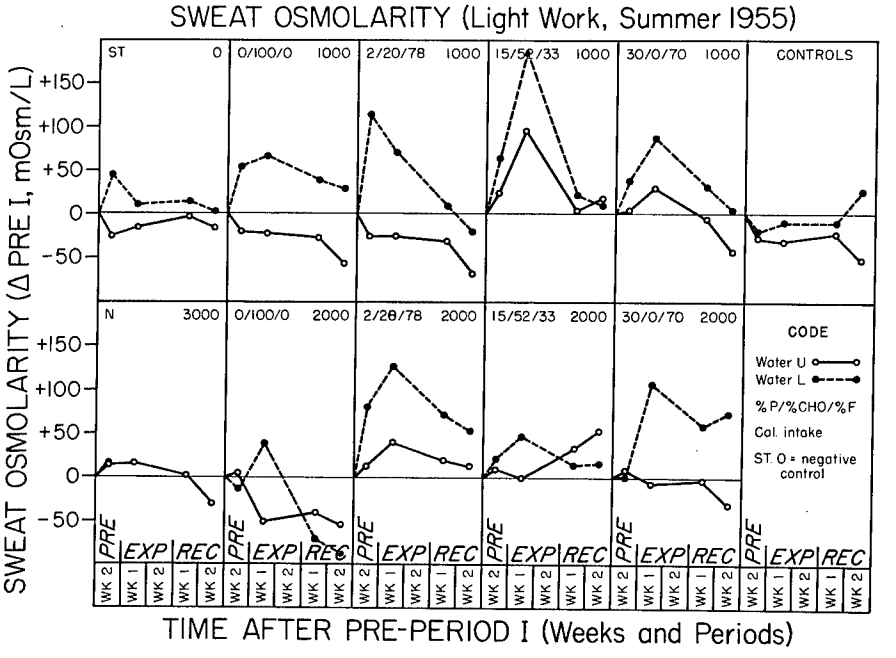


FIGURE III. 65. SWEAT OSMOLARITY: LIGHT WORK.

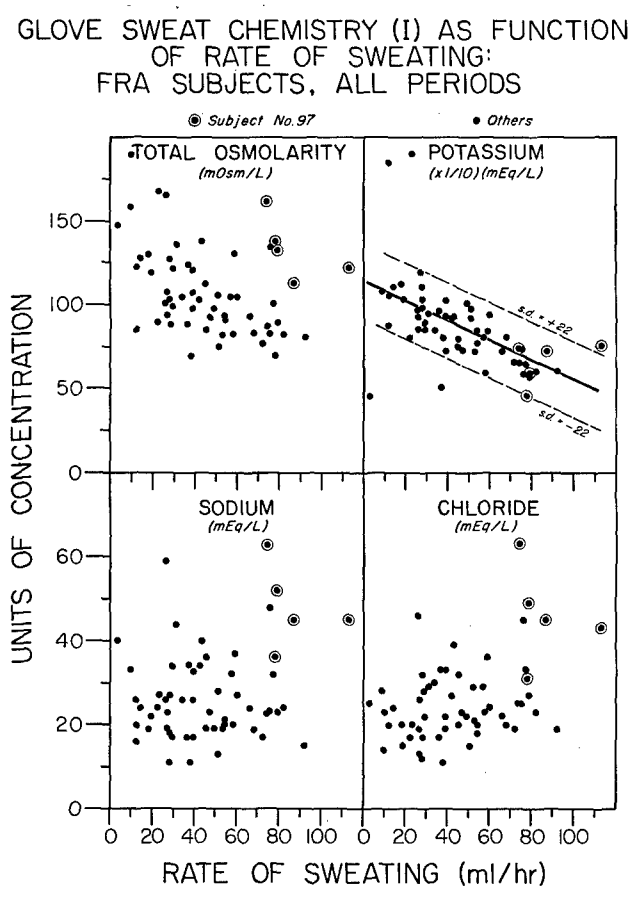


FIGURE III. 66. GLOVE SWEAT CHEMISTRY (I) AS A FUNCTION OF RATE OF SWEATING: FRA SUBJECTS, ALL PERIODS.

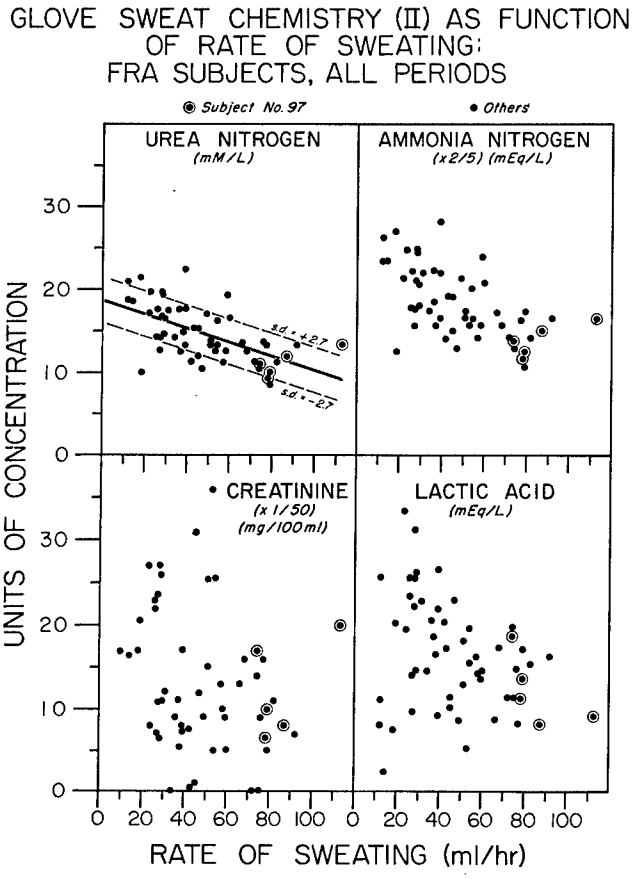


FIGURE III. 67. GLOVE SWEAT CHEMISTRY (II) AS A FUNCTION OF RATE OF SWEATING: FRA SUBJECTS, ALL PERIODS.

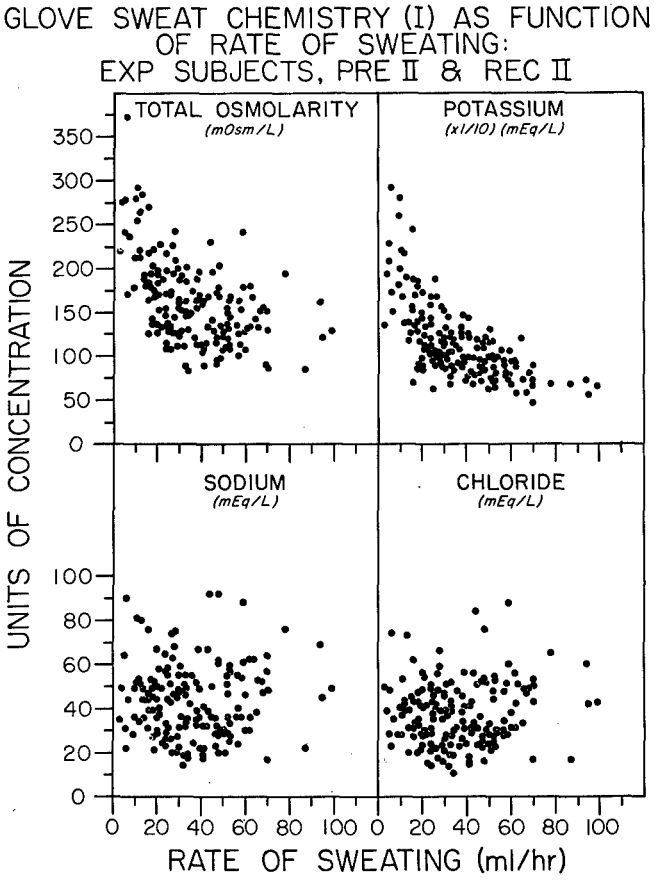


FIGURE III. 68. GLOVE SWEAT CHEMISTRY (I) AS A FUNCTION OF RATE OF SWEATING: EXP SUBJECTS, PRE II AND REC II.

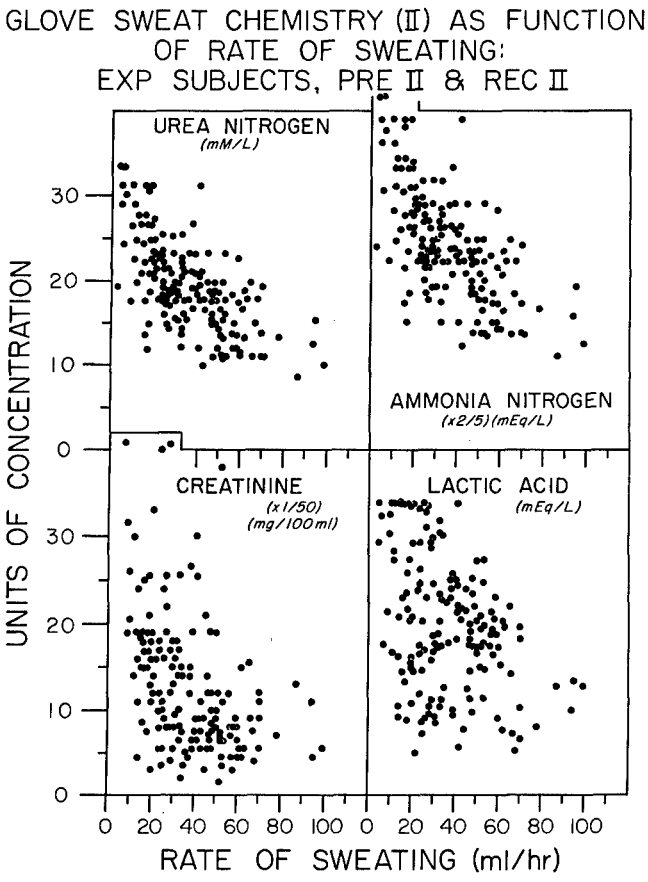


FIGURE III. 69. GLOVE SWEAT CHEMISTRY (II) AS A FUNCTION OF RATE OF SWEATING: EXP SUBJECTS, PRE II AND REC II.

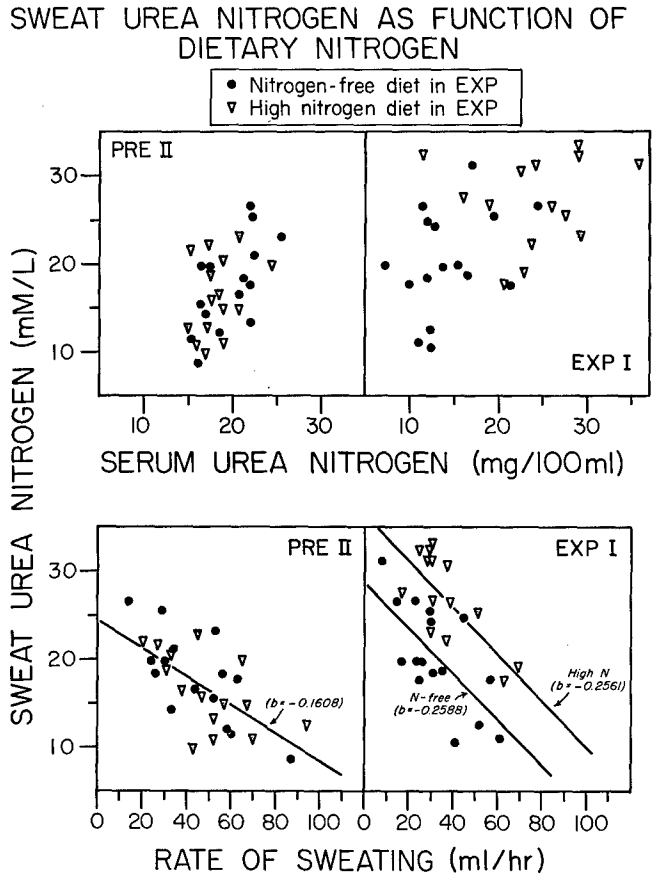


FIGURE III. 70. SWEAT UREA NITROGEN AS A FUNCTION OF DIETARY NITROGEN.

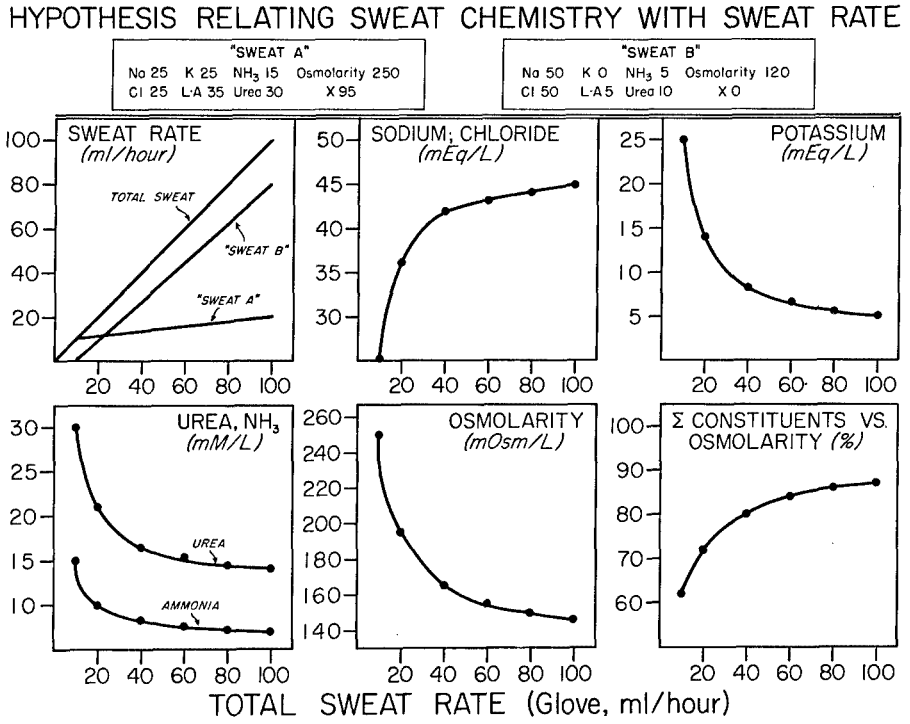


FIGURE III. 71. HYPOTHESIS RELATING SWEAT CHEMISTRY TO SWEAT RATE.

9. Clinical Reactions to Heat and Exercise

a. Subjects Incapacitated during March and Occurrence of Heat Flush and Irregular Pulse

PRE I. Uneventful; all subjects completed the four-mile march.

PRE II. Subject 8: This young white male gave up after seven laps of the 3.75-mile march of 2 July. On this day the dry-bulb temperature was 94.8°F, the wet-bulb, 78.3°F, and the wind velocity, 224 ft/min. The reason for his incapacitation was not evident. Reference to Table III. 150 indicates that the march had not unduly strained the heart or thermo-regulatory mechanism. It is of some interest to note that on the following day a heat rash (miliaria rubra) developed on the genitalia, which persisted for about 48 hours. Since the subject later developed an anxiety hyperventilation tetany, it may very well be that he was malingering.

EXP I. Subject 4: The young white male collapsed at the end of the tenth lap of the 3.75-mile march on 10 July. During the march the dry-bulb temperature averaged 96.0°F, wet-bulb temperature 79.9°F, and the wind velocity 201 ft/min. Examination revealed a pulse rate of 144 and a rectal temperature

of 102.0°F (Table III. 150). With bed rest the pulse rate and rectal temperature rapidly returned to normal: 11 minutes after ending the march the pulse rate was 80 and 21 minutes afterwards the oral temperature was 98.8°F.

TABLE III. 150

SUBJECTS FAILING TO COMPLETE HEAT ACCLIMATIZATION TEST

Subject Code No.	Nutrient Regimen	Laps Completed	Pulse Initial	Pulse Final	Rectal Temp. (°F) Initial	Rectal Temp. (°F) Final
8	5-in-1 (P II)	7	76	90	99.5	100.2
4	ST O U	10	70	144	100.0	102.0
31	30/0/70 1000 L	15*	68	180	99.5	101.5*
33	30/0/70 2000 L	6	64	148	98.5	100.5
34	30/0/70 2000 L	10	72	168	98.8	100.9
36	5-in-1 (R I)	8	84	144	99.7	100.9
2**	FRA (R II)	14	76	96	99.5	100.0

*Near collapse; oral temperature subsequently rose to 103.6°F.

**Recovering from suspected infectious mononucleosis.

Subject 31: This young white male just managed to complete the 3.75-mile march on 10 July. During the march the dry-bulb temperature averaged 94.9°F, the wet bulb 78.2°F, and the wind velocity 224 ft/min. At the end of the march the subject was suffering from severe stomach cramps, headache, and exhaustion. Examination revealed pulse rate of 180, rectal temperature of 101.5°F, severe conjunctivitis O.D., and extensive flush to face (Table III. 151.) He was sobbing from the pain. Demerol (50 mg) was given for pain. When it was discovered that hyperpyrexia had developed, the subject was placed in a cold shower and given intravenous fluids (Table III. 151). The maximum temperature reached was 103.6°F orally. With this treatment the hyperpyrexia was abolished. Within 60 minutes the temperature had returned to normal and the subject was resting more comfortably. A feeling of exhaustion persisted for 24 hours.

Subject 33: This young white male marched at the same time as Subject 31. He was only able to complete six laps of the 15 required (Table III. 150). In order to understand the reasons for his incapacitation we must first consider his clinical history prior to 10 July. After 24 hours of meat bar and limited water he began to complain of nausea, severe thirst, headache, abdominal pain, precordial pain, weakness, and dizziness. Two days later (9 July) he was brought to "Sick Bay" complaining of an inability to sweat. He stated that he had felt hot for the past 36 hours. On the day prior to admission he only drank 1800 ml of water. His flight was allowed 2700 ml. On day of admission he had consumed 1800 ml of water up to 1630 hours. On 9 July he had sweated normally in the morning. At noontime while marching back to camp after lunch his fellow subjects had told him that his back was dry---even though the hike was done under a hot sun. At this time there was sweat on the forehead and he staggered while marching. During this march a headache developed and

TABLE III. 151

POST-EXERCISE HYPERPYREXIA: SUBJECT 31

Time	Observation and Treatment
1652	Completed march
1707	Demerol, 50 mg, for pain
1710	Pulse 110, rectal temperature 103.2°F
1715	Rectal temperature 103.2°F
1720	Placed in shower and sprayed with cold water
1725	Oral temperature 103.6°F
1733	Pulse 66
1738	Onset of shivering
1740	Oral temperature 102.6°F
1746	1000 ml 5% glucose in saline I.V. begun
1749	Pulse 64
1757	Chills
1800	Oral temperature 100.6°F
1805	Pulse 50
1820	Pulse 45
1825	Oral temperature 99.0°F
1835	Pulse 50
1840	Oral temperature 99.0°F
1845	Pulse 48
1855	Oral temperature 99.0°F; removed from shower
1925	Pulse 50; blood pressure 135/38
1930	Oral temperature 98.8°F
1950	I.V. fluids changed to 5% dextrose in water; first bottle completed
2000	Oral temperature 98.6°F
2005	Pulse 54
2030	Pulse 54, oral temperature 98.4°F
2100	Pulse 58, oral temperature 98.6°F; I.V. fluids stopped after 500 ml of 5% dextrose in water had been administered

nausea which had started after breakfast persisted. He continued to sweat from his forehead until about 1600 hours at which time all sweating ceased and he became progressively weaker and dizzy. He reported urinary frequency but no polyuria. He was an anxious appearing well-developed well-nourished young man. A sticky sound accompanied his speech. The tongue was thickly coated with cafe-au-lait colored material. The skin was hot and completely dry. The groin and axillae were also dry. There were no lesions of any kind on the skin. A special search was made for miliarial lesions. The oral temperature was 101.6°F and respiratory rate was 28. There was a tachycardia (pulse of 100). The lying blood pressure was 138/80. One minute later, while standing, the pressure was 105/70. There was hyperreflexia of tendon reflexes. The remainder of the examination was not remarkable.

He was confined to bed and his nutrient regimen was not altered. During the evening he drank some water from his remaining allowance (900 ml) and ate

meat bar which caused more nausea and cramps. At 2230 hours the oral temperature was 99.0°F and total anhidrosis was still present.

On 10 July he participated in the three-hour test. At this time the oral temperature was 97.6 F, the lying blood pressure and pulse rate 120/64 and 46 respectively and the standing blood pressure and pulse rate 110/78 and 64 respectively. The minute urinary volume was 0.5 ml/hour. He continued to be anhidrotic.

The decision was made to have him march in the afternoon to study whether or not sweating could be induced. During the march he was accompanied by a medical officer. Sweating did develop, especially on the forehead. During the fifth and sixth laps he complained of increasing sense of warmth, pressure on his chest, and dizziness. At the end of the sixth lap he was removed from the march. The pulse rate was 148 and the rectal temperature was 100.5°F (Table III. 150). The respiratory rate was 43. He complained of tingling in hands, arms, chest, and mouth. A strongly positive Chvostek sign was elicited. Thirteen minutes later the only sweat present was on the forehead. Sixteen minutes after the end of march parasthesias of mouth and finger tips continued. At 19 minutes the rectal temperature was 101.4°F and the pulse was 76. At 44 minutes the rectal temperature and pulse were unchanged. At 46 minutes the tingling had disappeared. At 56 minutes the rectal temperature was 101.0°F and the pulse was 54. At 71 minutes the rectal temperature was 100.8°F and the pulse was 64. The total sweat loss during the march was 850 ml/hr.

He spent the remainder of the day in the Sick Bay. On 11 July he returned to his flight. Normal sweating had been restored.

Subject 34: This young white male marched with Subjects 31 and 33. He became incapacitated after 10 laps (Table III. 150). At this time his pulse rate was 168 and the rectal temperature was 100.9°F. He complained of marked exhaustion, stomach cramps, chilly sensation in the legs, and staggering gait. Examination revealed a facial flush. With bed rest he responded rapidly. He spent the remainder of the day in Sick Bay and on 11 July was discharged to his flight.

REC I. Subject 36: On 19 July this young white male became incapacitated after 8 laps (Table III. 151). During the march the dry bulb temperature averaged 88.2°F, the wet-bulb temperature 77.2°F, and the wind velocity 355 ft/min. He dropped out of the march complaining of severe vertigo. His face was markedly flushed and his pulse rate was 144 and the rectal temperature was 100.9°F. Nine minutes later the pulse was 88. Fourteen minutes later the rectal temperature was 100.8°F. At 39 minutes the rectal temperature was 100.0°F.

REC II. Subject 2: On 24 July this young white male became incapacitated after 14 laps (Table III. 151). During the march the dry-bulb temperature averaged 81.3°F, the wet-bulb temperature 76.0°F, and the wind velocity 205 ft/min. He quit marching because of severe abdominal pain and fatigue. His rectal temperature was 100.0°F, and the pulse rate was 96 (Table III. 151).

In order to evaluate this episode, certain facts of his clinical history are required. He was placed in Sick Bay on 9 July with a tentative diagnosis of infectious mononucleosis. On 14 July he was air evacuated to Chanute AFB for treatment. He returned on 20 July and was placed on Field Ration A and assigned to KP duty. The impression is that the subject's tolerance for moderate work in the heat had not fully recovered by 24 July.

Heat Flush. A number of subjects developed heat flush--facial peripheral vasodilatation--during the heat acclimatization test. The incidence of this sign was greatest in the recovery periods:

Period	Number
P II	1
EXP I	3*
REC I	11*
REC II	10

*Also Subjects 31 and 34 (v.s.)
**Also Subjects 36 (v.s.)

Examination of Table III. 152 brings out three additional facts. (1) The occurrence of the flush was not related to duration of rehabilitation. (2) Final pulse rate and rectal temperatures--measures of strain on body from marching effort--were not different from those measured among men who did not show such vasodilatation. (3) There was a marked tendency for the sign to be an individual characteristic. Subjects 17, 36, 51, 58, 71, 74, and 97 exhibited the sign two or three times. It may have been the physiological processes of rehabilitation were responsible for increasing the occurrence of this reflex vascular reaction.

TABLE III. 152

SUBJECTS EXHIBITING "HEAT FLUSH" TO FACE
AFTER HEAT ACCLIMATIZATION TEST

Subject Code No.	Nutrient Regimen	Pulse		Rectal Temperature (°F)	
		Initial	Final	Initial	Final
97*	FRA (P II)	86	164	100.0	102.1
17	15/52/33 1000 U	60	132	99.0	100.5
17	5-in-1 (R I)	68	118	99.2	100.5
51	5-in-1 (R I)	88	120	100.0	100.8
58	5-in-1 (R I)	84	138	99.0	100.5
71	5-in-1 (R I)	70	124	99.4	100.5
74	5-in-1 (R I)	86	124	99.8	100.8
76	5-in-1 (R I)	104	118	99.7	100.5
79	5-in-1 (R I)	94	116	99.7	100.5
85	5-in-1 (R I)	76	112	99.3	100.7
86	5-in-1 (R I)	68	90	99.2	100.2
97	FRA (R I)	88	140	99.2	100.5
17	5-in-1 (R II)	80	132	99.4	100.5
26	5-in-1 (R II)	80	152	99.0	101.0
36	5-in-1 (R II)	104	114	99.7	101.5
51	5-in-1 (R II)	96	108	99.5	101.4
58	5-in-1 (R II)	78	118	99.1	100.0
67	5-in-1 (R II)	80	114	99.1	100.2
71	5-in-1 (R II)	84	110	99.0	100.0
74	5-in-1 (R II)	100	146	99.1	100.1
92	5-in-1 (R II)	90	100	99.5	100.6
97	5-in-1 (R II)	68	148	99.5	100.3

*Experienced vertigo during 10th lap.

Irregularity of Pulse. Only four instances of irregularity of the pulse were observed immediately following the 3.75-mile march (Table III. 153). These were not related to nutrient regimen, pulse rate, or rectal temperature. The fact that no episodes were observed in recovery is of some interest. Apparently the processes of rehabilitation had less effect on the heart than on the peripheral vascular tree.

TABLE III. 153

SUBJECTS WITH IRREGULARITY OF PULSE
AFTER HEAT ACCLIMATIZATION TEST

Subject Code No.	Nutrient Regimen	Pulse		Rectal Temperature (°F)		Remarks
		Initial	Final	Initial	Final	
45	5-in-1 (P I)	68	112	98.0	101.9	Extrasystoles
45	5-in-1 (P II)	74	134	99.9	101.7	Bigeminal pulse
22	15/52/33 3000 U	92	154	99.9	101.0	Irregular pulse
78	30/0/70 2000 L	84	128	98.8	101.1	Extrasystoles

Other Observations. There were only three additional significant complaints among subjects doing the 3.75-mile march. Subject 11 stated that he had R.U.Q. pain in REC I. Subjects 57 and 59 complained of headaches in REC II.

b. Anhidrosis and Hypohidrosis: Clinical Observations

Three cases of total anhidrosis developed early in the experimental period among subjects who had been allowed one canteen (900 ml) of water per day. Subjects 74 and 76 became anhidrotic on 8 July, and 33 on 9 July. Since Subject 33 has been discussed in detail above, we shall deal here only with Subjects 74 and 76.

Subject 74 (0/100/0 2000 L). On 8 July this young white male reported to Sick Bay complaining of weakness, dizziness, occipital headache, and low back pain. (The latter two symptoms had been persistent since the subject arrived at Camp Atterbury and were attributable to anxiety over the trial. The symptoms rapidly cleared in the recovery periods.) Examination revealed a rectal temperature of 99.8°F, hot skin, total anhidrosis (including groin and axillae), and slightly infected left ear drum. A special three-hour test was conducted (Table III. 154A). When compared to similar tests done at other times it is evident that the subject had a mild fever, an elevated pulse rate both lying and standing, marked reduction of minute urinary volume, and no impairment of vasomotor reflexes. A water diuresis test was administered (Table III. 154B). The net recovery of the water load given on 8 July was zero. At this time--in spite of limited water intake--there had been a fall in the serum osmolarity and hematocrit (Table III. 155). The results of this water diuresis test were remarkable.

TABLE III. 154

SUBJECT 74: ANHIDROSIS
A. Three Hour Tests

Date	Blood Pressure (mm hg) Lying	Standing	Pulse Lying	Standing	Oral Temp. (°F)	Minute Urinary Vol. (ml).
27 June	145/80	142/105	68	96	98.6	2.41
2 July	132/88	110/84	64	100	98.9	0.83
8 July*	135/82	134/90	88	128	100.0	0.25
11 July	114/64	128/76	62	84	98.0	0.80
15 July	108/68	129/95	68	108	98.2	0.54
20 July	106/58	126/100	68	94	98.0	1.82
25 July	128/66	126/94	62	96	97.8	1.17

*Special Test.

B. Water Diuresis Test

Date	Water Load	Net Recovery
	ml.	%
28 June	1445	38.7
5 July	1375	20.9
8 July*	1320	0.0
10 July	1345	71.6
21 July	1410	94.7

*Special Test.

TABLE III. 155

SUBJECTS 74 and 76: BLOOD CHEMISTRY

Date	Serum Osmolarity (mOsm/L)		Hematocrit (%)		Serum Urea (mg %)	
	No. 74	No. 76	No. 74	No. 76	No. 74	No. 76
27 June	291	286	45.3	44.4	23.0	19.0
2 July	287	292	43.6	44.2	22.5	24.5
8 July*	272	300	43.0	47.5	16.5	40.8
11 July	283	284	46.5	49.0	11.9	11.5
15 July	276	282	44.0	47.1	7.6	21.6
20 July	282	274	42.6	43.9	16.5	16.2
25 July	280	278	45.0	44.0	22.4	26.0

*Special Test

Subjects subsisted on this regimen with restricted water intake generally diurese normally. It is of special interest to note that eight minutes after he had begun to drink the test dose of water on 8 July he began to sweat.

He remained in Sick Bay until the next day. He was kept on the same diet (0/100/0 2000). Even though he was permitted unlimited water, he drank less than two canteens during the remainder of the experimental period. This reaction was presumably caused by the lack of thirst associated with the pure carbohydrate diet---so-called voluntary dehydration. Some additional dehydration developed, for on July 11 the hematocrit had risen to 46.5%, the maximum value for this man. Nevertheless, sweating was normal thereafter. The progressive fall in serum urea nitrogen is the typical reaction to a high carbohydrate regimen.

On 10 July he was given another water diuresis test. In spite of a persistent negative water balance, he eliminated 71.6% of the dose. This reaction is one which we have found characteristic of a man subsisting on a high carbohydrate diet and limited water. The subject retained water on 8 July because he had not yet become sufficiently osmotically depleted to exhibit the characteristic behavior.

Subject 76 (30/0/70 1000 L). On 8 July the subject reported to Sick Bay

complaining of substernal tightness of 20 hours' duration. Examination revealed a temperature of 99.6°F (oral), pulse 144, cervical and axillary lymphadenopathy, total anhidrosis, and pharyngitis. A three-hour test was conducted (Table III. 156A). When compared with similar tests done at other times, on

TABLE III. 156

SUBJECT 76: ANHIDROSIS

A. Three-Hour Tests

Date	Blood Pressure (mm Hg) Lying	Standing	Pulse Lying	Standing	Oral Temp. (°F)	Minute Urinary Vol. (ml)
27 June	108/80	100/65	60	100	98.6	0.57
2 July	104/60	108/66	58	112	98.8	0.65
8 July*	130/90	120/80	112	140	100.0	0.62
11 July	118/44	93/75	64	100	97.6	0.77
15 July	104/55	96/86	56	84	97.2	0.42
20 July	118/70	104/93	54	82	98.6	2.33
25 July	106/70	105/76	68	94	98.6	0.62

*Special Test

B. Water Diuresis Test

Date	Water Load	Net Recovery
	ml.	%
28 June	1120	78.4
5 July	1120	35.2
8 July*	1065	2.1
10 July	1075	11.3
21 July	1130	86.5

*Special Test

8 July this subject was moderately febrile, he had a tachycardia and a relative increase of systolic and diastolic blood pressure. The vasomotor reflex reaction to standing, however, was normal. The minute urinary volume was not reduced from values of the pre-period (27 June and 2 July). This failure of the minute urinary volume to decrease with limitation of water was caused by the high osmotic excretion of the meat bar regimen. The low minute urinary volume of Subject 74 at this same time was due to the lower osmotic excretion of the pure carbohydrate regimen.

The subject was given a water diuresis test (Table III. 156B). Only 2.1% of the oral dose was excreted. Within one minute after drinking had begun, sweating commenced. At the time of the test this subject exhibited hemoconcentration---elevated serum osmolarity hematocrit and serum urea nitrogen (Table III. 155). This behavior was quite normal for men subsisting on diets with high osmotic content and restricted water.

The subject was returned to Sick Bay and maintained on meat bar and two

canteens of water (1800 ml) per day. The cervical and axillary lymphadenopathy persisted. A blood smear revealed atypical lymphocytes, but the heterophile reaction for infectious mononucleosis was negative. Sweating was normal. On 10 July he was given another water diuresis test; only 11.3% of the test dose was excreted (Table III. 156B). Evidence of hemoconcentration (elevated hematocrit) was still present on 11 July (Table III. 155). After drinking the water, no definite outburst of sweating was detected. One interesting comment, however, was made by the observer. Seventy-nine minutes after the test began, the left leg was hot and dry while the right leg was cool and damp with perspiration.

The diuretic reaction of subject 76 contrasts, on 10 July, with that of No. 74. Both men were on limited water. No. 74 had a greater negative water balance than No. 76 in EXP II: -2.10 liters/day vs. -0.86 liters/day. No. 74 excreted 71.6% of the test dose, No. 76 only 11.3%. These represent characteristic reactions such as we have described in detail in Section C.2.

Subject 76 was released from Sick Bay on 10 July. The remainder of the experimental period for this man was not remarkable.

Comment. Because of these two cases of anhidrosis in Flight 4 and marked weight losses among the subjects of Flight 2, water allowances for these two flights were increased on 8 July: Flight 2, three canteens per day and Flight 4, two canteens per day. On 9 July Subject 33 came to Sick Bay with total anhidrosis.

On 10 July four men in Flight 4 (Nos. 76, 78, 83, and 99) had sulfadiazine crystals in the urine. The sulfa drug had been given prophylactically to all men in this flight because of the case of Waterhouse-Friederikson's syndrome who died on 8 July. All men in the flight were given a water diuresis test in the evening of July 10 and on 11 July their water allowance was increased to three canteens per day. At the time of the test all men were carefully questioned regarding any abnormalities of sweating. Several histories of hypohidrosis were reported.

Hypohidrosis. In addition to the three young men who developed total anhidrosis, eight men either complained of abnormal reduction of sweating or were found to have dry skin when other subjects and the observers were actively sweating (Table III. 157). All of the occurrences of hypohidrosis were among subjects whose water intake was restricted. The first case appeared after 48 hours of limited water; the others developed within the next day or two. Examination of Table III. 158 strongly suggests the hot humid weather of July 7-10 may have precipitated this disturbance of eccrine sweat gland function.

TABLE III. 157

HYPOHIDROSIS: CLINICAL OBSERVATIONS

Subject Code No.	Date of Onset	Nutrient Regimen	Clinical Observations
26	8 July	ST 0	White male complained of dizziness, headache, thirst, and dry skin.
68	10 July	ST 0	Negro male complained of abdominal cramps, drowsiness, cessation of sweating, and impending death. Water diuresis test did not provoke sweating. Dry skin continued until 12 July when he was removed from experimental regimen.
70	12 July	ST 0	White male complained of abdominal pain and weakness on 11 and 12 July. Skin dry and face flushed on 12 July. He was removed from experimental regimen.
73	9 July	0/100/0 2000	White male complained of reduction of sweating. No outburst of sweating during water diuresis test of 10 July.
75	10 July	30/0/70 1000	White male complained of reduction of sweating. Skin was dry before water diuresis test. Water load provoked a sweat response.
78	10 July	30/0/70 2000	White male collapsed after marching from camp in afternoon. Examination revealed oral temp. of 99.8°F, hot dry skin with minimal sweating on forehead, stertorous breathing, and premature ventricular contractions (one per 10 beats). There was an outburst of sweating shortly after beginning to drink water dose.
79	10 July	2/20/78 1000	White male complained of reduction of sweating. Sweating began on forehead several minutes after beginning to drink water dose.
82	11 July	2/20/78	White male complained of arm and leg cramps. Skin was pale and dry; hyperreflexia of tendon jerks. Water dose of preceding night caused moderate outburst of sweating.

TABLE III. 158

ONSET OF ANHIDROSIS AND HYPOHIDROSIS IN RELATION TO TEMPERATURE AND HUMIDITY

Date of Onset	Maximum Temp. (°F)	1630 Rel. Humidity (%)	No. of Cases Anhidrosis	Hypohidrosis
July 6	95	46	0	0
July 7	92	54	0	0
July 8	93	81	2	1
July 9	99	81	1	1
July 10	96	53	0	4
July 11	94	35	0	1
July 12	93	34	0	1
July 13	95	34	0	0
July 14	90	99	0	0

The one case in Flight 2 (no. 26) developed the day on which two cases of anhidrosis appeared. That day the water allowances were increased as discussed above. No further cases of sweat gland dysfunction developed in that flight after 9 July. The remaining cases appeared in Flight 4, the subjects of which were allowed only two canteens of water (1800 ml/day). On 10 July when four more cases of hypohidrosis developed and several men passed urinary crystals of sulfadiazine, all the subjects in Flight 4 were given a water diuresis test and on 11 July they were allowed three canteens of water (2700 ml/day). Two of the men (nos. 68 and 78) with hypohidrosis were in especially poor clinical shape on 10 July and it is doubtful that they would have been able to stand any more exposure with continued water restriction. After the water allowance had been raised, there were two additional mild cases. The general appearance of the men improved considerably.

Problems. On 10 July, when the subjects of Flight 4 were given the water diuresis test, six men (Nos. 68, 73, 75, 78, 79, 82) exhibited evidence of disturbed sweating. In four of these men there was an outburst of sweating within a few minutes after the men began drinking the water load. In our total experience these two men with anhidrosis (Nos. 74 and 76) and six men with hypohydrosis have been given the water diuresis test at the time of sweat gland dysfunction. Of the eight, six have exhibited an outburst of sweating. Two questions arise: first, why the marked reduction in sweating and second, why the outburst of sweating?

Sweat gland dysfunction: Failure to deliver normal amounts of sweat to the surface of the skin may be caused by a disturbance in the hypothalamus, sweat gland fatigue, or mechanical occlusion of the eccrine sweat duct (Sargent and Slutsky, 1957; Shelley, Horvath, and Pillsbury, 1950; Sulzburger and Herrmann, 1954). The occlusive process is generally manifest as miliaria crystallina, rubra, or profunda. Since none of these eight men exhibited miliaria, we can rule that etiology out. The hypothalamic disturbance usually leads to hyperpyrexia with body temperatures well in excess of 105°F. None of our men exhibited hyperpyrexia. We cannot, however, eliminate the possibility that they were in the prodromal stage of this condition. Since we were watch-

ing all the subjects with just this eventuality in mind, we may have caught the syndrome before it had an opportunity to develop fully. We are inclined to doubt the explanation. Subject 33, for example, had every opportunity to develop hyperpyrexia. His anhidrosis was intermittent for a period of 48 hours, yet his body temperature did not rise unduly. We suggest the hypothesis that these men had a type of sweat gland fatigue. Sweat gland fatigue is characterized by (1) a reduction in the rate of sweat in spite of continued exposure to conditions conducive to sweating and (2) an elevation of the sweat chloride concentration (Sargent and Slutsky, 1957). The cause of the condition is unknown. It may occur among men who have been sweating at maximal or sub-maximal rates or among men who have been sweating only moderately.

Dehydration might be a factor. Let us examine pertinent data from this test. The mean water balances for the three men who became anhidrotic in EXP I are conflicting; there are no consistent differences with their paired

MEAN WATER BALANCE IN EXP I (liters/day)

Anhidrosis		Paired Control	
No. 33	-1.51	No. 34	-1.80
No. 74	-2.01	No. 73	-0.97
No. 76	-1.20	No. 75	-1.69

controls---men on identical regimens.

Weight loss is another measure of dehydration particularly when nutrient intake and work load are controlled. When the net weight loss is considered for our three men, two show greater losses than their controls, one, no

NET WEIGHT LOSS AT ONSET OF ANHIDROSIS

Anhidrosis			Paired Control		
	kg	% P II		kg	% P II
No. 33	-5.3	8.2	No. 34	-3.7	6.3
No. 74	-3.4	4.9	No. 73	-1.8	3.0
No. 76	-2.9	5.2	No. 75	-3.7	5.2

difference on a relative basis. Since many other subjects who did not become anhidrotic were equally dehydrated, we are not inclined to consider these differences significant.

Unfortunately, direct measurement of body water with deuterium oxide was not done at this point in the experimental period. We cannot therefore use the data to examine the dehydration hypothesis.

A similar analysis can be made for the subjects who were hypohidrotic. The results are equally unconvincing. We conclude then that dehydration was not the cause of the sweat gland dysfunction.

Dehydration, however, may have been contributory for our observations allow the deduction that minimal water allowances for the castaway expected to survive under conditions of moist heat should be approximately 2700 ml/day. No anhidrosis developed, and only one case (No. 70) had hypohidrosis after the daily water allowance was raised to three canteens.

One intriguing fact about the three cases of anhidrosis and eight cases of hypohidrosis is that all were subsisting on a nutrient mixture different from the "normal" (15/52/33). Men on diets of unusual distributions of calories

Nutrient Regimen	No. of Cases
ST 0	3
0/100/0	2
30/0/70	3
2/20/78	3
15/52/33	0

among protein, carbohydrate, and fat seem to be especially predisposed to sweat gland dysfunction. No subjects on 15/52/33 developed either anhidrosis or hypohidrosis.

Because we have previously shown that the unusual distributions of calories lead to marked disturbances in homeostasis, it might be argued that an integrative mechanism has broken down in these men. The nervous system and endocrine systems come to mind. Are we dealing with an abnormal output of antidiuretic hormone?

Let us assume that the water diuresis measures ADH. With high ADH we might expect, other conditions being equal, a small output of water during the diuresis test. On July 10 six men were tested. All were hypohydrotic. When we compare the net recovery we find that four of five had smaller net recoveries than their controls. These differences are not due to similar preperiod (P II) trends. Three facts are against the "ADH" interpretation.

RESPONSE TO WATER DIURESIS AMONG MEN HYPOHIDROTIC ON JULY 10

Hypohydrosis			Paired Controls		
No.	P II	July 10	No.	P II	July 10
68	74.4	49.5	69	78.1	56.6
73	72.9	59.7	74	20.9	71.6
75	78.4	2.4*	76	35.2	11.3
78	52.9	0.0*	77	60.4	----
79	60.4	30.6*	80	57.9	37.6
82	44.6	0.0*	81	71.8	0.0

*Outburst of sweating

First, other men who were not hypohidrotic had equally low net recoveries

(Section C. 2). Second, four of the hypohydrotic men exhibited a prompt outburst of sweating. It is inconceivable that drinking a few ounces of water would suddenly cause the circulating ADH to decrease. Finally, Amatruda and Welt (1953) have reported that pituitrin does not decrease the rate of sweating.

The fact that four men began to sweat within a few minutes after beginning to drink water also argues against the hypothesis that a reflex was involved. The reaction was too slow to have been caused by a reflex.

We are thus left with no satisfactory explanation of this failure of sweating. Neither our data nor the literature contribute a consistent explanation. We have a fertile problem for research. There is urgently needed a full understanding of the function of the sweat gland and its control. A final interesting fact is that only one Negro developed hypohidrosis and none anhidrosis. On the basis of the number of Negroes among the subjects, the operation of chance alone would lead to expectation of 2 or 3 cases. If it is reasonable to assume equal fitness among the 88 subjects, the conclusion would be that the Negro is more resistant to dysfunction of evaporative heat regulatory mechanism than is the white man.

Outburst of sweating: Our second problem concerns the outburst of sweating. A similar observation has been made by Lee and Mulder (1935). Kuno (1956) has suggested that the mechanism involves a gastro-hypothalamic reflex. His arguments are far from convincing. No one has made a critical study of the phenomenon. We have little to add except that study of the reaction might well lead to a better basic understanding of the eccrine sweat gland. It may be that the drinking response will serve as a test of sweat gland fatigue.

E. Renal Function and Osmotic Regulation

1. Urinary Volume

Urine flow was calculated from specimens collected under four different conditions. During the three-hour test an accurately timed specimen was obtained. We have called this output the "resting minute urinary volume." During and following the heat-acclimatization test two additional accurately timed specimens were collected. These outputs have been called the "exercise minute urinary volume" and the "post-exercise minute urinary volume," respectively. The latter was collected after one-hour of rest following the 3.75-mile march. Finally, each day a 24-hour output was obtained from each subject.

Resting Minute Urinary Volume. Data on the resting minute urinary volume are summarized for the pre-periods in Table III. 159. These data reveal considerable inter-individual and inter-group variability. Flights 2 and 4, which were destined to subsist on limited water in the experimental periods, consistently excreted urine at a slower rate than Flights 1 and 3. All five groups exhibited a small minute volume in P II than in P I, and in the cases of Flights 2, 3, and 4 this trend was significant at the 1 or 2% level.

The reasons for the inter-group differences are not clear. One might postulate that the men in Flights 2 and 4 were limiting water to train for the anticipated experience of water restriction. The results of the water diuresis test (Section III. C. 2) do not support this hypothesis. In P I Flights 2 and 4 had greater net recoveries than Flights 1 and 3. In P II the reverse was true. Furthermore, the mean 24-hour outputs of urine were not significantly different among the flights in either P I or P II (Table III. 175).

Since all the men were not tested simultaneously, it is possible that we are dealing with a diurnal variation. Flights 1 and 3 were tested from 0600 to 0900 and Flights 2 and 4 from 0900 to 1200. Our ration controls (FRA) allow examination of this hypothesis. Three of these men were tested with each flight. They were living under conditions of unrestricted food and water intake. If a diurnal process was affecting minute urinary volume, these men should show evidence of it. The data below allow no such interpretation.

Subject Code No.	Tested With Flight	Average Minute Volume, ml/min P I	P II
90 - 92	1	1.97	1.66
93 - 95	2	1.41	2.72
96 - 98	3	1.86	1.57
99 -101	4	2.05	0.80

The trend toward lower minute volumes in P II, on the other hand, can be explained. The weather was considerably warmer in P II than in P I. There was more sweating and, as a consequence, the urinary output of water was

reduced. This trend toward smaller urinary volumes in P II was evident not only in data on resting minute volumes but also, as will be indicated shortly, in data on exercise, post-exercise, and 24-hour volumes.

An examination was made of the frequency distributions of resting minute urinary volumes during P I, P II, and R II, periods when the subjects were on 5-in-1 and were considered to be normal (Table III. 160; Figure III. 72). It is evident that no unduly large minute volumes occurred, unlike the results in the winter study of 1954. We attribute this fact to the change in testing protocol between 1954 and 1955. In the latter study, as contrasted with the former, lengthening the test period one hour and requiring the subjects to void at the end of the first hour apparently eliminated the diuretic volumes observed in 1954 winter study.

The mode in P I was 0.88 ml/min. There were secondary modes at 1.63 and 2.63 ml/min. In P II the mode was at 0.63 ml/min with a secondary mode at 1.88 ml/min. In R II the mode was at 1.13 ml/min and there was a secondary mode at 2.88 ml/min. The trend toward smaller volumes in P II is again evident.

These distributions were statistically analyzed by the Chi-Square Test (Table III. 161). According to the results, P I and P II differed significantly (P less than 5%) as did P II and R II (P less than 1%). Presumably the greater minute volumes of R II were associated with the ad libitum feeding of that period.

The resting minute volumes of the subjects on Field Ration A tended to be greater than those of the subjects on 5-in-1. The mode for these men was at about 1.50 ml/min (Table III. 162; Figure III. 72). The distribution was quite flat from 0.00 to 3.00 ml/min, and 25.6% of the specimens fell in the class interval 2.01 to 3.00 ml/min.

Effect of experimental regimen: With few exceptions, all the men in Flights 1 and 2 had smaller minute volumes during the experimental period than during the pre- or recovery periods (Table III. 163). This trend was present whether or not the water was limited. The notable exception was the FRA group. These men did not change diet or work load during the experimental periods. Presumably the major cause for the reduced minute volume was the increased sweating provoked by hard work.

Limitation of water did not regularly cause a reduction in the minute urinary volume. When the solute load was low (ST 0, 0/100/0 1000 and 2000; 2/20/78 1000), there was little difference between U and L. When the solute load was large (15/52/33 2000 and 3000; 30/0/70 1000 and 2000) limitation of water was generally associated with an appreciable reduction in minute volume.

The smallest minute volumes were those from men on the pure carbohydrate regimen and starvation. In general the minute volume increased with solute load. This trend is most evident for men on limited water, but it also is

suggested among the men on unlimited water. The inter-relationships between water intake, nutrient regimen, and minute volume, however, are not as definitive as in the 1954 winter study. Presumably variation in rates of sweating have obscured the previously established trends.

The data for Flights 3 and 4--Light Work--(Table III. 163) are remarkable when compared to those for men doing hard work. In the first place, there is no general tendency to lower minute volumes in the experimental periods. In the second place, the minute volumes are remarkably similar, regardless of nutrient regimen. Low volumes are associated both with high and low solute loads, even in the cases where water was restricted. In the third place, when high solute regimens are compared, restriction of water was not always associated with a lower minute volume. We are inclined to attribute these various differences between hard and light work to differences in rates of sweating.

Exercise Minute Urinary Volume. The rate of excretion of urine collected during exercise was considerably lower than that collected while the subjects were resting (Table III. 164). As in the case of the resting minute volume, however, there was marked inter-individual variability during the pre-periods. The differences between groups, on the other hand, were not so large as in the case of the resting volume and were not correlated with anticipated limitation of water. This fact is further argument against the hypothesis that the subjects attempted to train for the experimental regimen. The exercise minute volume decreased from P I to P II and in the cases of Flights 1 and 2 the decrease was statistically significant.

Analysis of the frequency distribution of exercise minute volumes indicates that volumes greater than 1.50 ml/min were rare during P I, P II and R II (Table III. 165; Figure III. 73). The mode was 0.38 ml/min in all three periods. However, P I was characterized by a relatively high frequency of minute volumes in the classes 0.51 - 0.75 ml/min and 0.76 - 1.00 ml/min. This difference was significant when P I was compared with P II and R II by the Chi-Square test (Table III. 166). P II and R II were not significantly different. The men on the Field Ration A excreted urine at a faster rate than the men on 5-in-1. The mode for the former group was 0.63 ml/min and a considerable fraction passed minute volumes as high as 2.00 ml/min (Table III.167).

Effect of experimental regimen: Insofar as the flights on hard work are concerned, subsistence on an experimental regimen did not regularly cause a reduction in exercise minute urinary volume (Table III. 168). When the water intake was restricted, however, there was generally a reduction in minute volume from pre-period to experimental period. Furthermore, men on limited water excreted smaller minute volumes than men on unlimited water. Solute load also affected the minute volume, but only in the case of men on limited water. Such regimens as 30/0/70 and 15/52/33 caused greater minute volumes than 0/100/0 and 2/20/78.

Three subjects failed to complete the required 15 laps while they were on an experimental regimen: No. 3 (ST O U) was able to complete only 10 laps,

No. 33 (30/0/70 2000 L) only six laps, and No. 34 (30/0/70 2000 L) only ten laps. The case histories of these men will be detailed in a subsequent report.

During the recovery periods the minute volumes during exercise did not increase appreciably. The resumption of ad libitum feeding and drinking apparently had little effect on the rate of excretion of urine during exercise.

In general, the data for the subjects performing light work (Table III. 168) support the observations made for men doing hard work. Limitation of water and solute load were the two factors which exerted the most consistent effect on the exercise minute urinary volume.

Post-Exercise Minute Urinary Volume. After exercise the rate of excretion of urine increased (Table III. 169). This increase was probably due to (1) rest and (2) increased intake of fluids. In the pre-periods, however, the inter-individual and inter-group variability decreased. Apparently the marching tended to reduce the influence of factors causing differences between individuals and groups which were so evident in the resting state.

Again, on the other hand, we find that the minute volumes were smaller in P II than in P I. In the cases of Flights 1, 2, and 4 this trend was statistically significant.

The frequency distributions (Table III. 170; Figure III. 73) indicate these trends, too. In P I the mode was 0.88 ml/min; in P II, 0.38 ml/min; and R II, 0.63 ml/min. A considerable proportion of the men excreted urine at rates greater than 1.00 ml/min. According to the Chi-Square test (Table III. 171), the distribution of P I was significantly different from both P II and R II. P II, however, was not significantly different from R II.

The men on Field Ration A had greater minute volumes than subjects on 5-in-1 (Table III. 172). Their mode was 0.88 ml/min and over 12% of the men excreted volumes in excess of 1.50 ml/min.

Effect of experimental regimen: Hard work per se (Table III. 173) did not consistently cause a decrease in the post-exercise minute urinary volume. Furthermore, men on restricted water did not regularly excrete a smaller minute volume than men on unlimited water. In most cases, there was actually little difference between the two volumes. The smallest minute volumes were associated with 0/100/0 2000. In general, increasing solute load augmented the minute volume from low values of 0.22 (0/100/0 2000 L) to 0.94 ml/min (30/0/70 2000 L). In the recovery periods, there was no regular large increase in the minute volume. These observations apply equally well to the men doing light work (Table III. 173).

Twenty-Four Hour Urinary Volume. The pre-period values for the mean 24-hour outputs of urine by the five groups of subjects are summarized in Table III. 174). In both P I and P II Flight 3 excreted the largest volume. There was a tendency for Flights 2 and 4 to excrete less urine than Flights 1 and 3.

In P II the difference between the several groups was markedly reduced. Furthermore, all groups excreted less urine in P II than in P I---a trend already detected in the minute urinary volumes at rest, during exercise, and after exercise.

Effect of experimental regimen: In most cases we observed that hard work caused a reduction in the 24-hour volume of urine (Table III. 175). The exceptions to this trend were 0/100/0 1000 U, 15/52/33 3000 U, 30/0/70 1000 U, and 30/0/70 2000 U. With one exception--ST O--men on limited water excreted less than men on unrestricted water. The smallest 24-hour volumes were those of men on 0/100/0 2000 L. With increasing solute load there was a rather regular augmenting of the 24-hour volume. Maximal values were observed among men on 15/52/33 3000 L and 30/0/70 2000 L.

In contrast to hard work, light work did not cause a decrease in the 24-hour urinary volume (Table III. 175). Undoubtedly this fact reflects a lesser tendency to sweat among men performing light work than among men doing hard work. Limitation regularly caused a reduction of urinary volume. As solute load increased there was a gradual increase in the 24-hour volume. Minimal values were observed with the 0/100/0 L regimens and maximal values with the 15/52/33 2000 and 3000 L and 30/0/70 1000 and 2000 L regimens. ST O L (EXP II) was an exception to this tendency.

Recovery periods were generally correlated with large increases in the 24-hour volumes. Among the men who had been on hard work this tendency was much less striking than in the case of men who had been doing light work. Previous limitation of water was not regularly correlated with this increased urine volume in the recovery periods.

Certain discrepancies are to be found between urine volumes presented in Table III. 9 in the section on water balance, and those in Table III. 175. The reason for these differences, which are statistically minor in nature, is that for water balance only the days included in the balance period were summated. By contrast, the data for Table III. 175 are on the basis of all days except those of water diuresis tests. Hence, one would anticipate differences between the two sets of averages.

TABLE III. 159

PRE-PERIOD DATA ON RESTING
MINUTE URINARY VOLUME
(ml/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	2.05	0.77	37.6	21	2.00	1.06	53.1
2*	21	1.15	0.59	51.3	21	0.75	0.36	48.0
3**	21	2.40	1.00	41.7	21	1.30	0.82	63.1
4**	21	1.26	0.68	53.9	22	0.73	0.28	38.4
FRA	12	1.82	1.05	57.7	11	1.59	0.96	60.4

"t" test on P I vs. P II
*P less than 0.02
**P less than 0.01

TABLE III. 160

FREQUENCY DISTRIBUTION OF RESTING MINUTE URINARY VOLUMES: PRE AND RECOVERY PERIODS
(Men on 5-in-1 Ration)

Class Intervals	Number			Per Cent		
	P I	P II	R II	P I	P II	R II
0.00 - 0.25	0	0	0	0.00	0.00	0.00
0.26 - 0.50	4	10	0	4.72	11.80	0.00
0.51 - 0.75	6	24	9	7.08	28.32	12.87
0.76 - 1.00	15	16	8	17.70	18.88	11.44
1.01 - 1.25	12	10	10	14.16	11.80	14.30
1.26 - 1.50	5	6	4	5.90	7.08	5.72
1.51 - 1.75	8	3	7	9.44	3.54	10.01
1.76 - 2.00	7	5	4	8.26	5.90	5.72
2.01 - 2.25	1	1	2	1.18	1.18	2.86
2.26 - 2.50	6	2	6	7.08	2.36	8.58
2.51 - 2.75	9	1	5	10.62	1.18	7.15
2.76 - 3.00	3	1	7	3.54	1.18	10.01
3.01 - 3.25	2	2	1	2.36	2.36	1.43
3.26 - 3.50	2	1	2	2.36	1.18	2.86
3.51 - 3.75	2	1	0	2.36	1.18	0.00
3.76 - 4.00	2	1	3	2.36	1.18	4.29
4.01 - 4.25	0	0	1	0.00	0.00	1.43
4.26 - 4.50	1	1	1	1.18	1.18	1.43
Total	85	85	70	100.30	100.30	100.10

TABLE III. 161

STATISTICAL ANALYSIS OF RESTING MINUTE URINARY VOLUME: PRE AND RECOVERY PERIODS
(Men on 5-in-1 Ration)

Test	d.f.	χ^2	P
P I vs. P II	16	26.68	<0.05
P I vs. R II	16	12.93	n.s.*
P II vs. R II	16	33.55	<0.01

*n.s. = not significant

TABLE III. 162

FREQUENCY DISTRIBUTION OF RESTING URINARY VOLUMES: ALL PERIODS FOR MEN ON FIELD RATION A

Class Intervals	Number	Per Cent
0.00 - 1.00	18	23.04
1.01 - 2.00	25	32.00
2.01 - 3.00	20	25.60
3.01 - 4.00	13	16.64
4.01 - 5.00	1	1.28
5.01 - 6.00	1	1.28
Total	78	99.84

TABLE III. 163

RESTING MINUTE URINARY VOLUME
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	1.12	0.84	0.33	0.21	1.21	1.97	2.76	1.73	0.50	0.40	3.40	2.74
	L	1.12	0.79	0.42	0.57	2.45	2.51	1.37	0.77	0.42	0.80	3.03	1.97
0/100/0	U	2.22	2.40	0.30	0.41	4.10	4.18	2.21	0.75	0.84	0.69	3.22	1.39
1000	L	1.88	0.81	0.33	0.36	1.90	1.96	0.94	0.60	0.30	0.62	3.04	1.27
0/100/0	U	2.02	2.30	0.74	0.34	3.18	1.82	1.55	0.93	0.64	0.61	2.06	1.00
2000	L	1.09	0.52	0.20	0.20	2.04	1.14	2.93	0.53	0.65	0.79	----	----
2/20/78	U	1.80	1.52	0.38	1.43	4.02	3.05	2.06	0.88	1.54	0.62	3.58	1.92
1000	L	1.04	0.80	0.32	1.24	3.10	1.22	1.80	0.89	0.56	0.98	1.31	1.27
2/20/78	U	2.53	2.54	0.80	1.58	1.24	----	3.02	0.88	1.68	0.96	2.28	1.76
2000	L	0.66	0.64	0.52	0.31	2.92	1.93	1.20	1.13	0.50	1.25	1.47	1.12
15/52/33	U	1.81	2.52	0.98	0.90	1.76	2.02	2.18	1.20	0.30	0.62	2.48	1.96
1000	L	1.10	0.64	0.42	----	----	----	1.26	0.98	0.58	0.42	2.00	2.24
15/52/33	U	1.90	2.72	0.74	0.94	2.62	0.53	3.48	2.16	0.98	1.86	4.25	2.44
2000	L	1.16	0.67	0.56	0.61	1.40	3.39	0.89	0.42	0.48	0.38	1.64	0.77
15/52/33	U	3.15	1.92	1.82	2.24	3.50	2.52	2.14	1.01	1.39	0.62	3.47	0.63
3000	L	0.94	0.65	0.52	0.90	2.42	1.72	1.26	0.77	----	----	----	----
30/0/70	U	1.92	1.16	0.54	0.96	2.38	1.14	1.21	0.72	0.47	0.33	0.56	0.52
1000	L	0.87	1.40	0.58	0.75	1.87	2.50	1.04	0.56	0.69	0.58	1.52	0.80
30/0/70	U	2.92	3.22	1.22	1.35	4.76	3.42	2.69	1.77	0.74	0.70	3.30	3.26
2000	L	1.64	0.56	0.54	0.66	1.83	1.54	0.56	0.48	0.54	0.54	1.33	0.82
FRA		1.82	1.59	1.92	2.05	2.16	1.92	1.82	1.59	1.92	2.05	2.16	1.92

TABLE III. 164

PRE-PERIOD DATA ON EXERCISE MINUTE URINARY VOLUME
(ml/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1*	22	0.82	0.79	96.4	21	0.37	0.40	108.2
2**	21	0.71	0.21	26.9	20	0.47	0.12	25.6
3	20	0.57	0.28	49.2	20	0.39	0.35	89.7
4	21	0.60	0.22	36.7	21	0.43	0.27	62.8
FRA	12	0.84	0.37	44.2	11	0.65	0.35	53.9

"t" test on P I vs. P II
*P less than 0.05
**P less than 0.001

TABLE III. 165

FREQUENCY DISTRIBUTION OF EXERCISE MINUTE URINARY VOLUME: PRE AND RECOVERY PERIODS
(Men on 5-in-1 Ration)

Class	Number			Per Cent		
Intervals	P I	P II	R II	P I	P II	R II
0.00 - 0.25	2	12	7	2.38	14.63	10.44
0.26 - 0.50	30	52	41	35.70	63.39	61.17
0.51 - 0.75	28	13	12	33.32	15.85	17.90
0.76 - 1.00	13	3	1	15.47	3.66	1.49
1.01 - 1.25	8	0	3	9.52	0.00	4.48
1.26 - 1.50	1	0	1	1.19	0.00	1.49
1.51 - 1.75	0	2	1	0.00	2.44	1.49
1.76 - 2.00	0	0	0	0.00	0.00	0.00
2.01 - 2.25	0	0	1	0.00	0.00	1.49
2.26 - 2.50	0	0	0	0.00	0.00	0.00
2.51 - 2.75	0	0	0	0.00	0.00	0.00
2.76 - 3.00	1	0	0	1.19	0.00	0.00
3.01 - 3.25	0	0	0	0.00	0.00	0.00
3.26 - 3.50	0	0	0	0.00	0.00	0.00
3.51 - 3.75	1	0	0	1.19	0.00	0.00
3.76 - 4.00	0	0	0	0.00	0.00	0.00
Total	84	82	67	99.96	99.97	99.95

TABLE III. 166

STATISTICAL ANALYSIS OF EXERCISE
MINUTE URINARY VOLUME: PRE AND RECOVERY PERIODS
(Men on 5-in-1 Ration)

Test	d.f.	X^2	P
P I vs. P II	14	38.04	<0.001
P I vs. R II	14	26.00	<0.05
P II vs. R II	8	7.89	n.s.*

*n.s. = not significant

TABLE III. 167

FREQUENCY DISTRIBUTION OF EXERCISE
MINUTE URINARY VOLUME FOR MEN
ON FIELD RATION A: ALL PERIODS

Class Interval	Number	Per Cent
0.00 - 0.25	0	0.00
0.26 - 0.50	14	21.53
0.51 - 0.75	21	32.30
0.76 - 1.00	14	21.53
1.01 - 1.25	5	7.69
1.26 - 1.50	4	6.15
1.51 - 1.75	4	6.15
1.76 - 2.00	2	3.08
2.01 - 2.25	0	0.00
2.26 - 2.50	1	1.54
Total	65	99.97

TABLE III. 168

EXERCISE MINUTE URINARY VOLUME
(ml/min)

Experimental Regimen		Hard Work					Light Work				
		PRE		EXP	REC		PRE		EXP	REC	
		I	II	I	I	II	I	II	I	I	II
ST 0	U	0.68	0.37	0.19*	0.36	0.67	0.58	0.29	0.22	0.28	0.32
	L	0.72	0.40	0.26	0.31	0.51	0.55	0.32	0.38	0.36	0.30
0/100/0	U	0.88	0.36	0.92	0.45	0.38	0.51	0.28	1.12	0.16	0.34
1000	L	0.66	0.60	0.22	0.45	0.46	0.69	0.40	0.36	0.52	0.54
0/100/0	U	3.16	0.66	3.61	0.56	0.56	0.50	0.21	0.53	0.34	0.26
2000	L	0.52	0.48	0.16	0.34	0.36	0.20	0.34	1.51	0.57	0.36
2/20/78	U	0.62	0.44	0.32	0.46	0.52	0.42	0.33	1.06	0.30	0.45
1000	L	0.52	0.40	0.22	0.36	0.40	0.81	0.98	0.32	0.66	0.36
2/20/78	U	0.45	0.32	0.84	----	----	0.48	0.29	0.52	0.29	0.28
2000	L	0.68	0.48	0.32	0.46	0.72	0.81	0.44	0.30	0.44	1.18
15/52/33	U	0.40	0.34	0.32	0.25	1.25	0.90	0.62	0.86	0.62	0.50
1000	L	1.05	0.55	0.30	----	----	0.80	0.44	0.33	0.54	0.48
15/52/33	U	0.52	0.32	0.31	----	----	0.62	0.96	3.08	0.37	0.38
2000	L	0.70	0.36	0.51	0.34	0.59	0.52	0.28	0.38	0.56	0.70
15/52/33	U	0.72	0.46	0.56	0.32	0.53	0.84	0.36	0.53	0.48	0.45
3000	L	0.74	0.46	0.50	0.57	1.03	0.72	0.46	----	----	----
30/0/70	U	0.50	0.32	0.58	0.33	0.32	0.53	0.23	3.54	0.19	0.40
1000	L	0.56	0.60	0.51	0.35	----	0.38	0.25	0.64	0.52	0.36
30/0/70	U	0.40	0.31	1.80	0.90	0.50	0.30	0.38	1.19	0.31	0.34
2000	L	0.80	0.48	0.80*	0.60	0.37	0.59	0.48	0.60	0.81	0.44
FRA		0.84	0.65	0.80	0.75	1.05	0.84	0.65	0.80	0.75	1.05

*One or more subjects marched less than 15 laps.

TABLE III. 169

PRE-PERIOD DATA ON POST-EXERCISE
MINUTE URINARY VOLUME
(ml/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1*	22	0.99	0.42	42.4	21	0.56	0.21	37.5
2**	21	0.98	0.37	37.7	20	0.76	0.16	21.1
3	21	0.57	0.23	40.3	20	0.55	0.50	87.8
4*	21	1.04	0.21	20.2	20	0.65	0.19	29.2
FRA	12	0.91	0.25	27.4	11	0.76	0.31	40.8

"t" test on P I vs. P II
*P less than 0.001
**P less than 0.02

TABLE III. 170

FREQUENCY DISTRIBUTION OF POST-EXERCISE
MINUTE URINARY VOLUME: PRE AND RECOVERY PERIOD
(Men on 5-in-1 Ration)

Class Intervals	Number			Per Cent		
	P I	P II	R II	P I	P II	R II
0.00 - 0.25	3	3	1	3.53	3.62	1.51
0.26 - 0.50	12	33	22	14.11	39.76	33.33
0.51 - 0.75	18	29	24	21.17	34.94	36.36
0.76 - 1.00	21	13	12	24.70	15.66	18.18
1.01 - 1.25	18	3	4	21.17	3.62	6.06
1.26 - 1.50	8	0	2	9.41	0.00	3.03
1.51 - 1.75	3	1	0	3.53	1.20	0.00
1.76 - 2.00	2	0	1	2.35	0.00	1.51
2.01 - 2.25	0	0	0	0.00	0.00	0.00
2.26 - 2.50	0	0	0	0.00	0.00	0.00
2.51 - 2.75	0	1	0	0.00	1.20	0.00
Total	85	83	66	99.97	100.00	99.98

TABLE III. 171

STATISTICAL ANALYSIS OF POST-EXERCISE MINUTE URINARY VOLUME: PRE AND RECOVERY PERIODS (Men on 5-in-1 Ration)

Test	d.f.	X^2	P
P I vs. P II	10	37.07	<0.001
P I vs. R II	7	21.62	<0.005
P II vs. R II	10	6.92	n.s.*

*n.s. = not significant

TABLE III. 172

FREQUENCY DISTRIBUTION OF POST-EXERCISE MINUTE URINARY VOLUME FOR MEN ON FIELD RATION A: ALL PERIODS

Class Intervals	Number	Per Cent
0.00 - 0.25	0	0.00
0.26 - 0.50	6	9.23
0.51 - 0.75	13	19.99
0.76 - 1.00	17	26.15
1.01 - 1.25	12	18.46
1.26 - 1.50	8	12.30
1.51 - 1.75	8	12.30
1.76 - 2.00	0	0.00
2.01 - 2.25	1	1.54
Total	65	99.97

TABLE III. 173

POST-EXERCISE MINUTE URINARY VOLUME
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST O	U	0.72	0.41	0.34*	0.50	0.49	0.68	0.55	0.45	0.52	0.56
	L	0.95	0.70	0.44	0.50	0.50	0.87	0.44	0.47	0.73	0.75
0/100/0	U	0.68	0.46	0.58	0.33	0.38	0.83	0.52	0.34	0.34	0.36
1000	L	1.30	0.73	0.30	0.85	1.02	1.08	0.65	0.29	0.92	0.96
0/100/0	U	1.66	0.80	0.26	0.35	0.85	0.66	0.32	0.21	0.50	0.46
2000	L	0.86	0.75	0.22	0.66	0.75	0.84	0.42	0.20	1.37	0.67
2/20/78	U	0.88	0.66	0.31	0.42	0.72	0.54	0.43	0.43	0.53	0.62
1000	L	0.62	0.72	0.29	0.46	0.44	1.28	1.02	0.33	1.25	0.55
2/20/78	U	0.58	0.63	0.59	----	----	0.45	0.44	0.27	0.53	0.72
2000	L	1.12	0.76	0.43	0.45	0.62	1.27	0.75	0.44	1.13	1.27
15/52/33	U	1.14	0.54	0.31	0.36	0.55	0.32	0.58	0.80	0.54	0.56
1000	L	1.26	0.83	0.37	----	----	1.12	0.60	0.30	0.97	1.04
15/52/33	U	0.99	0.36	0.41	----	----	0.38	1.46	1.96	0.90	1.24
2000	L	1.51	0.72	0.63	0.57	0.87	0.90	0.45	0.49	1.38	0.89
15/52/33	U	1.66	0.80	0.64	0.46	0.71	0.78	0.46	0.55	0.78	0.66
3000	L	1.00	0.86	0.75	1.84	0.99	1.14	0.76	----	----	----
30/0/70	U	0.62	0.40	0.66	0.45	0.49	0.40	0.40	0.57	0.30	0.50
1000	L	0.70	0.98	0.63	0.63	----	1.02	0.42	0.69	1.22	0.74
30/0/70	U	1.20	0.68	1.03	0.58	0.65	0.38	0.26	2.77	0.38	0.42
2000	L	0.37	0.62	0.94*	0.50	0.41	1.02	0.58	0.80	1.15	0.73
FRA		0.91	0.76	1.06	1.02	1.22	0.91	0.76	1.06	1.02	1.22

*One or more subjects marched less than 15 laps.

TABLE III. 174

PRE-PERIOD DATA ON MEAN DAILY TWENTY-FOUR HOUR OUTPUT OF URINE
(ml/day)

Flight	P I		P II	
	M	Range	M	Range
1	1590	856-2405	1250	710-1790
2	1410	1069-2512	1160	762-2445
3	1640	1257-2440	1290	690-2575
4	1570	830-2863	1220	620-2317
FRA	1340	847-1892	1240	764-2118

FIGURE III. 72. FREQUENCY DISTRIBUTION OF RESTING MINUTE URINARY VOLUME.

FIGURE III. 73. FREQUENCY DISTRIBUTION OF EXERCISE MINUTE URINARY VOLUME.

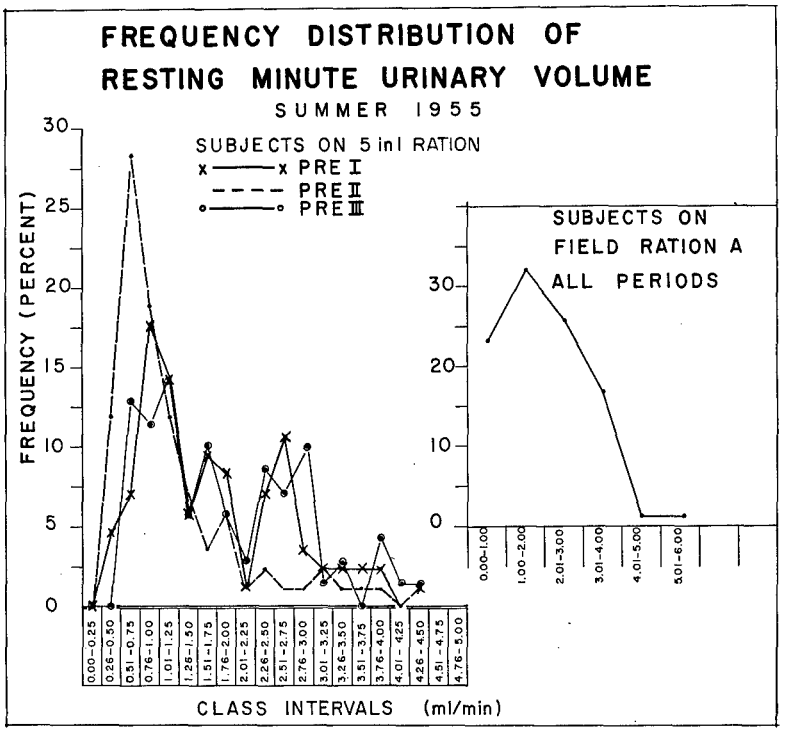


FIGURE III. 72.

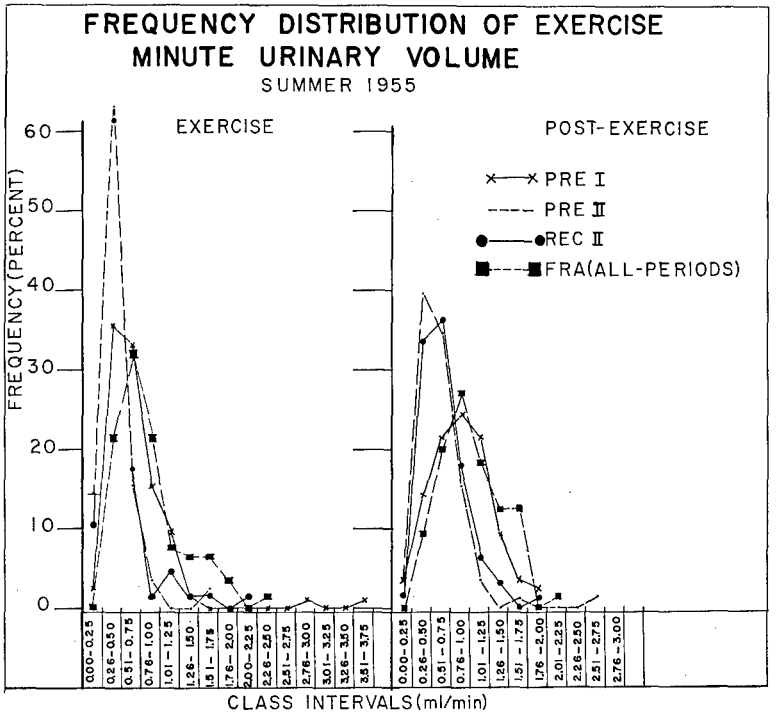


FIGURE III. 73.

TABLE III. 175

MEAN DAILY TWENTY-FOUR HOUR OUTPUT OF URINE

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	1270	880	780	790	1310	1270	1410	1060	1520	1330	1030	1660
	L	1330	1080	630	1030	1170	1570	1790	1390	700	1600	1300	2470
0/100/0	U	1340	1060	1380	970	990	1680	1670	1250	1650	1280	1320	1870
1000	L	1530	1200	410	620	1070	1670	1460	1120	490	1150	1470	1930
0/100/0	U	1970	1400	1390	1200	1970	1880	1460	1090	1010	870	1190	1340
2000	L	1350	890	350	360	830	1300	1470	930	590	1040	1440	1880
2/20/78	U	1500	1140	930	1950	1270	1980	1430	1250	1570	1770	900	1850
1000	L	1270	1080	450	880	1070	1320	2220	1740	680	1380	2180	2300
2/20/78	U	1970	1460	1230	1620	1640	----	1450	1100	1180	1590	1200	1500
2000	L	1330	1030	620	460	1200	1720	1720	1240	690	860	2580	2420
15/52/33	U	1430	1480	840	890	980	1430	1780	1450	1580	1450	1230	2500
1000	L	1800	1750	590	----	----	----	1730	1410	650	920	2060	1930
15/52/33	U	1470	1320	1140	1030	1060	1280	2410	2460	3740	3720	3350	3810
2000	L	1270	1060	850	930	1110	1490	1260	1080	690	1570	1400	1580
15/52/33	U	1880	1420	1450	2330	1440	1670	1960	1330	1570	1210	1260	1760
3000	L	1750	1440	820	1040	1850	2040	1470	1250	1290	----	----	----
30/0/70	U	1580	1050	1160	1400	1040	1480	1320	850	1720	1150	920	1170
1000	L	1260	1160	880	940	1210	1340	1330	920	710	1020	1290	1580
30/0/70	U	2020	1670	2180	2250	1460	2280	1690	1230	3390	2960	1330	1770
2000	L	1280	970	980	1190	1540	1910	1020	930	1360	980	1120	1360
FRA		1340	1240	1420	1570	1580	1650	1340	1240	1420	1570	1580	1650

2. Qualitative Examination of Urine

Urine was collected under three different conditions from all subjects throughout the period of study. During the three-hour test a specimen of urine was collected during resting over an interval of two hours. Prior to beginning the heat acclimatization test the subjects emptied their bladders. Immediately on terminating the one-hour march a urinary specimen was collected. This specimen was identified as the exercise urine. The subjects then returned to their barracks and after a one-hour rest, a post-exercise urine was collected. Each of these three specimens was accurately timed so that the rate of output of foreign elements could be calculated (Addis Count). All of the specimens were subjected to a routine urinalysis according to standard clinical pathological procedures (Sargent et al., 1954, 1955). In the sections which follow we shall discuss the results of the tests that were made on each of the three kinds of urine specimens.

a. Glycosuria

Only two subjects ever excreted reducing substances in the resting urine. Subject 17 showed a trace during EXP I. During this period he was on 15/52/33 1000 U. Subject 95 exhibited a trace during PRE II. This individual was on Field Ration A. No analyses for sugar were performed on exercise and post-exercise urinary specimens.

b. Urobilinogen

Several hundred analyses for urobilinogen were performed. There were six positive reactions recorded among tests on the resting urine (Table IV. 176). All of the positive reactions were confined to EXP I. The intensity of the reactions never exceeded +1. Five of the six reactions occurred in men who were subsisting on the pure carbohydrate regimen. The positive reactions among the men on this regimen did not seem to be related to caloric intake or water intake. The other positive reaction occurred in Subject 37 who was subsisting on 2/20/78 2000 L. This experience is somewhat different from that of our temperate study of 1953. Urobilinogen reactions at that time could not be related to experimental nutrient mixture. Since the reactions listed in Table 1 are so weak, we are not inclined to give them much physiological significance.

TABLE III. 176

SUMMARY OF POSITIVE UROBILINOGEN REACTIONS IN URINE OF THREE-HOUR TEST

Subject Code No.	Nutrient Regimen	Period	Reaction
5	0/100/0 1000 U	EXP I	Trace
6	0/100/0 1000 U	EXP I	Trace
27	0/100/0 1000 L	EXP I	Trace
30	0/100/0 2000 L	EXP I	Trace
37	2/20/78 2000 L	EXP I	Trace
51	0/100/0 2000 U	EXP I	+1

c. Albuminuria

There were only four positive reactions for albuminuria among the several hundred resting urinary specimens (Table III. 177). All four positive reactions occurred in EXP II. Not a single FRA subject showed a positive test. The albuminuria which was observed was presumably a non-specific reaction. The four subjects showing positive reactions were each on a different nutrient regimen.

Much less albuminuria was observed in resting urine during the 1955 summer tests than during the 1954 winter tests (Sargent et al., 1954). During the winter test albuminuria was much more common in the experimental periods and the tentative conclusion was reached that there we were dealing with albuminuria provoked by cold.

Exercise Urine. In the pre-periods albuminuria was observed eight times in exercise urinary specimens (Table III. 178). Most of the reactions were weak, but there were three strong reactions: one +1, one +3, and one +4. One FRA subject showed a trace. During the experimental period there were actually fewer positive reactions than in the pre-periods and none was more intense than +1. The period with the greatest number of positive reactions was REC I. During this period there were 13 positive reactions, five of which were +2 or +3. In REC II there was some reduction in the frequency of albuminuria. Here there were nine positive reactions, six of which were +2 or +3. In both recovery periods positive reactions were observed not only among subjects recovering from experimental nutrient mixtures but also among FRA subjects.

Post-Exercise Urine. There were four positive reactions for albuminuria among the post-exercise urines collected during the pre-periods (Table III. 179). All of the positive reactions occurred in PRE II and were limited to subjects in Flight 1. Their intensity, however, did not exceed +1. There were no positive reactions in EXP I. In REC I there were two positive reactions, both +1; and in REC II there were three, one of which was +2 and two of which were +3. A number of specimens in the recovery periods, especially among subjects who had been doing hard work, showed a pink to red color when tested for albumin. The meaning of this reaction is not clear.

Comment: It is a well-known fact that exercise will provoke the appearance of albumin in the urine. We have summarized our data supporting this fact in Table III. 180. During the entire study a total of 553 resting urinary specimens were tested for albumin. Four or 0.7% were positive. A total of 444 specimens were collected immediately at the termination of the one-hour march; 38 or 8.6% were positive for albumin. After one hour of rest following exercise, 451 specimens were tested; 5 or 1.1% showed albumin. Here is clear evidence that moderate exercise provokes albuminuria. The effect of exercise on the kidney was greatest in REC I, and presumably this was associated with the physiological readjustments which necessarily were taking place early in rehabilitation. Certainly albuminuria was much more frequently observed in the exercise urines than in the post-exercise urines. There is

no evidence that its occurrence is consistently correlated with a specific experimental regimen, i.e., water intake, caloric intake, work output, and distribution of calories between protein, carbohydrate, and fat. The significant finding, we believe, is the frequent occurrence of strongly positive reactions in post-exercise urines of the recovery periods. Since only one positive reaction was observed among subjects subsisting on Field Ration A, it is probable that the high incidence of albuminuria is in some way related to the recovery processes going on in subjects who had previously been subsisting on unusual experimental nutrient mixtures.

TABLE III. 177

SUMMARY OF POSITIVE ALBUMIN REACTIONS
IN URINE OF THREE-HOUR TEST

Subject Code No.	Nutrient Regimen	Period	Reaction
54	ST 0 U	EXP II	Trace
59	2/20/78 2000 U	EXP II	2+
61	15/52/33 1000 U	EXP II	2+
72	0/100/0 1000 L	EXP II	2+

TABLE III. 178

EXERCISE ALBUMINURIA
(0 to +4)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	0,0,0,0	0,0,0,0	0,0	0,0,0	0,0,1	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
							0,tr	0,0	0,0	tr,1	0,0
	L	0,0,0,0	0,0,0,0	0,0,0,0	0,0,0	0,0,0*	0,0,0,0	0,0,0,0	0,0,0,0	0,0,0	0,0,0
0/100/0	U	0,0	0,0	0,0	0	0	0,1	0,0	0,tr	1	0,0
1000	L	0,0	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0/100/0	U	0,0	0,0	0,tr	0,0	0,2	0,0	0,0	0,0,0	0,0	0,0**
2000	L	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0	0	0
2/20/78	U	0,0	0,0	0,0	0	0	0,0	0	0	0	1
1000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2/20/78	U	0,0	0,0	0,1	---	---	0	0	0,0	0,0	0,3
2000	L	0,2	0,0	0,0	0,2	0,0	0	0,0	0,0	0	0
15/52/33	U	0,0	0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0
1000	L	0,0	0	0	---	---	0,0	0,0	0,0	0,1	0,0
15/52/33	U	0,0	0,0	0,0	0	---	0,0	0,0	0,0	0,1	0,0
2000	L	0,0	0,tr	0	0	0	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0
3000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	---	---	---
30/0/70	U	0,0	0,0	0,0	0,0	0,0	0	0	0	0	0
1000	L	0,0	0,0	0,0	0	0	0,0	0,0	0,0	0,0	0,0
30/0/70	U	1,3	0,4	0,1	0,3	0,3	0,0	0,0	0,0	0,3	0,3
2000	L	0,0	0,tr	0,0	0,2	0,2	0,0	0,0	0	0	0
FRA	U	0,0,0	0,0,0	0,0,0	0,0,1	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0,2	0,0,0,0
						0,1					
	L	0,0,0	0,0	0,0	0,0,0,0	0,0,0	0,0,tr	0,0,0	0,0,0	0,0,0	0,0,0
						0,0					

*Pink color to reaction.
**Purple color to reaction.

TABLE III. 179

POST-EXERCISE ALBUMINURIA
(0 to +4)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	0,0,0,0	0,0,0,0	0,0,0,0	0,0*	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0,0	0,0,0
							0,0	0,0	0,0		0,0
	L	0,0,0,0	0,0,0,0	0,0,0,0	0,0,0*	0,0,0*	0,0,0,0	0,0,0,0	0,0,0,0	0,0,0	0,0,0
0/100/0	U	0,0	0,0	0,0	0*	0	0,0	0,0	0,0	0,0	0,0
1000	L	0,0	0	0,0	0,0	0,0*	0,0	0,0	0,0	0,0	0,0
0/100/0	U	0,0	0,tr	0,0	0,0	0,0	0,0	0,0	0,0,0	0,0	0,0
2000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0
2/20/78	U	0,0	0,0	0,0	0*	0	0,0	0	0	;	0
1000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2/20/78	U	0,0	0,tr	0,0	---	---	0	0	0	0	0*
2000	L	0,0	0,0	0,0	0,0	0,0	0	0,0	0,0	0	0
15/52/33	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1000	L	0,0	0	0	---	---	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0	0	0,0	0,0	0,0	0,0	0,0
2000	L	0,0	0,1	0	0	0	0,0	0,0	0,0	0,0	0,0
15/52/33	U	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
3000	L	0,0	0,0	0,0	0,0	0,0	0,0	0,0	---	---	---
30/0/70	U	0,0	0,tr	0,0	0,0	2	0	0	0	0	0
1000	L	0,0	0,0	0,0	0	0	0,0	0,0	0,0	0,0	0,0
30/0/70	U	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0,3
2000	L	0,0	0,0	0,0	0,0	0,3	0,0	0,0	0	0	0
FRA	U	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0,0	0,0,0,0
						0,0					
	L	0,0,0	0,0	0,0	0,0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
						0,0*					

*Pink to red color reaction.

TABLE III. 180

EFFECT OF MODERATE EXERCISE ON ALBUMINURIA
(Summer, 1955)

Period	Resting		Exercise		Post-Exercise	
	Number Tested	Number Positive	Number Tested	Number Positive	Number Tested	Number Positive
PRE I	97	0	97	5	97	0
PRE II	96	0	93	7	94	0
EXP I	92	0	86	4	90	0
EXP II	91	4	0	—	0	—
REC I	87	0	80	13	81	2
REC II	90	0	88	9	89	3
Total	553	4	444	38	451	5
%		0.7		8.6		1.1

d. Addis Count.

The sediment in the three urinary specimens was studied microscopically and the output of cellular elements was quantitated according to the technique of Addis (Sargent et al., 1954, 1955). We shall first consider data on epithelial cells and white cells, then hematuria, and finally cylindruria.

Epithelial Cells and White Blood Cells. Resting urine: In Table III. 181, pre-period data on the rate of excretion of epithelial cells and white blood cells have been summarized. Three findings stand out: (1) There is a very wide intra- and inter-group variability. (2) The subjects tended to excrete more white blood cells than epithelial cells. (3) There are no significant trends when P II and P I are compared.

Study of Table III. 182 suggest that there are no consistent changes in the output of epithelial cells which can be related to nutrient mixture, water intake, or work output. The FRA subjects exhibit a gradual increase in the output of epithelial cells to a maximum in EXP I. In the succeeding periods there is a gradual decline to REC II when the output reached levels comparable to that of P I. This general trend can be detected in the output of epithelial cells by subjects who were on the various experimental regimens. It is quite probable, therefore, that the trend is non-specific. It may represent a reaction to the weather, for EXP I was very hot.

A similar trend is evident in the data for white blood cells (Tables III. 183). In the case of these cells the maximum excretion is not reached until EXP II. Again the output of white blood cells does not seem to be related to any of the experimental conditions imposed upon the subjects, but seems rather to represent a non-specific response. The trend shown by the FRA's can be discerned among the other subjects.

Exercise urine: In the first pre-period, exercise and post-exercise urines were not subjected to Addis counts. A qualitative examination of the sediment, however, was made. Since those data are not directly comparable with values obtained by the Addis technique, observations on PRE I will not be reported in detail. Data from PRE II are summarized in Table III. 184. When Table III. 184 is compared with Table III. 181, it is evident that the rate of excretion of white blood cells and epithelial cells in the resting urine and exercise urine are of the same order of magnitude. Furthermore, the output of white blood cells in the post-exercise urine is not significantly different from that of the exercise urine. The post-exercise urine, however, contains fewer epithelial cells than does the exercise urine. As was previously noted for the resting urine, the data in Table III. 184 reveal wide inter- and intra-group variability in the rate of excretion of white blood cells and epithelial cells.

The output of epithelial cells in exercise urine during the several periods of the study reveals a trend quite similar to that noted in the resting urine (Table III. 185). The epithelial cells in urine from the FRA subjects reached a maximum in EXP I and then declined during the recovery periods. Although there is considerable variability, a similar trend can be detected in the urines passed by subjects on various experimental regimens.

No such trend is apparent in the data for the post-exercise urine. The only really significant finding for those urines is the rather general reduction in the rate of output of epithelial cells in the comparison to exercise urine.

The rate of output of the white blood cells during the several periods of the study, again, tended to show the trend already noted for the resting urine (Table III. 186). The rate of output of the white blood cells for the FRA subjects reached a maximum in EXP I and then declined to a very low level in REC II. In spite of rather wide variability, a similar trend can be seen among the other subjects.

In the case of the post-exercise urines, the maximum output of white blood cells tended to be maximal for the FRA's in REC I. For the other subjects there is such a wide variability that no trend is evident.

TABLE III. 181

PRE-PERIOD DATA ON ADDIS COUNT: ON RESTING URINE EPITHELIAL CELLS AND WHITE BLOOD CELLS
(Thousands/2hr)

Flight	P I Mean	P I Range	P II Mean	P II Range
		A. Epithelial Cells		
1	30.7	0.0- 121.5	19.8	0.0- 80.8
2	51.8	0.0- 130.4	9.4	0.0- 49.6
3	19.9	0.0- 111.9	10.7	0.0- 46.4
4	13.9	0.0- 96.0	11.5	0.0- 37.9
FRA	48.9	0.0- 136.7	85.2	0.0- 589.3
		B. White Blood Cells		
1	20.7	0.0- 273.6	35.4	0.0- 250.8
2	199.9	0.0-1,890.0	143.0	0.0-2,340.0
3	21.6	0.0- 156.6	18.4	0.0- 139.2
4	24.9	0.0- 288.0	172.9	0.0-2,520.0
FRA	338.3	0.0-3,623.0	326.7	0.0-3,024.0

TABLE III. 182

ADDIS COUNT ON RESTING URINE--EPITHELIAL CELLS
(Thousands/2 hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	3.2	27.7	27.2	5.6	3.4	5.0	0.0	8.0	25.1	126.9	46.1	14.6
	L	82.6	0.0	24.3	54.3	55.0	8.8	12.7	5.7	23.6	10.6	42.6	10.5
0/100/0	U	0.0	10.6	18.6	16.4	0.0	0.0	37.0	11.0	30.6	27.6	20.2	11.7
1000	L	37.8	18.6	85.4	18.8	22.6	50.8	10.9	12.5	119.4	11.6	0.0	9.0
0/100/0	U	60.8	7.8	41.2	21.8	48.2	58.5	11.6	0.0	10.1	24.6	14.8	0.0
2000	L	39.6	3.8	20.0	5.8	27.2	22.0	0.0	14.9	17.3	10.5	0.0	31.2
2/20/78	U	12.1	14.8	31.2	19.0	0.0	0.0	20.0	12.4	82.0	0.0	0.0	0.0
1000	L	57.7	0.0	48.6	3.6	42.4	16.2	0.0	12.2	39.0	25.6	35.8	17.0
2/20/78	U	31.2	0.0	26.2	21.0	33.1	----	34.1	8.4	6.4	15.0	51.6	43.4
2000	L	23.2	17.6	47.2	21.8	15.2	16.6	7.0	24.6	13.6	16.7	19.6	59.1
15/52/33	U	7.2	50.3	33.6	16.0	7.2	7.4	29.0	23.2	16.7	21.6	0.0	10.9
1000	L	51.6	4.7	28.0	----	----	----	20.6	4.2	90.0	4.6	54.6	20.6
15/52/33	U	80.6	39.3	169.8	25.0	0.0	7.1	0.0	17.4	0.0	24.7	0.0	0.0
2000	L	25.0	12.4	67.2	16.2	18.7	0.0	15.8	8.4	9.6	13.2	9.8	10.4
15/52/33	U	83.9	0.0	42.6	0.0	46.7	37.2	31.6	18.0	12.5	2.6	67.8	29.0
3000	L	18.2	0.0	71.4	23.8	36.4	50.8	0.0	8.4	----	----	----	----
30/0/70	U	25.6	26.1	11.4	55.3	17.8	0.0	0.0	0.0	6.3	13.2	7.5	6.9
1000	L	98.0	31.0	78.0	20.0	124.7	33.3	24.9	14.0	44.0	24.6	0.0	17.2
30/0/70	U	30.4	14.0	186.0	54.0	108.2	26.2	56.0	7.0	19.7	21.8	21.2	0.0
2000	L	54.3	15.0	96.6	21.2	0.0	37.8	48.0	16.0	7.2	0.0	0.0	20.8
FRA		48.9	85.2	220.3	156.6	89.0	57.9	48.9	85.2	220.3	156.6	89.0	57.9

TABLE III. 183

ADDIS COUNT ON RESTING URINE--WHITE BLOOD CELLS
(Thousands/2 hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	0.0	34.4	44.3	11.3	3.4	0.0	51.5	2.7	253.9	159.5	67.3	10.3
	L	113.7	3.9	145.9	190.8	92.9	0.0	12.7	3.7	100.7	26.2	18.1	10.5
0/100/0	U	0.0	21.8	105.0	27.3	0.0	0.0	37.0	11.0	36.4	223.2	20.2	11.7
1000	L	945.0	1,170.0	1,105.7	372.0	610.0	333.2	10.9	16.0	102.6	28.0	0.0	16.0
0/100/0	U	13.5	15.4	81.6	34.4	48.2	13.2	20.8	0.0	209.6	192.0	14.8	0.0
2000	L	127.4	7.6	31.2	42.0	27.2	0.0	19.5	40.1	60.6	10.5	0.0	31.2
2/20/78	U	0.0	14.8	78.0	19.0	0.0	0.0	0.0	0.0	6.3	26.4	14.9	0.0
1000	L	87.0	0.0	115.2	3.6	21.2	0.0	38.8	292.3	24.2	66.6	123.2	17.7
2/20/78	U	0.0	9.0	78.6	63.1	16.5	----	10.8	18.2	6.4	20.3	21.2	19.1
2000	L	54.6	13.6	139.4	56.6	15.2	0.0	12.4	85.2	77.8	16.7	39.2	14.8
15/52/33	U	14.5	17.7	33.6	27.8	7.2	0.0	0.0	69.6	13.3	31.6	0.0	43.4
1000	L	51.6	85.6	56.0	----	----	----	10.2	25.8	55.8	2.4	26.8	20.6
15/52/33	U	40.4	78.6	504.9	225.6	0.0	7.1	0.0	17.4	0.0	56.4	0.0	0.0
2000	L	19.3	55.6	336.0	73.2	18.7	0.0	8.0	16.8	9.6	133.8	41.6	4.4
15/52/33	U	22.2	0.0	28.4	101.4	22.2	0.0	0.0	67.2	169.2	9.4	43.4	23.6
3000	L	0.0	0.0	103.8	23.8	49.0	133.8	0.0	1,260.0	----	----	----	----
30/0/70	U	0.0	38.4	19.8	47.5	0.0	0.0	0.0	0.0	34.4	59.2	0.0	0.0
1000	L	642.0	112.8	135.6	40.0	49.9	0.0	148.7	133.2	64.8	64.8	0.0	0.0
30/0/70	U	136.8	125.4	1,354.8	120.4	749.7	52.4	40.0	12.4	20.5	0.0	0.0	0.0
2000	L	44.2	120.4	99.6	135.8	0.0	0.0	0.0	24.6	117.0	13.2	52.4	17.0
FRA		338.3	326.7	554.5	856.2	362.9	291.6	338.3	326.7	554.5	856.2	362.9	291.6

TABLE III. 184

PRE-PERIOD II DATA: ADDIS COUNT ON EXERCISE AND POST-EXERCISE URINE (Thousands/2 hr)

Flight	W.B.C.	Epithelials	R.B.C.	Casts
		Exercise Urine		
1	148.6	14.3	0.0	0.0
	0.0-1,833.7	0.0- 45.6	---	---
2	94.6	21.2	0.0	0.0
	0.0-608.4	0.0- 74.6	---	---
3	59.0	7.2	0.0	0.0
	0.0-604.4	0.0- 25.3	---	---
4	63.7	12.9	0.0	0.0
	0.0-998.4	0.0- 91.6	---	---
FRA	203.1	22.5	1.7	0.0
	0.0-1,785.6	0.0- 66.2	0.0-18.2*	---
		Post-Exercise Urine		
1	325.6	12.6	0.0	0.0
	0.0-3,318.9	0.0-135.9	---	---
2	167.1	12.1	0.0	0.0
	0.0-1,361.5	0.0- 48.2	---	---
3	12.2	6.4	0.0	0.0
	0.0-106.8	0.0- 25.7	---	---
4	43.7	9.7	0.0	0.0
	0.0-269.6	0.0- 79.8	---	---
FRA	38.0	41.5	0.0	0.0
	0.0-264.6	0.0-273.6	---	---

*Subject No. 98; other 10 men excreted no R.B.C.'s.

TABLE III. 185

ADDIS COUNT ON EXERCISE URINE--EPITHELIAL CELLS: HARD WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST O	U	5.7	26.1	2.9	10.3	1.9	19.0	0.0	4.0
	L	14.4	34.0	3.0	47.3	3.3	42.5	5.7	14.0
0/100/0	U	0.0	4.0	0.0	5.0	2.3	3.0	9.0	0.0
1000	L	31.7	43.0	28.5	70.0	19.3	12.0	45.0	106.5
0/100/0	U	21.0	0.0	7.0	3.5	68.0	10.0	8.0	10.0
2000	L	18.3	8.5	4.5	2.5	11.5	5.5	5.0	0.0
2/20/78	U	0.0	7.5	0.0	7.0	0.0	0.0	0.0	0.0
1000	L	34.8	29.5	7.0	46.0	40.6	12.0	0.0	34.0
2/20/78	U	5.8	56.0	----	----	19.2	14.5	----	----
2000	L	35.6	17.0	26.0	27.5	10.3	0.0	4.0	8.5
15/52/33	U	21.5	43.0	18.0	0.0	6.9	14.0	12.5	0.0
1000	L	16.6	20.0	----	----	0.0	0.0	----	----
15/52/33	U	24.1	9.5	11.5	----	18.2	16.0	11.5	----
2000	L	0.7	82.0	0.0	157.0	12.3	0.0	23.0	81.0
15/52/33	U	37.0	17.0	2.0	8.5	3.8	0.0	0.0	0.0
3000	L	0.0	33.5	5.5	0.0	0.0	15.5	0.0	0.0
30/0/70	U	29.5	60.0	21.0	7.5	2.8	14.5	3.5	6.0
1000	L	16.0	27.5	19.0	1.5	18.0	25.5	0.0	1.5
30/0/70	U	10.4	76.0	20.5	19.0	11.3	0.0	32.0	45.5
2000	L	53.4	27.0	19.5	5.0	12.2	0.0	0.0	2.5
FRA		22.5	55.0	43.5	32.3	41.5	16.3	47.4	32.4

TABLE III. 185 (Contd.)

ADDIS COUNT ON EXERCISE URINE--EPITHELIAL CELLS: LIGHT WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	6.9	19.0	7.9	14.6	9.0	18.2	7.5	30.4
	L	4.3	49.2	20.5	4.3	4.8	38.5	26.5	9.7
0/100/0	U	6.8	48.0	10.0	21.0	16.7	9.0	13.5	4.0
1000	L	5.0	7.0	13.5	7.5	3.8	10.0	0.0	7.5
0/100/0	U	5.6	11.3	8.5	0.0	6.0	3.0	0.0	6.5
2000	L	12.0	34.0	8.0	14.0	9.3	0.0	0.0	26.0
2/20/78	U	0.0	28.0	0.0	6.0	0.0	6.0	0.0	0.0
1000	L	25.8	2.0	23.0	8.0	9.9	15.5	10.0	0.0
2/20/78	U	17.8	0.0	2.0	0.0	4.4	0.0	17.5	0.0
2000	L	7.7	28.5	6.0	0.0	3.3	5.5	15.0	17.0
15/52/33	U	14.8	0.0	39.0	18.5	12.8	0.0	13.5	23.0
1000	L	12.0	39.0	23.0	3.0	4.4	10.0	6.0	40.0
15/52/33	U	12.8	81.5	0.0	27.5	0.0	0.0	7.5	40.0
2000	L	2.0	9.0	7.5	26.5	8.5	5.0	18.5	44.0
15/52/33	U	0.0	181.5	6.5	17.5	3.1	27.5	13.5	0.0
3000	L	45.8	----	----	----	15.1	----	----	----
30/0/70	U	6.1	0.0	2.0	5.0	5.3	8.0	12.0	7.0
1000	L	12.8	22.0	31.5	11.0	39.9	22.0	0.0	0.0
30/0/70	U	3.4	8.5	2.0	19.5	4.0	2.5	4.0	8.0
2000	L	6.9	0.0	11.0	29.5	3.3	0.0	0.0	117.0
FRA		22.5	55.0	43.5	32.3	41.5	16.3	47.4	32.4

TABLE III. 186

ADDIS COUNT ON EXERCISE URINE--WHITE BLOOD CELLS: HARD WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	47.0	26.1	32.3	10.3	8.3	70.7	3.7	6.3
	L	315.0	226.0	221.3	172.0	238.4	246.2	84.3	34.7
0/100/0	U	7.6	32.5	0.0	5.0	13.8	20.0	9.0	0.0
1000	L	7.9	1313.5	967.0	1320.0	0.0	1510.0	1093.0	2952.5
0/100/0	U	0.0	59.5	2.5	11.0	1663.2	10.5	40.0	3.0
2000	L	3.5	240.5	2.0	9.5	53.6	111.5	0.0	5.5
2/20/78	U	2.4	34.5	0.0	0.0	0.0	17.5	0.0	0.0
1000	L	19.4	140.0	12.0	15.0	4.0	5.5	12.5	6.0
2/20/78	U	11.0	49.5	----	----	4.8	39.0	----	----
2000	L	117.0	109.0	49.0	9.5	132.2	5.5	0.0	2.5
15/52/33	U	25.7	100.5	15.0	16.5	0.0	60.5	47.0	0.0
1000	L	100.5	12.0	----	----	11.9	10.0	----	----
15/52/33	U	488.6	712.5	11.5	----	964.9	566.0	11.5	----
2000	L	0.0	190.0	0.0	1463.0	697.0	59.0	99.0	2158.0
15/52/33	U	15.7	37.0	6.5	11.5	46.3	17.0	32.5	4.5
3000	L	9.6	77.0	10.5	69.5	14.8	25.0	5.0	150.0
30/0/70	U	922.4	29.5	26.0	8.0	22.2	33.5	3.5	6.0
1000	L	21.2	150.0	14.0	1.5	46.9	65.0	59.0	1.5
30/0/70	U	6.2	172.0	647.0	439.5	687.4	360.0	660.0	582.5
2000	L	91.8	90.0	45.0	17.5	229.5	18.5	0.0	0.0
FRA		203.1	477.7	211.5	24.1	254.5	265.5	381.4	71.1

TABLE III. 186 (Contd.)

ADDIS COUNT ON EXERCISE URINE--WHITE BLOOD CELLS: LIGHT WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	140.7	380.0	98.7	55.2	23.7	50.8	95.3	38.0
	L	7.1	55.8	33.0	3.0	1.7	45.5	75.0	5.3
0/100/0	U	109.8	184.5	20.5	177.5	22.6	98.5	39.0	81.0
1000	L	17.0	27.0	13.5	7.0	18.2	19.5	97.0	7.5
0/100/0	U	5.0	26.7	8.5	0.0	1.8	17.0	3.5	0.0
2000	L	34.4	584.0	23.0	14.0	29.1	3.0	0.0	8.0
2/20/78	U	0.0	42.0	0.0	6.0	4.1	23.0	7.0	0.0
1000	L	22.9	21.0	5.5	3.0	50.0	6.5	41.0	0.0
2/20/78	U	2.5	4.8	2.0	0.0	4.4	1.2	60.0	0.0
2000	L	37.6	100.00	6.0	0.0	53.4	33.5	0.0	0.0
15/52/33	U	44.9	0.0	112.0	111.5	17.2	2.5	90.0	76.0
1000	L	19.3	37.0	21.5	9.0	12.4	16.5	13.0	8.0
15/52/33	U	46.4	20.0	1.5	16.5	2.0	10.0	7.5	43.0
2000	L	7.1	4.0	3.5	86.0	134.8	12.5	28.0	86.0
15/52/33	U	2.6	49.0	3.5	66.0	6.2	37.5	33.5	68.5
3000	L	7.3	----	----	----	51.3	----	----	----
30/0/70	U	30.6	47.0	15.0	5.0	10.6	15.0	12.0	7.0
1000	L	505.2	99.0	48.0	21.5	114.4	9.0	28.0	6.0
30/0/70	U	12.0	21.5	6.0	55.0	4.0	28.5	8.0	85.5
2000	L	6.9	32.0	11.0	18.0	13.2	0.0	0.0	10.0
FRA		203.1	477.7	211.5	24.1	254.5	265.5	381.4	71.1

Red Blood Cells. Resting urine: In the urine of only two subjects did red blood cells appear during the pre-periods (Table III. 187). The great majority of the occurrences of microscopic hematuria took place during the experimental periods and probably represent a specific reaction of the kidney to the experimental regimen (Table III. 188). Only one FRA subject, No. 99, showed red blood cells in the urine during the experimental period. Microscopic hematuria was much more common among the subjects doing light work than among those doing hard work. In the hard work flights, (Table III. 188), red blood cells were passed by subjects subsisting on the following regimens: ST 0; 0/100/0 1000 and 2000; 2/20/78 2000; 15/52/33 1000 and 2000; and 30/0/70 1000 and 2000. Dehydration was not correlated with the appearance of red blood cells in the urine. In the light work flights, on the other hand, microscopic hematuria was most frequently observed among subjects on limited water (Table III. 188). Red blood cells were observed in the urine in one or both of the experimental periods in subjects subsisting on all experimental regimens except 2/20/78 1000 and 2000 U, and 15/52/33 1000 and 2000 U. The possibility must be entertained that the microscopic hematuria of the men in Flight 4 was provoked by sulfadiazine, which was given prophylactically, after one of the men in this flight had died because of meningococcemia. Subject 99, the only FRA who showed red blood cells in his urine, was similarly treated

with sulfadiazine. Even if we discount the results of this flight, there was more hematuria among the men of Flight 3 than among the men of Flights 1 and 2. The frequency of red blood cells in the urine rapidly decreased in the recovery periods (Table III. 188). Only an occasional subject excreted this type of cell during REC I or REC II.

Exercise urine: Only one subject, No. 99, excreted red cells in the urine of PRE I. The qualitative notation was "Rare RBC's." One other subject, No. 98, excreted red cells in the urine of PRE II (Table III. 184).

The majority of instances of microscopic hematuria occurred during EXP I (Table III. 189). In the case of men doing hard work, microscopic hematuria was detected among men subsisting on ST 0; 0/100/0 1000; 2/20/78 1000 and 2000; 15/52/33 1000 and 2000; 30/0/70 1000 and 2000; and FRA. There was a strong tendency for this hematuria to persist in the post-exercise urine. Dehydration was not correlated significantly with red cells in the urine. In the recovery periods both exercise and post-exercise urine did show, in several instances, red blood cells. In the case of the men doing light work (Table III. 189), hematuria was again maximal during EXP I, and the correlation with nutrient regimen was approximately the same as that detected in the hard work groups. There was, however, much less microscopic hematuria in the post-exercise urine. In contrast to the results for resting urine (Table III. 188), there was no significant tendency for the men of Flight 4 to excrete more red blood cells than the men in Flight 3. This finding argues against the previous suggestion that sulfadiazine may have caused the microscopic hematuria of the resting urine. In the recovery periods, although several men did show hematuria, its frequency was markedly reduced.

Comment. A study was made of the effect of exercise on hematuria during the experimental period. The men selected for this analysis were those who excreted red blood cells in at least one of the three urinary specimens collected; viz., resting, exercise, and post-exercise. A total of 55 men had microscopic hematuria in at least one of the three urinary specimens. These subjects are listed in Table III. 190, together with their nutrient regimen and the quantitative output of red blood cells. Only 12.7% of the specimens which were positive during rest were negative during exercise and post-exercise. Of the total resting specimens, 40% were positive for red blood cells. More than twice this number were positive during exercise. Only 38.9% of the post-exercise specimens contained red cells. When the average rate of excretion of red cells was calculated, we found that in the resting urine, the output was 11,600 per two hours, in the exercise urines, 67,900 for two hours, and in the post-exercise urines, 34,500. These results, in contrast to those obtained for cylindruria (vide infra), indicate that exercise not only accentuates an existing microscopic hematuria, but also provokes hematuria independently of the experimental nutrient mixtures.

During recovery much the same phenomena are evident. Seventeen subjects excreted red cells in one or the other of the two recovery periods (Table III. 191). Twenty-nine and four tenths per cent of the specimens which were positive during rest were negative during exercise and post-exercise. Of the total resting specimens 29.4% were positive, of the exercise urines, 56.2% were positive, and of the post-exercise urines, 62.5% were positive. When we examine the mean rate of output of red blood cells, we find that during rest the rate of excretion was 9,800 for two hours, during exercise 23,800, and during

post-exercise 14,100. Again we have clear evidence that moderate exercise can provoke microscopic hematuria.

These results are in complete accord with the reports of other investigators. Some of this work has recently been reviewed by Sargent and Johnson (1956).

TABLE III. 187

PRE-PERIOD DATA ON ADDIS COUNT ON RESTING URINE: RED BLOOD CELLS (Thousands/2 hr)

	P I		P II	
Flight	Mean	Range	Mean	Range
1	0.0	---------	0.0	-----
2	0.0	---------	0.0	-----
3	2.1	0.0-43.8[1]	0.0	-----
4	0.0	---------	0.0	-----
FRA	2.0	0.0-23.6[2]	0.0	-----

[1] No. 49

[2] No. 96

TABLE III. 188

ADDIS COUNT ON RESTING URINE--RED BLOOD CELLS
(Thousands/2 hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.0	0.0	0.0	0.0	8.9	0.0	0.0	0.0	5.1	29.3	0.0	0.0
	L	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	28.6	44.2	0.0	0.0
0/100/0	U	0.0	0.0	18.6	0.0	0.0	0.0	21.9	0.0	7.4	9.2	0.0	0.0
1000	L	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	93.0	11.6	0.0	0.0
0/100/0	U	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	102.7	0.0	0.0
2000	L	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	17.3	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0
2/20/78	U	0.0	0.0	5.6	0.0	0.0	---	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	16.6	0.0	0.0	54.6	0.0	0.0	0.0
15/52/33	U	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	---	---	---	0.0	0.0	10.8	0.0	0.0	0.0
15/52/33	U	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0
3000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	---	---	---	---
30/0/70	U	0.0	0.0	4.2	7.9	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0
1000	L	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	5.2	16.2	23.6	19.6
30/0/70	U	0.0	0.0	18.2	47.0	0.0	0.0	0.0	0.0	5.0	9.4	0.0	0.0
2000	L	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	7.2	0.0	0.0
FRA		2.0*	0.0	0.0	30.1**	0.0	0.0	2.0*	0.0	0.0	30.1**	0.0	0.0

*See Table III. 187

**Only one (No. 99) of 11 men exhibited urinary red blood cells.

TABLE III. 189

ADDIS COUNT ON EXERCISE URINE--RED BLOOD CELLS: HARD WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	0.0	15.5	0.0	0.0	0.0	5.3	0.0	0.0
	L	0.0	29.8	0.0	0.0	0.0	4.2	0.0	0.0
0/100/0	U	0.0	22.5	0.0	5.0	0.0	2.0	0.0	0.0
1000	L	0.0	34.0	0.0	0.0	0.0	34.5	0.0	0.0
0/100/0	U	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	2.5	---	---	0.0	0.0	---	---
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	1111.5	0.0	0.0	0.0	774.0	0.0	0.0
1000	L	0.0	0.0	---	---	0.0	0.0	---	---
15/52/33	U	0.0	21.0	4.2	---	0.0	9.0	4.2	0.0
2000	L	0.0	14.0	0.0	0.0	0.0	0.0	7.5	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/0/70	U	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
1000	L	0.0	4.5	0.0	0.0	0.0	4.5	0.0	0.0
30/0/70	U	0.0	20.0	20.5	31.5	0.0	0.0	15.5	19.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRA		1.7	142.3	0.0	0.0	0.0	2.6	0.0	0.0

TABLE III. 189 (Contd.)

ADDIS COUNT ON EXERCISE URINE--RED BLOOD CELLS: LIGHT WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	0.0	64.2	0.2	3.6	0.0	16.0	0.2	1.6
	L	0.0	9.5	8.0	0.0	0.0	7.5	9.0	0.0
0/100/0	U	0.0	33.0	0.0	2.5	0.0	0.0	0.0	0.0
1000	L	0.0	2.0	0.0	0.0	0.0	4.0	0.0	0.0
0/100/0	U	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	141.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	7.0	0.0	0.0	0.0	16.0	0.0	0.0
15/52/33	U	0.0	0.0	47.5	0.0	0.0	0.0	27.5	0.0
1000	L	0.0	39.5	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	20.0	0.0	0.0	0.0	0.0	0.0	3.0
2000	L	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	7.5	0.0	0.0	0.0	2.5
3000	L	0.0	---	---	---	0.0	---	---	---
30/0/70	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	17.0	0.0	0.0	0.0	0.0	0.0	0.0
30/0/70	U	0.0	0.0	0.0	53.0	0.0	6.5	0.0	18.5
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRA		1.7	142.3	0.0	0.0	0.0	2.6	0.0	0.0

TABLE III. 190

EFFECT OF MODERATE EXERCISE ON MICROSCOPIC HEMATURIA DURING EXP I
(Thousands/2 hr)

Subject Code No.	Experimental Nutrient Regimen	Microscopic Hematuria Resting	Exercise	Post-Exercise	Subject Code No.	Experimental Nutrient Regimen	Microscopic Hematuria Resting	Exercise	Post-Exercise
1	ST 0 U	0.0	20.5	0.0	55	30/0/70 2000 U	10.1	0.0	5.0
3	ST 0 U	0.0	20.0	9.0	56	30/0/70 2000 U	0.0	0.0	8.0
4	ST 0 U	0.0	6.0	7.0	64	15/52/33 2000 U	0.0	40.0	0.0
5	0/100/0 1000 U	0.0	41.0	0.0	65	15/52/33 3000 U	6.3	0.0	0.0
6	0/100/0 1000 U	0.0	4.0	4.0	67	ST 0 L	7.1	11.0	12.0
7	0/100/0 2000 U	0.0	0.0	5.0	68	ST 0 L	91.2	4.0	9.0
10	30/0/70 1000 U	8.4	0.0	0.0	69	ST 0 L	10.9	----	16.0
12	30/0/70 2000 U	36.3	40.0	0.0	70	ST 0 L	5.3	26.0	5.0
15	2/20/78 2000 U	0.0	5.0	0.0	71	0/100/0 1000 L	186.0	4.0	8.0
16	2/20/78 2000 U	11.2	0.0	0.0	73	0/100/0 2000 L	17.3	141.0	0.0
18	15/52/33 1000 U	11.2	2223.0	1548.0	74	0/100/0 2000 U	0.0	3.0	0.0
19	15/52/33 2000 U	18.1	6.0	0.0	75	30/0/70 1000 L	0.0	34.0	0.0
20	15/52/33 2000 U	0.0	36.0	18.0	76	30/0/70 1000 L	10.3	0.0	0.0
23	ST 0 L	0.0	20.5	0.0	79	2/20/78 1000 L	18.4	0.0	0.0
24	ST 0 L	0.0	2.0	0.0	80	2/20/78 1000 L	16.9	0.0	0.0
25	ST 0 L	0.0	4.0	0.0	81	2/20/78 2000 L	0.0	14.0	32.0
26	ST 0 L	0.0	11.0	0.0	82	2/20/78 2000 L	109.2	0.0	0.0
27	0/100/0 1000 L	0.0	61.0	69.0	83	15/52/33 1000 L	21.6	24.0	0.0
28	0/100/0 1000 L	0.0	7.0	0.0	84	15/52/33 1000 L	0.0	55.0	0.0
31	30/0/70 1000 L	0.0	2.2	----	86	15/52/33 2000 L	0.0	15.0	0.0
32	30/0/70 1000 L	0.0	4.3	0.0	90	FRA	0.0	8.0	0.0
36	2/20/78 1000 L	0.0	16.0	0.0	91	FRA	0.0	37.0	0.0
42	15/52/33 2000 L	0.0	14.0	0.0	96	FRA	0.0	31.0	29.0
45	ST 0 U	7.9	11.0	12.0	100	FRA	0.0	274.0	0.0
46	ST 0 U	5.6	114.0	6.0	101	FRA	0.0	15.0	0.0
47	ST 0 U	0.0	43.0	16.0	Per Cent of Specimens Positive		40.0	81.5	38.9
48	ST 0 U	12.0	149.0	41.0	Mean of All Specimens		11.6	67.9	34.5
49	0/100/0 1000 U	14.9	47.0	0.0	Per Cent of Specimens Positive for Resting, Negative for Exercise and Post-Exercise		12.7		
50	0/100/0 1000 U	0.0	19.0	0.0					
54	ST 0 U	0.0	4.0	5.0					

TABLE III. 191

EFFECT OF MODERATE EXERCISE ON MICROSCOPIC HEMATURIA DURING RECOVERY
(Thousands/2 hr)

Subject Code No.	Experimental Nutrient Regimen			Microscopic Hematuria Resting	Exercise	Post-Exercise
			Recovery I			
4	ST 0 U			28.0	0.0	0.0
9	30/0/70	1000	U	0.0	0.0	7.0
12	30/0/70	2000	U	0.0	41.0	31.0
19	15/52/33	2000	U	0.0	----	17.0
62	15/52/33	1000	U	0.0	95.0	55.0
70	ST 0 L			0.0	32.0	36.0
75	30/0/70	1000	L	47.3	0.0	0.0
			Recovery II			
6	0/100/0	1000	U	0.0	5.0	0.0
12	30/0/70	2000	U	0.0	63.0	38.0
38	2/20/78	2000	L	38.0	0.0	0.0
42	15/52/33	2000	L	15.0	0.0	0.0
49	0/100/0	1000	U	0.0	5.0	0.0
54	ST 0 U			0.0	18.0	8.0
56	30/0/70	2000	U	0.0	106.0	37.0
63	15/52/33	2000	U	0.0	0.0	6.0
65	15/52/33	3000	U	0.0	15.0	5.0
75	30/0/70	1000	L	39.2	0.0	0.0
Per Cent of Specimens Positive				29.4	56.2	62.5
Mean of all Specimens				9.8	23.8	14.1
Per Cent of Specimens Positive for Resting, Negative for Exercise and Post-Exercise				29.4		

Cylindruria. Resting urine: Only two subjects (Nos. 71 and 78) passed casts in the resting urine (Table III. 192). Casts were observed in the urinary sediment with greatest frequency during the experimental periods (Table III. 193). In the vast majority of instances these casts were of the hyaline type. Among the men doing hard work, casts were seen in the urine of men subsisted on ST 0; 0/100/0 1000 and 2000; 15/52/33 1000; and 30/0/70 1000 and 2000. Dehydration was unrelated to the appearance of casts. Among the men doing light work, casts were seen in the urine of subjects subsisted on ST 0; 0/100/0 1000; 2/20/78 1000 and 2000; and 30/0/70 2000. As in the case of red blood cells, restriction of water was rather significantly correlated with the appearance of casts among these subjects. The fact that this cylindruria may have been provoked by sulfadiazine must not be overlooked. Since the distribution of the casts in the urine is similar to that observed in the winter test of 1954, we are inclined to believe that the cylindruria is more likely related

to diet than to sulfadiazine. During the recovery period no subject passed any casts.

Exercise Urine: No urinary specimen collected either in PRE I or PRE II contained casts. Cylindruria tended to be maximal during EXP I (Table III. 194). In the case of men doing hard work, cylindruria occurred among men subsisted on ST 0; 0/100/0 1000; 2/20/78 1000; 15/52/33 1000; 30/0/70 2000; and FRA. This cylindruria tended to persist into the post-exercise period. Casts were present in urine collected during the recovery periods, and again there was a strong tendency for casts to be present in both exercise and post-exercise urine. The frequency of cylindruria was, however, lower in the recovery than in the experimental period. In the case of men doing light work (Table III. 194), casts were present in the urine of men subsisted on ST 0, 30/0/70 1000 and FRA. Cylindruria was about as frequent in the recovery periods as during the experimental periods, and in both instances there was a tendency for the casts to be present in both exercise and post-exercise urine. Furthermore the casts occurred more frequently during REC I and may have been associated with the process of rehabilitation.

Comment: In order to evaluate the effect of exercise on cylindruria, men were selected who excreted casts in at least one of the three urinary specimens collected; viz., resting, exercise, and post-exercise. The subjects who met this criterion of selection are listed in Table III. 195, together with the nutrient mixture they were eating and the quantitative output of casts in each of these urinary specimens. There are 32 men in that table. Twenty-eight per cent of the specimens which were positive during rest were negative during exercise and during the post-exercise period. Of the total number of resting specimens, 56.3% were positive for casts. This value does not differ significantly from the percentages of positive specimens among exercise and post-exercise urines. This fact indicates that the experimental nutrient mixture was the primary cause for the presence or absence of casts. On the other hand, when we calculate the average number of casts, we find clear evidence that exercise caused an accentuation of the rate of excretion of these formed elements. During rest 27,400 casts were excreted per two-hour period. During exercise 57,200 were excreted. The increased output continued in the post-exercise period, for there we see a rate of excretion of 67,700.

In the recovery period 10 subjects excreted casts in one of the three urine specimens collected (Table III. 196). None of the resting specimens contained casts. In contrast, 80% of the exercise urines contained casts, and 70% of the post-exercise urines. The rate of excretion of casts in the exercise urines was 135,100. In the post-exercise urine the rate of excretion averaged 252,200. Here we see the same phenomenon which was observed in the experimental period. Exercise provoked a marked cylindruria in 10 subjects. This cylindruria persisted for at least one hour following the period of exercise.

TABLE III. 192

PRE-PERIOD DATA ON ADDIS COUNT ON RESTING URINE: CASTS
(Thousands/2 hr)

Flight	P I		P II	
	Mean	Range	Mean	Range
1	0.0	-----	0.0	-----
2	0.0	-----	0.0	-----
3	0.0	-----	0.0	-----
4	0.5	0.0-10.9[1]	0.3	0.0-7.2[2]
FRA	0.0	-----	0.0	-----

[1] No. 71

[2] No. 78

TABLE III. 193

ADDIS COUNT ON RESTING URINE--CASTS
(Thousands/2 hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	57.0	77.6	0.0	0.0
	L	0.0	0.0	2.5	45.1	0.0	0.0	0.0	0.0	25.9	0.0	0.0	0.0
0/100/0	U	0.0	0.0	1.1	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	5.4	0.0	186.0	0.0	0.0	0.0
0/100/0	U	0.0	0.0	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	---	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.0	0.0	0.0
15/52/33	U	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	---	---	---	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	---	---	---	---
30/0/70	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/0/70	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	3.4	0.0	0.0	0.0	0.0	3.6*	3.6	3.6	0.0	0.0
FRA		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*See Table III. 192

TABLE III. 194

ADDIS COUNT ON EXERCISE URINE--CASTS: HARD WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	0.0	76.9	0.0	0.0	0.0	98.0	0.0	0.0
	L	0.0	108.2	0.0	0.0	0.0	122.5	0.0	0.0
0/100/0	U	0.0	2.0	0.0	5.0	0.0	0.0	0.0	0.0
1000	L	0.0	2.0	0.0	0.0	0.0	1.5	0.0	0.0
0/100/0	U	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	4.5	0.0	0.0	0.0	3.5	0.0	0.0
2/20/78	U	0.0	0.0	---	---	0.0	0.0	---	---
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	42.0	11.5	0.0	0.0	26.0	22.0	0.0
1000	L	0.0	0.0	---	---	0.0	0.0	---	---
15/52/33	U	0.0	0.0	0.0	---	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/0/70	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/0/70	U	0.0	4.0	0.0	19.0	0.0	0.0	0.0	11.5
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRA		0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.0

TABLE III. 194 (Contd.)

ADDIS COUNT ON EXERCISE URINE--CASTS: LIGHT WORK
(Thousands/2 hr)

Experimental Regimen		Exercise Urine				Post-Exercise Urine			
		P II	EXP I	R I	R II	P II	EXP I	R I	R II
ST 0	U	0.0	170.6	0.0	0.0	0.0	226.8	0.0	0.0
	L	0.0	36.8	290.7	0.0	0.0	14.8	585.0	0.0
0/100/0	U	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0
1000	L	0.0	0.0	13.0	0.0	0.0	0.0	45.0	0.0
0/100/0	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/20/78	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/52/33	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000	L	0.0	---	---	---	0.0	---	---	---
30/0/70	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/0/70	U	0.0	0.0	0.0	40.5	0.0	0.0	1.5	26.5
2000	L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRA		0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.0

TABLE III. 195

EFFECT OF MODERATE EXERCISE ON CYCLINDRURIA DURING EXP I
(Thousands/2 hr)

Subject Code No.	Experimental Nutrient Regimen			Cylindruria Resting	Exercise	Post-Exercise
1	ST 0 U			13.6	16.8	156.0
3	ST 0 U			0.0	106.0	83.0
4	ST 0 U			3.7	108.0	153.0
5	0/100/0	1000	U	2.1	0.0	0.0
6	0/100/0	1000	U	10.9	4.0	0.0
7	0/100/0	2000	U	16.1	0.0	0.0
12	30/0/70	2000	U	0.0	8.0	0.0
17	15/52/33	1000	U	0.0	6.0	0.0
18	15/52/33	1000	U	11.2	78.0	52.0
23	ST 0 L			10.2	316.0	418.0
24	ST 0 L			0.0	68.0	21.0
25	ST 0 L			0.0	12.0	47.0
26	ST 0 L			0.0	37.0	4.0
27	0/100/0	1000	L	0.0	0.0	3.0
28	0/100/0	1000	L	0.0	4.0	0.0
29	0/100/0	2000	L	0.0	0.0	8.0
32	30/0/70	1000	L	8.5	0.0	0.0
34	30/0/70	2000	L	6.9	0.0	0.0
36	2/20/78	1000	L	0.0	9.0	7.0
45	ST 0 U			0.0	54.0	31.0
46	ST 0 U			273.0	585.0	569.0
47	ST 0 U			12.0	61.0	88.0
48	ST 0 U			0.0	149.0	466.0
54	ST 0 U			0.0	4.0	0.0
67	ST 0 L			7.1	0.0	0.0
69	ST 0 L			16.4	---	12.0
70	ST 0 L			80.0	141.0	47.0
71	0/100/0	1000	L	372.0	0.0	0.0
78	30/0/70	2000	L	7.2	0.0	0.0
80	2/20/78	1000	L	5.6	0.0	0.0
82	2/20/78	2000	L	21.8	0.0	0.0
90	FRA			0.0	8.0	0.0
Per Cent of Specimens Positive				56.3	64.6	53.1
Mean Count of All Specimens				27.4	57.2	67.7
Per Cent of Specimens Positive for Resting, Negative for Exercise and Post-Exercise				28.1		

TABLE III. 196

EFFECT OF MODERATE EXERCISE ON CYLINDRURIA DURING RECOVERY
(Thousands/2 hr)

Subject Code No.	Experimental Nutrient Regimen			Cylindruria Resting	Exercise	Post-Exercise
			Recovery I			
18	15/52/33	1000	U	0.0	23.0	44.0
50	0/100/0	1000	U	0.0	0.0	9.0
55	30/0/70	2000	U	0.0	0.0	3.0
70	ST O L			0.0	1163.0	2300.0
72	0/100/0	1000	L	0.0	26.0	90.0
			Recovery II			
6	0/100/0	1000	U	0.0	5.0	0.0
7	0/100/0	2000	U	0.0	8.0	0.0
12	30/0/70	2000	U	0.0	38.0	23.0
56	30/0/70	2000	U	0.0	81.0	53.0
90	FRA			0.0	7.0	0.0
Per Cent of Specimens Positive				0.0	80.0	70.0
Mean Count of All Specimens				0.0	135.1	252.2

3. Osmotic Regulation

a. Resting Urine

Urine-Serum Osmolar Concentration. Pre-period data on serum osmolarity, U/S osmotic ratio, and urinary osmolar excretion are summarized in Table III. 197. Insofar as the serum values are concerned (Table III. 197A), the significant findings are (1) the inter- and intra-group consistency and (2) the downward trend from P I to P II. Three of the five groups exhibited decreases that were significant by the "t" test and two showed no change. We can speculate that this downward trend was provoked by the rising environmental temperatures. Additional evidence that this trend may have been caused by the hot weather is the lower serum osmolar concentrations compared with those measured on subjects in the winter study (Sargent et al., 1955). The latter difference may also have been, in part, methodological. The winter sera were analyzed with a Beckman thermometer; the summer sera with a thermistor (the Fiske Osmometer). Validation studies on the comparability of these two procedures suggest that the thermometer tends to give values some 10m Osm/L higher than the thermistor.

The U/S osmolar ratios were more variable both from group to group and from individual to individual (Table III. 197B). The urine averaged hypertonic to the plasma and in all five groups there was greater hypertonicity in P II than in P I. In three groups, Flights 2, 3, and 4, the upward tendency of the U/S ratio was highly significant. Undoubtedly we deal here with increased tubular reabsorption of water by the kidney in the face of greater sweating induced by the hot weather of P II.

The urinary osmolar excretion exhibited no consistent trends (Table III. 197C). Three groups showed less solute output in P II than in P I. These were the same groups which had exhibited significant increases in the U/S ratio. Here, however, only the means of Flight 2 were significantly different. Flight 1 and the FRA subjects actually excreted more osmotic material in P II than in P I. The downward trends suggest increased tubular reabsorption of the Na -- renal compensation for Na loss via sweat.

Regimens and serum osmolarity: We find further demonstration of the downward trend in serum osmolarity from P I to P II in the paired means for the hard work groups (Table III. 198). The data for EXP I reveal a general trend toward increased serum osmolarity as the osmotic content of the ration increased. The outstanding examples of this tendency are 15/52/33 2000 and 30/0/70 1000 and 2000. In EXP II these trends are no longer evident; in fact, there is a general reduction of serum osmolarity. What accounts for this phenomenon is not at once apparent. In REC I the osmolarity of the serum tends again to increase. In REC II, the values stabilize.

The light-work flights, in contrast, exhibit few of the trends (Table III. 198) pointed out for the hard-work groups. The really striking finding is the lack of any marked variations. This relatively constancy points to work load as the probable factor responsible for augmenting the effects of nutrient regimens on serum osmolarity. Hard work means more sweating and thus greater strain on homeostatic mechanisms responsible for regulating serum osmolar concentration. When the regimen possesses high osmotic demands, i.e., high obligatory urine volume, limitation of water produces increased osmolar concentrations of the serum.

Regimen and U/S osmolar ratio: The trend toward increased hypertonicity of the urine in P II is manifested by all paired means except two -- 15/52/33 and 30/0/70 1000 L -- among men in the hard work flights (Table III. 199; Figure III. 74). For the men subsisting on unlimited water, two types of variations in the experimental periods are evident: (1) small and erratic variations (e.g., 0/100/0, 15/52/33 1000 and FRA) and (2) excretion of increasingly hypertonic urine in one or both experimental periods. (e.g., ST 0, 2/20/78 2000, 15/52/33, and 30/0/70). In the recovery periods the ratios are uniformly low in REC I. In REC II they are either maintained low or show a tendency to rise.

The light work groups exhibit the same general variations (Table III. 199; Figure III. 75). There are, however, several most significant exceptions. With water limited or not, men on 0/100/0 were unable to excrete highly concentrated urine. U/S ratios close to 1.00 were observed even though water was restricted. Men on 2/20/78 and unlimited water exhibited much the same phenomenon. Those on limited water acted like the hard work group, with high U/S ratios in EXP I and low ratios in EXP II.

Particular attention is directed to the observations regarding men on restricted water. These subjects exhibited a basic phenomenon on which our researches have been most consistent; viz., the failure of the low osmotic

regimen to support production of highly concentrated urine by the kidney. Such regimens apparently do not provide an adequate osmotic demand and consequently the kidney just cannot conserve water effectively. The men doing hard work while subsisting on 0/100/0 excreted concentrated urine in EXP I, but not in EXP II. The men on the same regimen, but doing light work, never did excrete a concentrated urine. Greater catabolism and greater sweating probably accounted for the difference. Men on 2/20/78 1000 behaved like those hard working subjects on 0/100/0. Men on the 2000-Calorie regimen doing light work reacted like these hard working subjects, but those doing hard work excreted a concentrated urine in both EXP I and EXP II. We have interpreted these results to mean that there is a certain minimum osmotic load which must be available for effective renal conservation of water. If that minimum is not available a dilute urine results. This minimum is probably supplied by the 2/20/78 2000 regimen; it is not supplied by the 0/100/0 regimens. The practical implication is that, rather than promoting conservation of water as reported by Gamble (1947), any pure carbohydrate ration accentuates dehydration by not providing the kidney with sufficient osmotic load to allow effective tubular reabsorption of glomerular filtrate.

Regimen and urinary osmotic excretion: The relative osmotic demands placed on the kidney can be measured in terms of the urinary osmotic excretion. Data on this measurement are given in Table III. 200. Attention is called to two facts: (1) The rank order of the several regimens is identical with that in the temperate and cold weather studies (Sargent et al., 1954, 1955). (2) For all regimens except 0/100/0 the osmotic outputs are lower than in the winter of 1954 (Sargent et al., 1955). This difference is probably accounted for in the osmolar excretion by the sweat glands.

In order to examine more fully the renal osmotic demands of the various regimens, we have made an estimate of the osmotic intake as described in detail above in Section III. B 12. "Intake" was calculated from the sum of protein (as urea), sodium, potassium, chloride, and phosphorus. The correlation between this estimate and the urinary osmolar output was very good ($P<0.001$) for both the winter 1954 and summer 1955 data. The regression equations, however, were different because of the lower urinary osmotic output in the summer:

$$\text{Winter 1954: } Y_w = 0.883\ X_w - 305;\ Syx = \pm 100$$

$$\text{Summer 1955: } Y_s + 1.959\ X_s - 459;\ Syx = \pm 86$$

where Y is the osmolar intake for winter (w) and summer (s) and X is the urinary osmolar output for the same periods. Both Y and X are expressed as milliosmols/day.

This high degree of association justifies our expressions "osmotic load" when referring to urinary osmotic output and "osmotic depletion" after a regimen very low in nitrogen and minerals. Furthermore, the regression equations will facilitate calculation of the minimum osmotic load which should be imposed by the survival ration for the kidney of the castaway most effectively to conserve body water.

In this connection the question naturally arises regarding renal handling of organic and inorganic solutes. Is the osmotic effect of a high urea load different from the osmotic effect of a high sodium chloride load? Our data agree completely with the work of Rapoport and associates (1949) that the relations between urinary flow and load are "independent of the ionic or chemical character of the solutes." An osmol is an osmol no matter whether it be urea, sodium, potassium or chloride. A detailed study on this point will be found in Appendix II.

Obligatory and Isomotic Urinary Volumes. Additional measures of the impact of the osmotic load on body water are obligatory urinary volume and isosmotic urinary volume (Figures III. 76, III. 77, and III. 78). We have previously identified these two parameters as V_o and V_I, respectively (Sargent et al., 1955). V_o is the minimum urinary volume reached as the U/S ratio becomes maximal; V_I is the urinary volume at U/S ratio of 1.00, a point of minimum renal osmotic work. Both V_o and V_I are closely correlated with osmotic load. We have recalculated these relationships using all our data for subjects on fixed nutrient regimens: data on the FRA subjects have been excluded (Figure III. 78).

For V_o we have a correlation coefficient of +0.95 (P 0.001) with minute urinary solute output; for V_I we have a correlation coefficient of +0.92 (P 0.001). The regression equations are:

$$L = 1378.52\ V_o - 17.96;\ Syx = \pm 76.2$$

$$L = 264.27\ V_I + 47.70;\ Syx = \pm 91.6$$

where L is the minute urinary osmolar excretion.

If we make the assumption the V_I/V_o is a measure of the maximum concentrating ability of the human kidney, we find from the above regression equations that:

$$V_I/V_o = 5.22\ (L - 47.70)/(L + 17.96)$$

This equation raises our estimate of last year (Sargent et al., 1955) from 5.00 to 5.22. We have reason to believe that this estimate is the more reliable one not only because it is based on more data but also because it agrees with another method of estimating maximal concentrating ability.

The relation between the U/S ratio and the urine volume can be described by an equation of the form $\ln(U/S) = \ln a = bV$, where a and b are constants which vary with the solute load. We have studied data from the 1954 and 1955 trials to see how closely such equations describe the investigative results.

Three solute loads were selected: low, intermediate, and high. The results are summarized in Table III. 201. It is evident that in each case there is a very high correlation, but in two cases the standard deviation is very low--0/100/0 and 30/0/70. We are inclined, for the sake of argument, to give most weight to these regressions. A plot of these equations reveals that all three tend to converge on a common point, i.e. all three cross at points within the area defined by the standard deviations of the 0/100/0 and 30/0/70 regimens. We postulate that this zone delimits the theoretical maximum of the urine/serum osmolar ratio. The curious fact is that all the points of cross lie in a region of negative urinary volumes. Such a finding leads us to speculate that the kidney might have a pumping mechanism for propelling such highly concentrated urine into the ureters. Perhaps the smooth muscle about the distal convoluted tubule and pelvis provides the necessary morphological element (Narath, 1951).

If our hypothesis that V_T/V_o at a maximal osmotic load also defines the maximum concentrating ability of the kidney, the constant 5.22 should lie with the zone of maximal U/S ratio. If the natural logarithm of 5.22 (1.6525) is substituted in the regressions for 0/100/0 and 30/0/70, we obtain -0.26 ml/min and -0.13 ml/min for the respective V's. These values agree quite well. Furthermore, a U/S ratio of 5.22 lies very close to the center of the zone of maximal concentrating ability.

It is of interest to compare these theoretical considerations with our individual observations on maximal urine/serum ratios (Table III. 202). Over the three years of these studies we have observed U/S ratios over 5.00 on eight occasions. The absolute maximum was 5.9 in a man subsisting on 3000 Calories/day of 5-in-1 and restricted water. Most of the urinary volumes are high because the data are based on 24-hour outputs rather than two-hour excretions. These data do, however, prove that our theoretical arguments agree with the actual facts. Furthermore, they strongly indicate that the general assumption of renal physiologists that the human kidney can maximally concentrate urine 4.1 times the serum osmolarity is too low. We must await further work to explain the meaning of the negative volume.

Minimal Solute Load for Effective Renal Conservation of Water. We have already alluded to the fact that when the solute load is very low, our data suggest that the kidney is not capable of effectively conserving water. Two types of observations point to the fact that there is in fact a minimum osmotic load below which the kidney fails to concentrate urine and above which it concentrates normally. These two types of observations agree remarkably well.

First, we have regularly been impressed that when charts are made of the U/S ratio vs V for various nutrient regimens, men on very low solute loads excrete urine diluter than serum with increasing V's, i.e. the U/S ratio approaches 0.00 rather than 1.00. With high solute loads, the U/S ratio approaches 1.00 at equivalent rates of urinary excretion. Since a U/S ratio of 1.00 implies minimum osmolar work and a U/S ratio less than 1.00 suggests inability to concentrate urine when V is held constant and is of a magnitude

which does not suggest diuresis (i.e., V is less than 5.00 ml/min), we examined the curves to find at what minimum solute load the U/S ratio began to approach 1.00 instead of 0.00. The minimum was of the order of 500 micro-osmols per minute.

Second, we plotted the net recovery of the water diuresis test dose against solute load for those men who had been subsisting on restricted water (Section III. 62). All data for 1954 and 1955 were used. The relationship between net recovery and solute load could be described by an equation of the form

$$R = -a(L-b)^{1/n} + c$$

where R = net recovery, L = minute urinary osmolar excretion, a is the value of R when L is zero, c is the point of maximal decrease of R with increasing L, and b is the value of L for R = c. The exponent 1/n which fits the data most closely is 1/5. The data suggest that b is close to 470 micro-osmols/min. At values below 470, the subjects excrete the test dose in precisely the manner of well-hydrated subjects. Even though dehydrated (Sargent et al., 1955), they cannot conserve water. Above 470, the subjects retain most of the test dose. Now the kidney can conserve water.

These analyses agree remarkably well. They point to the fact that the castaway's kidney must excrete a minimum of some 500 micro-osmols/min of solute in order to be able effectively to conserve whatever drinking water he may have at his disposal. Most significantly then, these observations emphasize that pure carbohydrate is not a desirable survival ration. Its failure to promote effective renal water conservation entirely negates all of Gamble's (1947) previous claims that pure carbohydrate is the ration of choice for the castaway.

TABLE III. 197

PRE-PERIOD DATA ON URINE AND SERUM OSMOLARITY: RESTING URINE

Flight	P I N	P I M	P I s.d.	P I C.V.	P II N	P II M	P II s.d.	P II C.V.
		A. Serum Osmolarity, mOsm/L						
1***	22	286	4.6	1.6	21	278	6.5	2.3
2***	21	286	2.9	1.0	21	281	5.2	1.8
3	21	287	3.5	1.2	21	286	0.9	0.3
4	21	284	3.1	1.1	22	285	2.8	1.0
FRA*	12	286	2.4	0.8	11	280	7.9	2.8
		B. Urine/Serum Osmolar Ratio						
1	22	1.74	0.8	45.4	21	2.07	0.8	40.6
2**	21	2.82	0.7	23.8	21	3.37	0.6	16.9
3***	21	1.67	0.8	47.3	21	2.80	0.8	27.1
4***	21	2.42	0.8	32.2	22	3.39	0.6	16.8
FRA	12	1.86	0.8	42.5	11	2.51	1.1	43.8
		C. Urinary Osmolar Excretion, μOsm/min						
1	22	897	201	22.4	21	939	176	18.7
2*	21	833	236	28.4	21	679	215	31.6
3	21	986	300	30.4	21	889	223	25.1
4	21	753	219	29.1	22	696	270	38.9
FRA	12	778	259	33.3	12	930	635	68.3

"t" test values:

*P less than 0.05

**P less than 0.01

***P less than 0.001

TABLE III. 198

SERUM OSMOLARITY
(mOsm/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	280	279	284	280	282	265	286	286	280	281	282	278
	L	286	284	282	276	288	283	283	284	279	282	283	282
0/100/0	U	289	289	279	274	286	280	284	288	280	274	282	282
1000	L	283	283	280	275	286	284	286	285	280	276	281	281
0/100/0	U	287	277	280	275	283	272	292	286	282	277	280	282
2000	L	291	274	287	276	280	279	288	286	274	272	282	280
2/20/78	U	288	274	287	276	284	284	287	286	282	280	284	284
1000	L	287	282	283	272	284	284	282	284	276	276	282	274
2/20/78	U	288	274	286	290	282	---	288	283	282	280	282	281
2000	L	285	278	288	286	286	281	288	287	284	281	294	282
15/52/33	U	286	286	288	276	285	285	286	287	283	282	282	282
1000	L	285	281	282	---	---	---	286	284	275	278	280	280
15/52/33	U	286	270	282	275	276	276	284	285	282	284	284	283
2000	L	288	282	300	288	290	290	284	286	292	277	282	284
15/52/33	U	288	276	282	282	283	281	289	288	284	282	281	284
3000	L	286	282	281	283	288	287	284	282	---	---	---	---
30/0/70	U	284	280	284	279	282	280	288	287	290	284	286	286
1000	L	287	272	293	277	284	288	285	287	283	282	277	282
30/0/70	U	290	275	283	283	285	284	286	285	290	286	280	272
2000	L	287	284	297	285	284	284	281	288	286	281	280	279
FRA		286	280	284	284	283	282	286	280	284	284	283	282

TABLE III. 199

RESTING U/S OSMOLAR RATIO

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	2.64	2.73	4.29	5.71	2.85	2.08	1.52	2.72	3.08	2.66	1.49	2.01
	L	2.76	3.14	3.94	2.96	1.93	1.48	2.14	3.38	3.56	2.20	1.40	1.93
0/100/0	U	1.66	1.71	2.04	2.22	1.16	1.12	1.05	3.35	1.00	1.02	1.16	2.45
1000	L	2.18	3.22	3.90	2.36	2.18	1.44	2.04	3.86	2.55	1.65	1.40	2.57
0/100/0	U	1.23	1.74	1.25	1.64	1.17	1.74	2.62	2.83	1.09	1.36	1.82	2.88
2000	L	3.13	3.56	3.27	1.94	1.44	2.76	1.25	3.20	1.26	1.61	2.01	2.40
2/20/78	U	1.92	2.42	3.32	1.00	1.18	1.28	1.88	2.70	0.94	1.87	1.23	1.93
1000	L	2.85	2.89	4.28	1.42	1.21	2.58	1.87	2.77	2.92	1.50	2.29	2.00
2/20/78	U	1.44	1.81	2.70	1.00	1.97	----	0.84	3.54	1.63	1.72	1.82	2.14
2000	L	3.22	3.72	3.71	3.51	1.24	1.94	2.15	3.12	3.26	1.63	2.03	2.32
15/52/33	U	2.26	1.08	2.52	2.20	2.05	2.36	1.82	2.76	2.92	2.68	1.38	1.99
1000	L	3.18	4.44	4.02	----	----	-----	2.58	3.14	3.04	3.52	2.22	2.13
15/52/33	U	1.39	1.44	2.70	2.73	1.55	2.76	1.32	1.65	2.03	1.40	0.98	1.50
2000	L	2.54	3.32	3.08	3.31	2.11	1.11	2.40	3.78	3.12	3.80	2.25	3.20
15/52/33	U	1.12	1.94	1.89	1.36	1.08	1.56	2.32	3.40	2.41	3.66	1.37	3.54
3000	L	3.08	3.64	3.93	3.54	1.92	2.14	2.70	3.14	----	----	----	----
30/0/70	U	1.68	3.18	3.92	2.88	1.90	2.82	2.51	3.27	3.01	3.65	3.02	3.84
1000	L	3.51	2.96	2.55	3.31	2.11	1.29	3.50	3.50	2.96	2.94	2.12	3.15
30/0/70	U	1.18	1.46	2.32	2.77	1.12	1.32	1.04	2.46	3.00	3.24	1.20	1.42
2000	L	1.96	3.56	3.76	4.06	1.98	1.74	3.32	4.06	4.04	3.92	2.75	3.67
FRA		1.86	2.51	2.12	1.70	1.64	1.95	1.86	2.51	2.12	1.70	1.64	1.95

TABLE III. 200

RESTING URINARY OSMOTIC EXCRETION
(μOsm/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	757	677	403	331	690	948	958	1145	445	293	1320	1395
	L	877	667	377	295	1095	866	819	689	427	378	1178	917
0/100/0	U	1043	1042	194	249	1361	1313	648	728	204	146	1053	867
1000	L	843	669	307	183	1039	769	645	658	213	193	1188	929
0/100/0	U	568	882	212	180	1038	940	884	781	200	142	1066	741
2000	L	976	557	245	211	915	804	953	658	242	137	1061	814
2/20/78	U	1047	917	334	393	1344	1110	1078	725	406	327	1253	1074
1000	L	827	689	353	282	1065	885	867	700	434	409	845	686
2/20/78	U	1060	1070	611	458	689	---	878	454	624	461	1046	808
2000	L	592	654	566	310	978	986	698	1057	452	573	879	728
15/52/33	U	915	933	754	446	768	1094	1071	944	256	467	916	1096
1000	L	919	665	480	---	---	---	916	827	484	409	1201	1240
15/52/33	U	756	1059	589	739	1122	420	1287	1002	556	683	1190	1017
2000	L	824	658	563	629	885	1243	540	463	430	400	1040	690
15/52/33	U	1019	1031	655	850	1066	1107	1321	949	614	625	1339	628
3000	L	706	656	563	896	832	794	870	794	---	---	---	---
30/0/70	U	983	876	597	766	1230	866	872	678	410	343	482	575
1000	L	878	1084	429	688	1124	930	543	555	573	454	748	690
30/0/70	U	963	1160	801	1022	1454	1283	794	1024	647	610	1102	1256
2000	L	917	566	806	756	880	717	585	564	629	595	1027	843
FRA		778	930	847	873	809	834	778	930	847	873	809	834

TABLE III. 201

STUDY OF RELATION BETWEEN U/S RATIO AND URINARY VOLUME AT THREE OSMOTIC LOADS (Resting Urine)

Nutrient Regimen	Urinary Osmolar Excretion*	ln(U/S) = lna + bV				
		a	b	r	Syx	P
1954: 0/100/0 2000; 1955: 0/100/0 1000 and 2000; N = 46	204	1.2459	-1.5738	-0.82	±0.34	<0.001
1954: 2/20/78 1000; 1955: 15/52/33 1000; N = 28	479	1.4373	-0.6530	-0.65	±0.93	<0.001
1954: 30/0/70 2000; N = 16	1074	1.5919	-0.4475	-0.83	±0.22	<0.001

*micro-osmols/min.

TABLE III. 202

MAXIMUM URINE/SERUM RATIO IN THREE YEARS OF EXPERIENCE

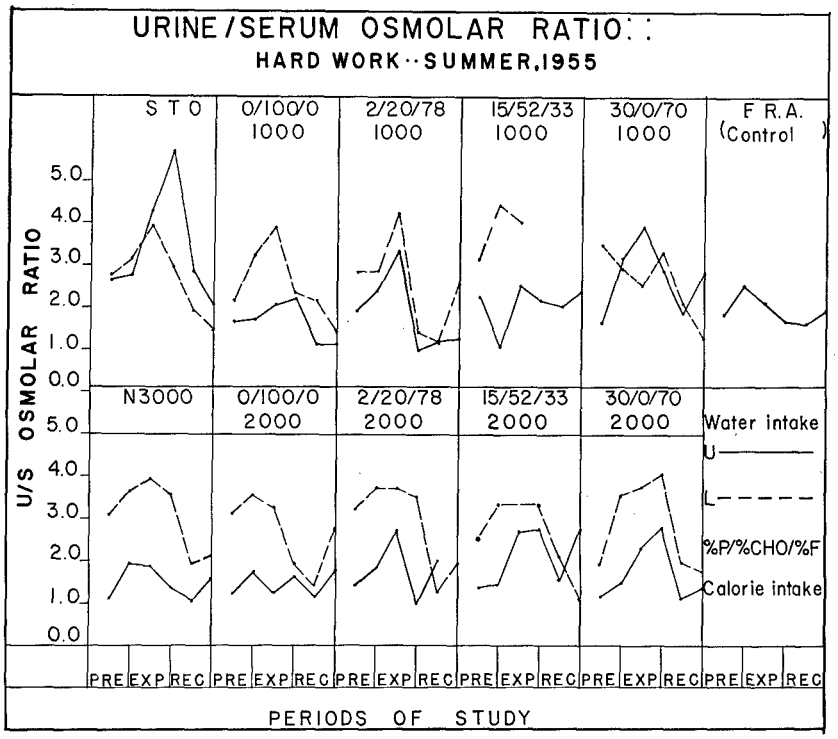
Year	Subject No.	Nutrient Regimen	Urinary ml/day	Volume ml/min	U/S ratio
1953	12	5-in-1	1240	0.86*	5.7
	5	N 3000 U	1080	0.75*	5.2
			1000	0.69*	5.2
	6	N 3000 L	810	0.56*	5.3
			860	0.60*	5.9
			925	0.64*	5.3
			650	0.45*	5.5
1955	1	ST O U	---	0.21**	5.7

*Based on 24-hour volume

**Based on urine of three-hour test

FIGURE III. 74. RESTING URINE/SERUM OSMOLAR RATIO: HARD WORK.

FIGURE III. 75. RESTING URINE/SERUM OSMOLAR RATIO: LIGHT WORK.



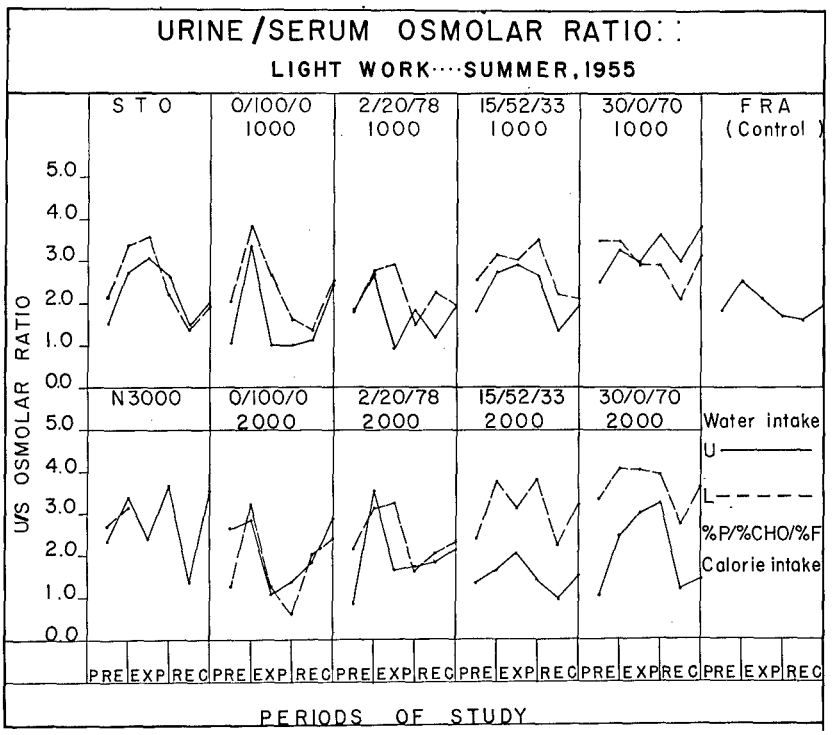


FIGURE III. 75

FIGURE III. 76. OSMOTIC U/S RATIO VS. URINE VOLUME, RESTING CONDITION, PRE- AND RECOVERY PERIODS.

FIGURE III. 77. OSMOTIC U/S RATIO VS. URINE VOLUME, RESTING CONDITION, EXPERIMENTAL PERIODS.

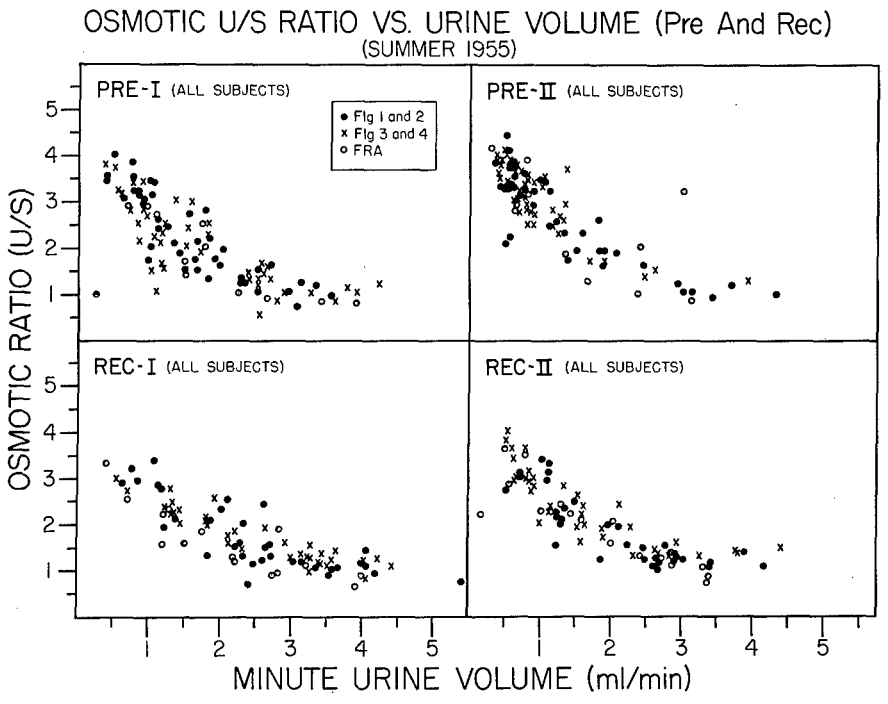


FIGURE III. 76

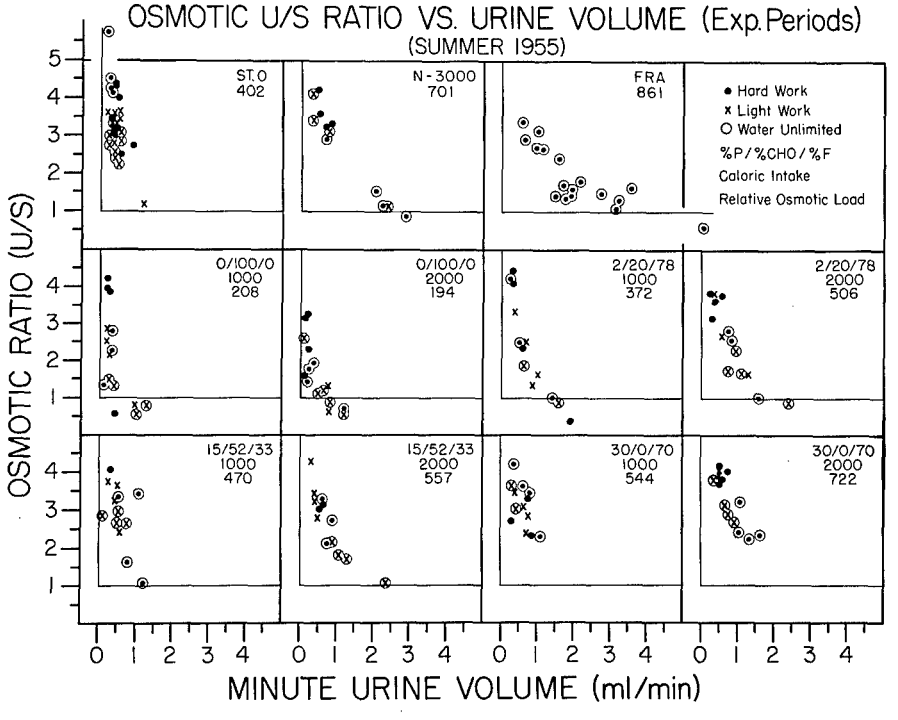


FIGURE III. 77

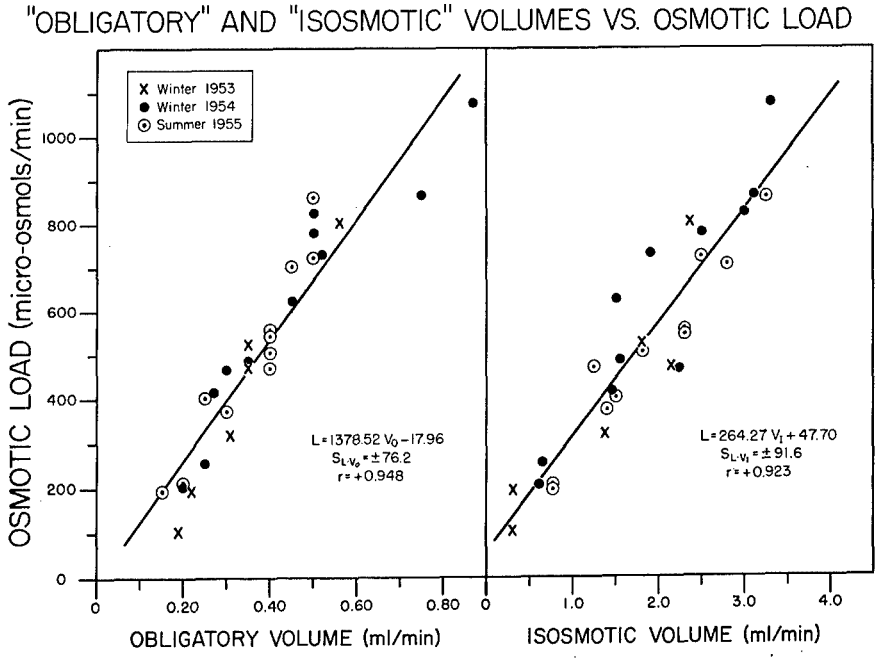


FIGURE III. 78. "OBLIGATORY" AND "ISOSMOTIC" VOLUMES VS. OSMOTIC LOAD, RESTING CONDITION, EXPERIMENTAL PERIODS.

b. Exercise Urine

The osmolar concentration of urinary specimens collected during the march of the heat acclimatization test was measured and the minute urinary osmolar excretion was calculated. On the assumption the serum osmolarity did not differ significantly from the values measured on serum collected during the morning of the days these marches were performed, we calculated the osmotic U/S ratios.

The pre-period data for the U/S ratios and the minute urinary osmolar excretion for the men participating in the march are summarized in Table III. 203. As might have been expected, the values for the U/S ratio during exercise are uniformly higher than those calculated from resting data. The standard deviations and the coefficients of variation are appreciably lower. Under conditions of moderate stress, it is frequently observed that individual variability became less. The measures of variance then became more a measure of the accuracy with which homeostatic mechanisms adjust the organism to the new situation. We also note that each group of subjects exhibits a rise in the U/S ratio from P I to P II. Such an increase was observed in the resting data (Table III. 197) and, in both cases, was probably caused by the hotter weather of P II.

The minute urinary osmolar excretion, in contrast, was uniformly lower among the resting urinary specimens than among the exercise specimens. There were no consistent alterations in the measures of variance. The lower rates of osmotic output were conditioned by renal conservation of water and salt in the sweating subject. Since the U/S ratios uniformly increased, it follows that more water was conserved than salt. The renal response to salt loss in sweating is seen in comparison of the minute urinary osmolar excretions of P I and P II. The values are uniformly lower in the latter period. Greater heat caused increased sweating and consequently increased the drain on body salt. The kidney responded by reducing the rate of output of osmotically active substances.

Regimen and U/S Osmolar Ratio. Although there was only one opportunity to calculate U/S ratios during the experimental period, several interesting trends emerged. In the flights doing hard work (Table III. 204), with one exception (15/52/33 2000), men on limited water had higher U/S ratios than men on unlimited water. Changes from the pre-periods to the experimental periods were inconsistent. Three values fell below 2.00---0/100/0 1000 and 2000 U and 2/20/78 2000 U---suggesting marked dilution of the urine. Two values rose over 4.00---15/52/33 1000 and 3000 L and 30/0/70 1000 L---indicating extensive conservation of water. In the recovery periods, the U/S ratios tend to show greater uniformity and approached values comparable to those of the pre-periods.

Similar trends are evident among the subjects who did light work (Table III. 204). With two exceptions, ST 0 and 0/100/0 1000, men on limited water have higher U/S ratios than men on unlimited water. There are no consistent changes from the pre-periods to the experimental periods. Seven values fall below 2.0: 0/100/0 1000 and 2000 U, 0/100/0 2000 L, 2/20/78 1000 and 2000 U, and 30/0/70 1000 U. No value exceeds 4.00 in the experimental period. In P II, however, there are four values above 4.00. In the recovery periods, the values again stabilize and approximate those of the pre-periods.

Regimen and Osmotic Excretion. In a general way the minute urinary osmotic excretions by the exercising men are similar to those for resting men. Data for both the hard work and light work flights are given in Table III. 205. Among men doing hard work the lowest values are found in ST 0, 0/100/0, and 2/20/78; the highest values in the 15/52/33 2000 and 3000 and 30/0/70 regimens. As in the pre-period, most of the exercise values are lower than the resting values. Limitation of water tended to lower the osmotic excretion among the low osmotic diets; e.g., 0/100/0 1000 and 2000 and 2/20/78 1000. Among the high osmotic diets; e.g., 15/52/33 2000 and 3000 and 30/0/70 1000 and 2000, limitation of water was associated with an increased osmotic excretion.

Supporting observations are evident among the men doing light work. There is a general agreement between osmotic intake and osmotic excretion. The maximum values for light work groups are not, however, as high as those seen among men doing hard work. The effect of limitation of water, on the other hand, is different. ST 0 and 30/0/70 1000 caused an increase in osmotic excretion when water was limited; all other regimens, independently of osmotic

intake, caused a decrease. These results suggest that, in hot weather, renal mechanisms are more severely taxed in the hard working man than in the light working man. There is greater catabolism and a great load of wastes to be eliminated. When the osmotic load is high, restriction of water accentuates these tendencies.

TABLE III. 203

PRE-PERIOD DATA ON EXERCISE URINARY OSMOLARITY

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
			A. Urine/Serum Osmolar Ratio					
1	22	2.99	0.88	29.4	21	3.50	0.59	16.8
2	21	3.32	0.53	16.0	21	3.46	0.34	9.8
3	20	2.75	0.41	14.9	20	3.36	0.62	18.4
4	21	3.00	0.41	13.7	21	3.72	0.69	18.1
FRA	12	3.05	0.35	11.6	11	3.46	0.56	16.3
			B. Urinary Osmolar Excretion, μOsm/min					
1	22	569	377	66.5	21	360	115	31.7
2	21	666	92	13.6	21	485	178	36.7
3	20	439	192	43.9	20	331	181	54.8
4	21	519	168	32.4	21	412	118	28.6
FRA	12	697	332	46.5	11	603	252	42.1

TABLE III. 204

EXERCISE U/S OSMOLAR RATIO

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST O	U	3.18	3.80	3.75	3.57	3.25	2.79	3.09	3.30	2.30	3.18
	L	2.94	3.37	3.78	3.59	2.76	2.98	4.15	2.96	3.12	3.19
0/100/0	U	2.76	3.00	1.98	3.22	3.78	2.77	3.57	1.32	2.36	3.59
1000	L	3.54	3.49	3.42	3.58	3.39	3.12	4.16	2.42	3.08	3.32
0/100/0	U	1.52	2.88	0.36	2.40	2.99	2.56	3.80	1.43	3.66	3.77
2000	L	3.51	2.90	3.29	3.29	3.58	2.40	3.50	1.37	2.92	3.38
2/20/78	U	3.20	3.51	3.31	3.32	3.21	2.97	3.57	1.01	2.94	3.45
1000	L	3.70	3.60	3.70	3.36	3.27	2.79	2.42	2.64	3.46	3.07
2/20/78	U	3.48	3.28	1.98	----	----	2.98	3.67	1.74	2.66	3.20
2000	L	3.44	3.54	3.68	3.10	2.70	2.64	3.40	3.13	2.86	2.16
15/52/33	U	3.66	3.28	2.64	3.09	3.28	2.63	3.15	2.60	2.40	3.35
1000	L	2.60	3.53	4.16	----	----	3.27	3.54	3.48	3.28	3.82
15/52/33	U	2.88	3.66	3.38	----	----	2.48	2.35	0.64	2.39	2.30
2000	L	3.42	3.54	3.34	3.31	3.08	2.92	3.67	3.16	3.30	3.66
15/52/33	U	2.84	3.65	2.72	2.93	2.59	3.02	4.28	3.34	3.97	3.86
3000	L	3.73	3.77	4.10	3.22	2.36	3.52	4.20	----	----	----
30/0/70	U	2.84	4.18	3.38	3.81	3.48	2.14	3.87	0.68	4.23	3.15
1000	L	3.19	3.38	4.00	3.07	----	3.36	3.84	2.70	3.06	3.92
30/0/70	U	3.38	3.44	2.14	2.16	3.04	2.75	2.94	2.54	3.28	3.48
2000	L	3.46	3.68	3.56	2.48	2.72	3.00	3.72	3.80	3.09	3.71
FRA		3.05	3.46	3.27	3.09	2.73	3.05	3.46	3.27	3.09	2.73

TABLE III. 205

EXERCISE URINARY OSMOTIC EXCRETION
(μOsm/min)

Experimental Regimen		Hard Work					Light Work				
		PRE		EXP	REC		PRE		EXP	REC	
		I	II	I	I	II	I	II	I	I	II
ST 0	U	450	308	199	365	465	439	251	205	177	296
	L	597	377	285	326	413	471	388	318	320	281
0/100/0	U	722	326	259	415	402	426	288	288	102	338
1000	L	676	542	222	470	446	616	482	222	445	500
0/100/0	U	1455	532	437	378	451	376	226	206	346	282
2000	L	634	387	146	318	354	153	320	172	470	341
2/20/78	U	516	416	296	434	474	356	312	303	251	441
1000	L	544	410	234	342	366	638	484	230	626	416
2/20/78	U	450	284	342	---	---	400	272	256	218	249
2000	L	678	480	345	408	526	593	403	262	370	720
15/52/33	U	410	320	226	220	1210	619	512	478	209	461
1000	L	768	562	352	---	---	750	435	316	491	520
15/52/33	U	430	320	292	---	---	409	544	558	246	244
2000	L	688	354	511	326	526	438	301	338	524	737
15/52/33	U	577	462	410	259	369	750	431	490	528	479
3000	L	744	489	573	502	534	717	555	---	---	---
30/0/70	U	406	394	704	354	313	328	256	694	230	360
1000	L	596	574	588	305	---	365	272	492	446	392
30/0/70	U	392	292	668	364	434	230	296	454	284	322
2000	L	798	504	848	358	386	498	506	653	701	456
FRA		697	603	698	629	728	697	603	698	629	728

4. Nitrogenous Compounds of Serum

Serum Urea Nitrogen. Pre-period data on serum urea nitrogen are summarized in Table III. 206. Although there are some differences between groups, there are no significant differences between periods. The interindividual variability of serum urea nitrogen is of a low order of magnitude and quite consistent from group to group.

In previous studies on nitrogenous compounds in the serum we have observed two facts. The level of serum urea nitrogen is proportional to the intake of protein. Second, dehydration regularly causes an elevation of serum urea nitrogen. These facts have been confirmed by the results of the summer test (Table III. 207). In the case of the men performing hard work (Table III. 207, Figure III. 79) we notice that there is a marked decrease in serum urea nitrogen among men subsisting on 0/100/0 1000 and 2000 and 2/20/78 1000 and 2000. In contrast, men subsisting on 30/0/70 1000 and 2000 show an increase in serum urea nitrogen during the experimental periods. There is little change in the level of serum urea nitrogen among the subjects subsisting on the other regimens.

Limitation of water caused a marked increase in this nitrogenous compound. This elevation was most pronounced in EXP I. In EXP II the effects of limitation of water was minimized because the water restriction was modified to prevent further occurrence of anhidrosis.

These general observations hold for the men performing light work (Table III. 207 and Figure III. 80). The variations, however, tend to be less marked.

Serum Creatinine. The pre-period values for serum creatinine (Table III. 208) agree very well with values reported from the 1954 winter tests. We can observe the usual intergroup and interindividual variability. The coefficients of variation for serum creatinine are of the same order of magnitude as are those for serum urea nitrogen, and there are no significant differences between the mean values of PRE I and those of PRE II.

Variations in serum creatinine from period to period are summarized for both the hard work groups and for the light work groups in Table III. 209. In the case of men doing hard work, we observe that those subjects on low protein rations (0/100/0 and 2/20/78) exhibit very little change in the serum creatinine. Among the men on high protein regimens, however, there is a tendency for the values to increase, and the increments are generally greater among men on limited water than among men on unlimited water. The same general observations hold for subjects doing light work. The most significant fact brought out in Table III. 209 is that serum creatinine varies less from period to period and from regimen to regimen than does serum urea nitrogen.

TABLE III. 206

PRE-PERIOD DATA ON SERUM UREA NITROGEN
(mg/100 ml)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	20.6	3.7	18.0	21	19.7	3.7	18.8
2	21	19.0	2.8	14.7	21	19.6	1.5	15.5
3	21	17.2	5.3	30.8	21	15.5	2.4	15.5
4	21	16.3	2.8	17.2	22	18.5	2.8	15.1
FRA	12	17.1	2.5	14.6	11	21.0	3.8	18.1

TABLE III. 207

SERUM UREA NITROGEN
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	22.4	17.6	23.8	18.8	18.6	15.3	17.2	15.2	18.8	18.9	14.3	18.9
	L	16.3	19.8	26.7	21.9	20.8	15.0	14.5	17.4	17.1	12.6	20.6	17.7
0/100/0	U	24.5	23.7	16.8	18.6	26.6	19.6	19.2	19.5	14.2	15.4	19.0	22.4
1000	L	18.8	19.8	20.9	14.5	20.8	17.2	15.8	18.0	12.2	13.2	19.4	20.4
0/100/0	U	24.2	19.0	12.4	9.1	20.6	15.0	16.8	13.5	10.5	9.3	16.0	19.8
2000	L	18.6	21.1	17.5	13.5	18.2	15.7	23.2	19.5	9.9	7.6	16.5	22.4
2/20/78	U	20.7	18.4	16.6	11.1	18.2	17.1	15.2	15.2	11.0	8.6	12.1	17.4
1000	L	19.7	20.4	22.8	15.0	16.3	23.4	16.2	16.4	22.2	13.6	19.4	16.4
2/20/78	U	19.0	22.8	11.6	7.0	25.2	----	14.8	15.4	10.8	7.5	15.3	17.8
2000	L	20.8	19.5	22.5	13.0	18.7	20.5	16.6	21.0	15.8	9.2	23.4	23.5
15/52/33	U	20.2	19.2	17.8	17.2	17.8	16.6	13.5	14.6	10.4	16.0	23.0	18.8
1000	L	20.4	20.2	21.6	14.7	----	----	14.4	15.4	18.4	14.6	16.8	18.0
15/52/33	U	19.9	21.0	19.2	19.2	20.7	16.2	13.8	14.8	14.6	13.5	19.8	18.0
2000	L	22.6	18.6	34.6	20.0	16.4	17.0	15.0	20.8	21.8	16.8	17.4	18.4
15/52/33	U	16.8	22.4	17.4	17.6	21.2	17.0	14.2	15.4	17.8	20.3	15.6	20.4
3000	L	20.8	18.8	26.4	23.9	15.2	14.1	17.0	18.2	----	----	----	----
30/0/70	U	16.2	14.5	22.2	20.6	18.2	13.2	18.0	17.2	16.1	20.0	19.5	25.6
1000	L	18.8	19.1	28.3	26.0	20.6	10.8	19.4	22.6	17.8	23.2	17.1	25.5
30/0/70	U	20.0	18.8	24.2	24.2	23.3	21.2	18.6	15.5	21.0	22.4	18.8	20.8
2000	L	15.8	17.8	32.2	34.2	14.0	11.3	12.6	17.1	29.0	23.6	13.0	22.0
FRA		17.1	21.0	17.5	17.2	19.6	18.6	17.1	21.0	17.5	17.2	19.6	18.6

TABLE III. 208

PRE-PERIOD DATA ON SERUM CREATININE
(mg/100 ml)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.79	0.06	7.6	21	0.79	0.09	11.4
2	21	0.79	0.09	11.4	21	0.81	0.07	8.6
3	21	0.84	0.18	21.4	21	0.79	0.19	24.0
4	21	0.69	0.14	20.3	22	0.73	0.11	15.1
FRA	12	0.85	0.05	5.9	11	0.78	0.12	15.4

TABLE III. 209

SERUM CREATININE
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.80	0.74	0.88	0.94	0.73	0.66	0.84	0.96	0.92	0.96	0.80	0.90
	L	0.79	0.75	0.84	0.86	0.67	0.63	0.83	0.73	0.87	0.92	0.78	0.75
0/100/0	U	0.86	0.80	0.93	1.05	0.74	0.83	0.79	0.72	0.88	0.94	0.74	0.83
1000	L	0.70	0.76	0.90	0.80	0.68	0.60	0.92	0.67	0.80	0.96	0.72	0.74
0/100/0	U	0.72	0.74	0.88	0.88	0.70	0.72	0.79	0.82	1.13	0.97	0.90	0.96
2000	L	0.82	0.84	0.96	1.22	0.78	0.76	0.72	0.76	0.89	1.00	0.65	0.73
2/20/78	U	0.88	0.88	0.86	0.97	0.71	0.88	0.84	0.86	0.86	0.80	0.82	0.85
1000	L	0.82	0.83	0.79	1.10	0.75	0.84	0.86	0.80	0.72	0.98	0.74	0.86
2/20/78	U	0.80	0.66	0.82	0.90	0.94	----	0.74	0.73	0.78	0.76	0.70	0.72
2000	L	0.74	0.86	0.92	1.12	0.73	0.68	0.92	0.78	0.90	1.01	0.95	0.99
15/52/33	U	0.76	0.79	0.78	1.02	0.65	0.74	1.01	0.68	0.94	0.92	0.74	0.79
1000	L	0.88	0.84	1.00	1.00	----	----	0.76	0.66	0.78	0.90	0.75	0.72
15/52/33	U	0.86	0.82	0.75	0.92	0.74	0.87	1.00	0.76	0.96	1.16	0.78	0.78
2000	L	0.86	0.90	1.02	1.22	0.80	0.86	0.78	0.69	0.93	0.74	0.71	0.72
15/52/33	U	0.74	0.82	0.82	1.03	0.68	0.80	0.89	0.78	0.86	1.12	0.85	0.83
3000	L	0.75	0.85	0.88	0.94	0.82	0.87	0.70	0.75	----	----	----	----
30/0/70	U	0.64	0.82	0.77	1.21	0.84	0.82	0.84	0.72	1.01	0.91	0.92	0.90
1000	L	0.82	0.80	0.82	1.00	0.88	0.67	0.89	0.78	0.97	0.91	0.67	0.71
30/0/70	U	0.79	0.90	1.02	1.30	0.80	0.90	0.74	0.72	0.88	0.82	0.76	0.82
2000	L	0.72	0.74	0.84	1.07	0.72	0.72	0.78	0.72	0.96	0.91	0.60	0.73
FRA		0.85	0.78	0.83	0.81	0.79	0.82	0.85	0.78	0.83	0.81	0.79	0.82

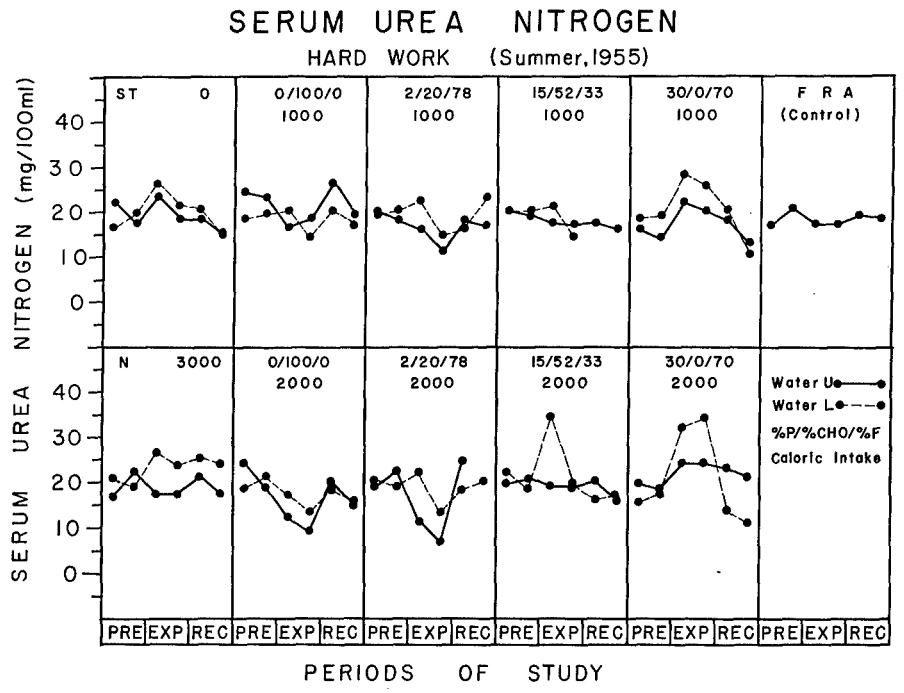


FIGURE III. 79. SERUM UREA NITROGEN: HARD WORK

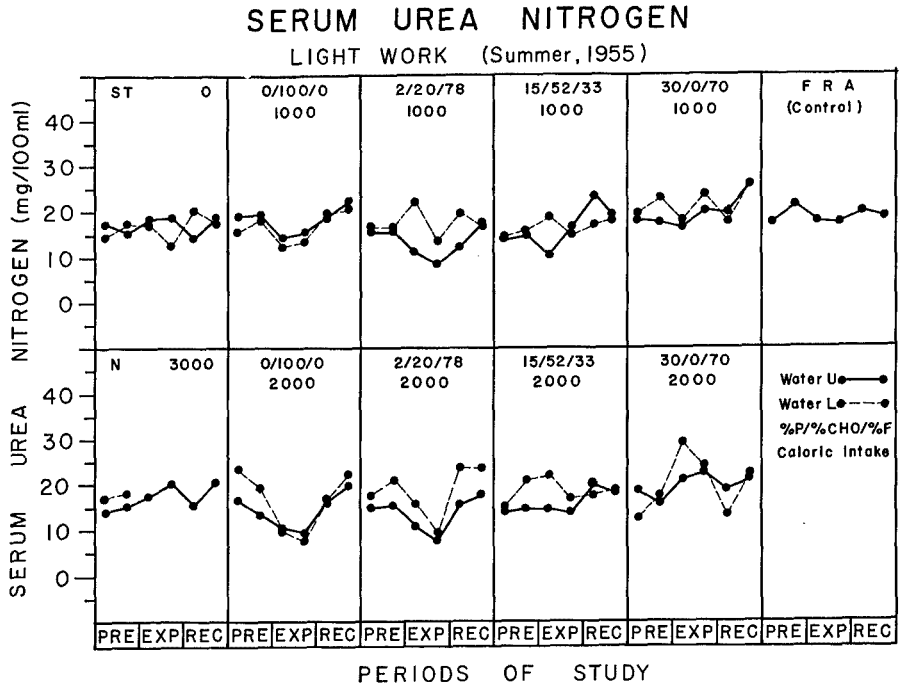


FIGURE III. 79. SERUM UREA NITROGEN: LIGHT WORK

5. Renal Clearance

During the course of the summer tests three different clearance measurements were made: (1) osmotic clearance, (2) creatinine clearance, (3) urea clearance. The clearances were measured both while the subjects were resting (three-hour test), and also while the subjects were marching (heat acclimatization test). An accurately timed specimen of urine was collected during both of these tests. The only blood drawn, however, was that obtained in the morning during the three-hour test. In calculating the clearance for the period of exercise which occurred in the afternoon, the assumption was made that there had been no appreciable change in the composition of the blood collected during the morning of the same day. We realize that in some cases this assumption may not be valid. Certainly this is true in the case of the men who were subsisting on the high protein diets. On the other hand, we feel that this calculation has been worthwhile since it has allowed us to find out whether or not there were any gross changes in renal function evoked by exercise. It is important for the reader to remember how the exercise clearances were calculated in making his own evaluation of our data.

a. Osmotic Clearance

Osmotic Clearance During Rest. Osmotic clearance while the subjects were subsisting on 5-in-1 ration or Field Ration A was of the order of 2.50 ml/min (Table III. 210). This value agrees very well with similar data presented in WADC TR 53-484, Part 2. There is considerable variation in the clearance from group to group and also from individual to individual. The clearance values decrease in PRE II in the cases of four of the five groups; only Flight 1 showed a small increase. None of the differences between PRE I and PRE II, however, were statistically significant.

Data for the osmotic clearances for subjects performing both hard work and light work are in Table III. 211. There are no significant differences which can be attributed to work or water intake. Furthermore, we find that the subjects subsisting on Field Ration A maintain a reasonably constant osmotic clearance throughout the period of study. The significant factor in determining variations in osmotic clearance is nutrient regimen. Subjects on the low osmotic regimens have very low osmotic clearances. Subjects on high osmotic regimens have high osmotic clearances. Those on intermediate osmotic loads have intermediate osmotic clearances. The lowest clearances are to be found among the subjects on 0/100/0 2000. The highest clearances are to be found among the subjects on 30/0/70 2000 and 15/52/33 3000. Most of the subjects show a marked increase in osmotic clearance in the recovery periods. In some cases the values are of the order of 5 ml/min. These high clearances merely reflect the fact that the subjects consumed a large amount of food containing osmotically active material during these periods.

Comment: Homer W. Smith (1952) has proposed that one can calculate a water clearance by deducting the osmotic clearance from the minute urinary volume. In our experience which now involves 8698 man-days, we have found no

positive water clearances. All our values are negative numbers of greater or lesser magnitude. We have no idea what the meaning of the negative water clearance is. Since we have no reason to doubt the validity of our measurements, we will not present any material on water clearance.

Osmotic Clearance during Exercise. Pre-period data on osmotic clearances of exercising subjects are given in Table III. 212. Although of the same low order of magnitude as the resting clearances, these data indicate that during exercise, osmotic clearance decreases. We also see that the standard deviation is lower for exercise than for resting clearances. The coefficients of variation, however, are of the same order of magnitude. This fact we interpret to mean that exercise does not appreciably increase the inter-individual variability. The clearances of P II are all lower than those of P I. A similar trend was noted above for osmotic excretion. Presumably this trend reflects the stimulation of hot weather on water and salt conserving processes.

Regimen and osmotic clearance: The osmotic clearances during the experimental periods reflect the osmotic intakes both for subjects in the hard work flights and in the light work flights (Table III. 213). The low osmotic clearances occur among men on low osmotic intakes, the high clearances among men on high intakes. Water intake had no consistent effect on clearance.

TABLE III. 210

PRE-PERIOD DATA ON RESTING OSMOTIC CLEARANCE
(ml/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	3.14	0.66	21.0	21	3.34	0.72	21.6
2	21	2.91	0.84	28.8	21	2.42	0.80	33.0
3	21	3.44	1.03	30.0	21	3.10	0.79	25.4
4	21	2.65	0.75	28.3	22	2.44	0.77	31.6
FRA	11	2.92	0.67	23.0	10	2.66	0.94	35.3

TABLE III. 211

RESTING OSMOTIC CLEARANCE
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	2.70	2.44	1.42	1.18	3.26	3.57	3.33	3.65	1.52	1.04	4.67	5.04
	L	3.07	2.22	1.65	1.64	4.78	3.60	2.89	2.43	1.52	1.34	4.17	3.25
0/100/0	U	3.60	3.64	0.74	0.91	4.76	4.69	2.30	2.52	0.73	0.53	3.74	3.06
1000	L	2.97	2.35	1.10	0.66	2.64	2.70	2.26	2.30	0.76	0.70	4.23	3.30
0/100/0	U	1.98	3.18	0.76	0.66	3.67	3.48	3.05	2.73	0.71	0.51	3.80	2.64
2000	L	3.13	2.03	0.86	0.76	3.27	2.88	3.32	2.30	0.88	0.50	3.76	2.91
2/20/78	U	3.64	3.36	1.16	1.42	4.73	3.91	3.76	2.53	1.44	1.17	4.41	3.69
1000	L	2.88	2.44	1.39	1.02	3.74	3.10	3.07	2.46	1.58	1.48	3.00	2.52
2/20/78	U	3.68	3.43	2.14	1.58	2.44	----	3.24	2.35	2.20	1.65	3.71	2.88
2000	L	2.08	2.35	1.96	1.08	3.42	3.52	2.54	3.70	1.59	2.04	2.99	2.58
15/52/33	U	3.20	3.30	2.60	1.62	2.71	3.84	3.76	3.29	0.90	1.66	3.24	3.88
1000	L	3.24	2.40	1.70	2.26	----	----	3.22	2.91	1.76	1.47	4.28	4.44
15/52/33	U	2.64	3.92	2.08	2.69	4.06	1.52	4.53	3.52	1.98	2.40	4.19	3.59
2000	L	2.86	2.40	2.04	2.18	3.05	4.29	1.90	1.61	1.14	1.43	3.70	2.44
15/52/33	U	3.54	3.74	2.32	3.02	3.76	3.84	4.57	3.28	2.16	2.22	4.76	2.10
3000	L	2.46	2.31	2.00	3.16	2.89	2.76	3.06	2.81	----	----	----	----
30/0/70	U	3.47	3.13	2.10	2.74	4.36	3.09	3.03	2.36	1.41	1.21	1.68	2.01
1000	L	3.06	3.99	1.46	2.48	3.96	3.23	1.90	1.93	2.02	1.61	2.71	2.44
30/0/70	U	3.32	4.22	2.83	3.62	5.10	4.54	2.77	3.60	2.24	2.13	3.94	4.64
2000	L	3.20	2.00	2.05	2.66	3.10	2.54	2.08	1.96	2.20	2.12	3.67	3.02
FRA		2.92	2.66	2.98	3.20	2.86	2.96	2.92	2.66	2.98	3.20	2.86	2.96

TABLE III. 212

PRE-PERIOD DATA ON EXERCISE OSMOTIC CLEARANCE
(ml/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	21	1.72	0.44	25.6	21	1.30	0.43	33.1
2	21	2.33	0.60	25.8	20	1.63	0.46	28.2
3	20	1.53	0.66	43.1	19	1.04	0.43	41.3
4	20	1.91	0.58	30.1	21	1.45	0.40	27.6
FRA	12	2.52	1.07	42.4	11	2.15	0.92	42.7

TABLE III. 213

EXERCISE OSMOTIC CLEARANCE
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	1.61	1.11	0.70	1.29	1.78	1.53	0.98	0.87	0.46	1.88
	L	2.09	1.32	1.01	1.13	0.66	1.67	1.37	1.15	1.22	2.42
0/100/0	U	2.50	1.13	0.96	1.45	1.44	1.50	1.00	1.02	0.36	1.20
1000	L	2.39	1.87	0.80	1.64	1.58	2.16	1.69	0.79	1.58	1.78
0/100/0	U	2.11	1.92	1.54	1.34	1.66	1.28	0.79	0.64	1.24	1.00
2000	L	2.20	1.41	0.51	1.14	1.27	0.85	1.12	0.79	1.67	1.22
2/20/78	U	1.79	1.52	1.03	1.53	1.67	1.24	1.03	1.08	0.88	1.55
1000	L	1.90	1.45	0.82	1.20	1.28	2.26	1.70	0.84	2.20	1.16
2/20/78	U	1.56	1.04	1.20	----	----	1.39	0.90	0.91	0.77	0.88
2000	L	2.38	1.72	1.20	1.43	1.87	2.12	1.40	0.92	1.26	2.55
15/52/33	U	1.43	1.14	0.78	0.78	1.25	2.17	1.78	1.68	1.44	1.64
1000	L	2.73	1.95	1.25	----	----	1.63	1.54	1.16	1.75	1.86
15/52/33	U	1.50	1.18	1.04	----	----	1.44	0.53	1.98	0.86	0.86
2000	L	2.39	1.25	1.70	1.13	1.81	1.54	1.05	1.20	1.86	1.14
15/52/33	U	2.00	1.68	1.46	0.92	1.32	2.60	1.50	1.73	1.88	1.68
3000	L	2.60	1.74	2.04	1.74	1.86	2.52	1.96	----	----	----
30/0/70	U	1.44	1.46	2.47	1.26	1.11	1.14	0.89	2.39	0.80	1.26
1000	L	2.08	2.10	2.04	1.07	----	1.28	1.45	1.74	1.60	1.38
30/0/70	U	1.36	1.06	2.36	1.28	1.53	0.80	1.04	1.56	1.02	1.18
2000	L	2.78	1.78	2.86	1.26	1.01	1.78	1.76	2.28	2.50	1.63
FRA		2.52	2.15	2.46	2.07	2.39	2.52	2.15	2.46	2.07	2.39

b. Creatinine Clearance

Resting Urinary Creatinine. Before considering the data on resting creatinine clearance, we shall briefly look at the information on urinary creatinine, for these data, together with the values for serum creatinine, are used in calculating the creatinine clearance. The data for the pre-periods are summarized in Table III. 214. We note that there is some variation in the mean values from flight to flight and from individual to individual. The mean values, however, do not differ appreciably from those reported from the 1954 winter test.

In Table III. 215 are shown the variations in urinary creatinine for subjects doing hard work. The only noteworthy observations are (1) the fall in creatinine among subjects on low protein diets and (2) the rise in creatinine among the subjects on high protein diets. The same general observation holds for subjects doing light work (Table III. 215). The FRA subjects, on the average, excreted quite similar amounts of creatinine from period to period throughout the study.

Resting Creatinine Clearance. Pre-period data on resting creatinine clearance (a measure of glomerular filtration rate) are summarized in Table III. 216. Attention is directed to several significant observations. First, the mean values of the resting creatinine clearances within periods were lower for Flights 1 and 2 than for Flights 3 and 4 and the FRA's. Second, comparing PRE I and PRE II there is a distinct rise in the creatinine clearance. Third, the interindividual variability of resting creatinine clearance was approximately half that observed in the winter study.

A statistical analysis was made of the increase of the creatinine clearance from P I to P II. The mean clearance for all the subjects on 5-in-1 ration was 157 ml/min in PRE I and 177 ml/min in PRE II. Both by the "t" test (Table III. 216) and the Chi-Square test (Table III. 217), the differences between the two periods were highly significant. The rise is of considerable interest for it has been frequently reported in the literature (Kenney, 1952a, 1952b; Pitesky and Last, 1951; Radigan and Robinson, 1949; Smith, Robinson, and Pearcy, 1952) that heat causes the glomerular filtration rate to decrease. Although these observations were made both on resting and on working subjects, Byfield, Tesler, and Keeton (1943) could not find a change in the glomerular filtrate rate (by inulin clearance) when their sedentary patients were exposed to heat. It will be recalled that there was a considerable warming of the weather from PRE I to PRE II, and with this warming trend there was an increase in the clearance rather than the decrease noted by other workers. It may be that the reported decrease is a response of the kidney to acute exposure of the subject to heat. The subjects of our investigation had been exposed to heat for several days before the clearances of P II were measured.

Because of the rather large interindividual variability and the change in clearance from P I to P II, it was necessary to establish some reference point with which to compare the clearance values for the experimental and recovery periods. We adopted PRE II as our standard for two reasons. First, the coefficients of variation were smaller in this period than in PRE I. Second, the weather continued to be hot from PRE II to the end of the study. The

clearances for the individual subjects were expressed as a percentage of the value for PRE II. That is, the PRE II value was set equal to 100% (Figures III. 81 and III. 82).

The actual values for resting creatinine clearances are given in Table III. 218 for subjects doing both hard work and light work. In the case of the hard work subjects there are a number of noteworthy trends (Figure III. 81). In general, subjects on the 0- and 1000-Calorie regimens exhibited lower clearances in the experimental periods than did the subjects on the 2000- and 3000-Calorie regimens. Subjects on starvation had the lowest clearances observed. There are no significant differences between subjects on limited water and those on unlimited water. With respect to nutrient mixture, the most regular patterns are present among the subjects on 0/100/0, 2/20/78, and 15/52/33: the low values for clearances occurred in either EXP I or EXP II. Subjects on meat bar (30/0/70) did not exhibit the decrease in creatinine clearance seen among the other regimens. This deviation must have been caused by the fact that the clearance is not reliable when the subjects are consuming large amounts of protein. Subjects on 15/52/33 3000 and Field Ration A showed no significant variations throughout the period of study. In general, the creatinine clearance tended to return to pre-period values in recovery. Notable exceptions were 2/20/78 2000 and 30/0/70 1000 and 2000.

With regard to the subjects doing light work (Figure III. 82) there is confirmation of some of the major trends noted among the subjects doing hard work. Clearances in the experimental periods tended to be lower among subjects on 0- and 1000-Calorie regimens than among the subjects on 2000- and 3000-Calorie regimens. Again, the differences between limited and unlimited water are not very striking. Certainly there are some differences, but they are not consistent. The most regular patterns of decreased clearance in the experimental periods were exhibited by subjects on 0/100/0, 2/20/78, and 15/52/33 1000. The variations seen among the subjects on 15/52/33 2000 and 3000 and 30/0/70 1000 and 2000 are quite erratic. In general, the light-working men on meat bar reacted differently than did the subjects performing hard work. Some showed a distinct tendency toward low values of clearance in the experimental periods. It is possible that the lower serum levels among these men may have led to more reliable creatinine clearances because there was less tubular secretion of the creatinine. In the recovery period, there was less of a tendency for the clearances to return to pre-period values than was noted among the subjects doing hard work. It is doubtful that this downward tendency of the clearances from PRE to REC represents deterioration of renal function. It may, however, represent a real decrease in glomerular filtration rate due to chronic exposure to heat.

Exercise Urinary Creatinine Excretion. Pre-period data for the minute urinary output of creatinine during exercise are grouped in Table III. 219. The mean values average only slightly higher than the resting values and there is no consistent change within groups from P I to P II. Variance is greatly increased by exercise. We note higher standard deviations and coefficients of variation.

The effect of regimen on urinary creatinine excretion was similar in exercise as it was in resting (Table III. 220).

Exercise Creatinine Clearance. The creatinine clearances tended to be higher in P I than in P II (Table III. 221). The mean for P I was 189 ± 44; for P II, 179 ± 46. The difference, however, was not significant (Tables III. 221 and III. 222). In P I the mean clearance during exercise was higher than that during resting. In P II, the values were almost identical. The variances in rest and exercise were of the same order of magnitude.

Data on the exercise creatinine clearance during the several periods of the summer test are tabulated according to nutrient regimen in Table III. 223. The regimens which were low in nitrogen were associated with markedly decreased clearance and the regimens in which the nitrogen content was high were associated with marked increased clearances in the experimental period. In the latter case, the trend merely reflects the alteration in urinary excretion of creatinine caused by a noon meal. We conclude that these data are not sufficiently controlled to permit any deductions regarding altered renal function which may have been caused by regimen itself.

TABLE III. 214

PRE-PERIOD DATA RESTING URINARY CREATININE
(mg/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	1.18	0.19	16.1	21	1.32	0.12	9.1
2	21	1.16	0.29	25.0	21	1.32	0.19	14.4
3	21	1.42	0.29	20.4	21	1.56	0.19	12.2
4	21	1.30	0.16	12.3	22	1.31	0.17	13.0
FRA	11	1.45	0.38	26.2	11	1.41	0.29	20.6

TABLE III. 215

RESTING URINARY CREATININE
(mg/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	1.22	1.15	0.92	0.78	1.05	1.13	1.24	1.68	1.04	1.05	1.17	1.23
	L	0.94	1.20	1.09	0.87	1.38	1.13	1.28	1.25	1.22	1.21	1.20	1.17
0/100/0	U	1.22	1.27	1.22	1.01	1.27	1.26	1.26	1.41	0.94	1.16	1.20	1.11
1000	L	1.16	1.16	1.24	1.08	0.80	0.98	1.32	1.31	0.87	1.18	1.32	1.18
0/100/0	U	1.16	1.30	1.05	1.02	0.94	1.25	1.47	1.70	1.18	1.36	1.42	1.36
2000	L	1.24	1.18	1.54	0.93	0.91	1.23	1.38	1.30	1.23	1.33	1.09	1.11
2/20/78	U	1.04	1.22	0.98	1.29	0.93	1.31	1.66	1.60	1.23	1.41	1.51	1.48
1000	L	1.04	1.32	1.40	0.92	0.96	1.06	1.42	1.36	1.35	1.42	1.20	0.98
2/20/78	U	1.37	1.50	1.46	0.94	0.78	----	1.38	1.50	0.98	1.42	1.33	1.32
2000	L	0.86	1.52	1.64	1.08	1.12	1.21	1.36	1.43	1.16	1.44	1.40	1.10
15/52/33	U	1.34	1.21	1.30	1.22	0.76	1.53	1.42	1.46	0.76	1.42	1.02	1.29
1000	L	1.25	1.38	1.57	1.15	----	----	1.36	1.36	1.42	1.24	1.36	1.28
15/52/33	U	1.12	1.38	1.26	1.17	1.39	0.99	1.80	1.69	1.54	1.86	1.27	1.41
2000	L	1.34	1.52	1.46	1.01	1.05	1.25	1.07	1.06	1.43	1.18	1.34	1.10
15/52/33	U	1.07	1.31	1.29	1.31	1.10	1.16	1.62	1.61	1.58	1.50	1.62	1.36
3000	L	1.70	1.31	1.74	1.56	1.04	1.16	1.29	1.34	----	----	----	----
30/0/70	U	1.19	1.36	1.52	1.62	1.18	1.20	1.34	1.43	0.95	1.26	0.96	1.06
1000	L	1.15	1.44	1.50	1.34	1.10	0.87	1.33	1.22	1.55	1.29	1.02	1.16
30/0/70	U	1.08	1.58	1.75	1.90	1.24	1.46	1.24	1.26	1.16	1.49	1.24	1.17
2000	L	1.07	1.30	1.50	1.58	0.84	0.98	1.19	1.52	1.42	1.28	1.32	1.15
FRA		1.45	1.41	1.66	1.52	1.33	1.54	1.45	1.41	1.66	1.52	1.33	1.54

TABLE III. 216

PRE-PERIOD DATA ON RESTING CREATININE CLEARANCE
(ml/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	152	27	17.8	21	167	25	15.0
2	21	147	42	28.8	21	163	22	13.5
3	21	169	36	21.3	21	196	22	11.2
4	21	161	33	20.5	22	180	37	20.6
FRA	11	167	52	31.1	10	184	54	29.3

Statistical Analysis

Mean clearance for P I, Flights 1-4: 157 ± 35
Mean clearance for P II, Flights 1-4: 177 ± 29

t = 3.93 P less than 0.001

TABLE III. 217

PRE-PERIOD FREQUENCY DISTRIBUTION FOR RESTING CREATININE CLEARANCE FOR MEN ON 5-in-1 RATION
(ml/min)

Class Intervals	P I		P II	
	N	%	N	%
51-75	2	2.35	0	0.00
76-100	4	4.70	0	0.00
101-125	7	8.23	1	1.18
126-150	22	25.87	14	16.46
151-175	26	30.58	34	39.98
176-200	15	17.64	19	22.34
201-225	5	5.88	13	15.28
226-250	4	4.70	3	3.53
251-275	0	0.00	0	0.00
276-300	0	0.00	1	1.18
Total	85	99.95	85	99.95

x^2 Test: P I vs. P II

x^2 = 18.52; P less than 0.05

TABLE III. 218

RESTING CREATININE CLEARANCE
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	152	157	104	83	143	175	145	175	113	110	148	139
	L	120	162	130	102	200	170	156	143	140	133	157	158
0/100/0	U	140	160	137	96	172	138	160	200	109	126	163	134
1000	L	166	151	139	132	115	169	143	196	107	124	184	159
0/100/0	U	159	176	119	116	135	174	191	206	105	144	160	142
2000	L	151	141	160	78	117	162	198	171	138	133	163	152
2/20/78	U	120	140	113	133	131	149	203	187	143	176	184	174
1000	L	126	161	185	83	127	128	169	173	187	148	163	116
2/20/78	U	174	225	178	104	83	---	191	206	129	191	192	189
2000	L	117	177	178	96	156	178	143	188	128	143	147	111
15/52/33	U	176	160	166	120	122	204	141	219	83	154	137	163
1000	L	149	163	157	115	---	---	182	205	183	138	180	179
15/52/33	U	133	169	169	127	188	114	181	221	161	161	165	179
2000	L	156	169	143	83	131	145	137	153	159	159	188	152
15/52/33	U	144	160	158	127	165	145	183	206	184	135	191	164
3000	L	226	155	138	167	126	135	189	179	---	---	---	---
30/0/70	U	187	166	198	198	140	147	160	199	94	138	104	118
1000	L	140	182	186	134	125	130	150	157	162	141	154	163
30/0/70	U	136	174	172	146	158	162	173	173	133	184	161	143
2000	L	148	176	180	147	116	137	153	214	148	141	220	158
FRA		167	184	204	192	171	189	167	184	204	192	170	186

TABLE III. 219

PRE-PERIOD DATA ON EXERCISE CREATININE EXCRETION
(mg/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	1.66	0.65	39.1	21	1.24	0.23	18.5
2	21	1.57	0.32	20.4	20	1.32	0.23	17.4
3	20	1.52	0.40	26.3	20	1.45	0.56	38.6
4	21	1.40	0.36	25.7	22	1.58	0.26	16.5
FRA	12	1.46	0.20	13.7	11	1.68	0.36	21.4

TABLE III. 220

EXERCISE CREATININE EXCRETION
(mg/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	1.26	1.25	0.95	1.29	2.33	1.60	1.31	0.81	0.90	1.33
	L	1.38	1.33	0.92	1.56	2.09	1.50	1.42	1.04	1.00	1.29
0/100/0	U	1.66	1.06	1.06	1.38	1.37	1.25	1.30	0.66	0.78	1.27
1000	L	1.54	1.35	0.90	1.37	1.53	1.67	1.60	1.21	1.16	1.63
0/100/0	U	3.09	1.41	1.16	1.51	1.65	1.50	1.18	1.09	1.29	1.23
2000	L	1.66	0.98	0.92	1.56	1.54	0.78	1.31	1.21	1.54	1.40
2/20/78	U	1.66	1.44	1.16	1.59	1.66	1.42	1.52	0.58	1.04	1.60
1000	L	1.46	1.22	0.94	1.54	1.48	1.72	1.80	1.10	1.52	1.26
2/20/78	U	1.44	1.29	1.19	----	----	1.43	1.34	0.96	1.20	1.07
2000	L	1.80	1.45	1.20	1.66	1.76	1.52	1.62	0.90	1.47	2.06
15/52/33	U	1.44	1.17	1.18	1.12	3.10	1.54	1.54	0.94	1.12	1.55
1000	L	1.24	1.42	1.28	----	----	1.36	1.68	1.44	1.23	1.61
15/52/33	U	1.38	1.24	1.46	----	----	2.02	2.40	2.52	1.20	1.68
2000	L	1.42	1.26	1.71	1.50	1.89	1.45	1.64	0.67	1.26	3.26
15/52/33	U	1.56	1.24	1.84	1.26	1.28	1.92	1.65	2.12	1.29	1.68
3000	L	1.57	1.36	1.92	1.79	1.72	1.54	1.89	----	----	----
30/0/70	U	1.58	1.42	2.01	1.40	1.42	1.17	1.16	0.89	0.89	1.06
1000	L	1.76	1.38	2.05	1.36	----	1.28	1.36	2.02	1.20	1.40
30/0/70	U	1.50	0.96	2.42	1.48	1.46	1.05	1.23	1.80	1.14	1.34
2000	L	2.07	1.48	2.88	1.71	1.50	1.16	1.62	2.01	1.62	1.41
FRA		1.46	1.68	1.89	1.74	1.64	1.46	1.68	1.89	1.74	1.64

TABLE III. 221

PRE-PERIOD DATA ON EXERCISE CREATININE CLEARANCE
(ml/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	21	195	46	23.6	21	158	33	20.9
2	21	200	50	25.0	20	164	32	19.5
3	20	181	40	22.1	19	175	48	27.4
4	20	178	33	18.6	22	218	45	20.6
FRA	12	171	23	13.5	11	224	46	20.5

Subjects on 5-in-1:
P I = 198 ± 44: P II = 179 ± 46
Means not significantly different by "t" test

TABLE III. 222

PRE-PERIOD FREQUENCY DISTRIBUTIONS FOR
EXERCISE CREATININE CLEARANCE*

Class	P I		P II	
Interval	N	%	N	%
51-75	0	0.00	1	1.22
76-100	0	0.00	0	0.00
101-125	2	2.44	5	6.10
126-150	13	15.86	18	21.96
151-175	19	23.18	19	23.18
176-200	18	21.96	15	18.30
201-225	17	20.74	12	14.64
226-250	5	6.10	6	7.32
251-275	6	7.32	4	4.88
276-300	0	0.00	0	0.00
301-325	1	1.22	2	2.44
326-350	0	0.00	0	0.00
351-375	1	1.22	0	0.00
Total	82	100.04	82	100.04

*Distributions not significantly different by X^2 test.

TABLE III. 223

EXERCISE CREATININE CLEARANCE
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	159	172	106	176	206	192	140	89	115	153
	L	175	183	97	189	170	181	195	116	134	178
0/100/0	U	238	134	115	186	151	159	186	74	112	154
1000	L	214	170	99	201	260	182	239	154	162	222
0/100/0	U	227	192	131	217	231	198	142	98	146	129
2000	L	201	116	97	203	202	164	172	136	237	192
2/20/78	U	192	164	135	224	189	176	182	67	127	188
1000	L	177	147	118	207	178	202	230	152	208	154
2/20/78	U	180	179	147	---	---	213	182	152	197	219
2000	L	241	170	131	230	258	160	207	102	155	208
15/52/33	U	189	148	150	172	215	153	227	102	151	198
1000	L	141	172	128	---	---	180	252	184	164	225
15/52/33	U	159	148	195	---	---	200	192	258	155	221
2000	L	164	140	169	188	220	189	252	217	178	196
15/52/33	U	209	151	223	187	160	217	223	247	152	202
3000	L	210	159	220	217	197	225	254	---	---	---
30/0/70	U	244	173	248	169	175	139	161	88	97	118
1000	L	215	174	236	155	---	144	175	212	179	197
30/0/70	U	192	106	239	185	163	145	171	208	150	164
2000	L	288	202	344	238	211	147	225	209	270	193
FRA		171	224	231	205	198	171	224	231	205	198

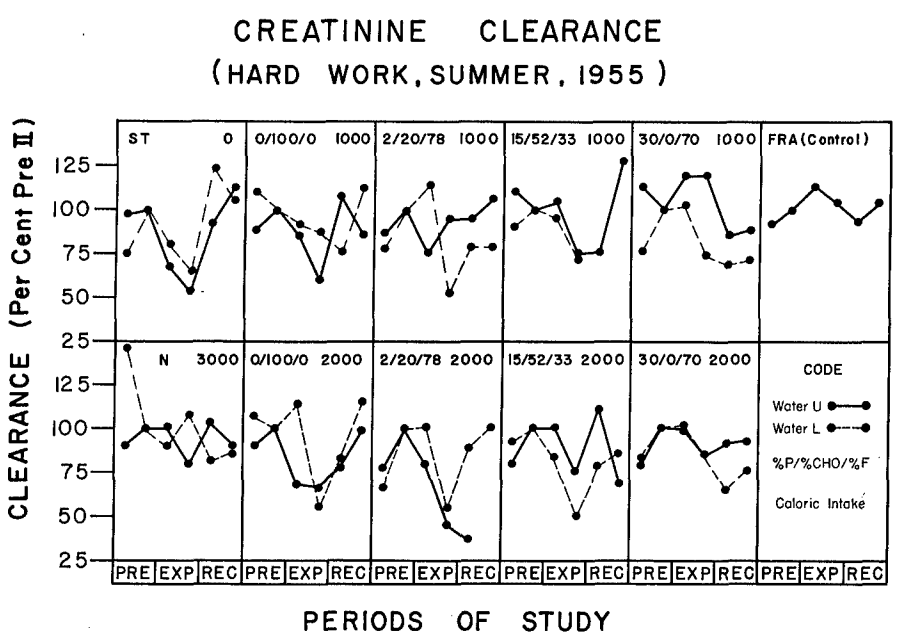


FIGURE III. 81. RESTING CREATININE CLEARANCE: HARD WORK

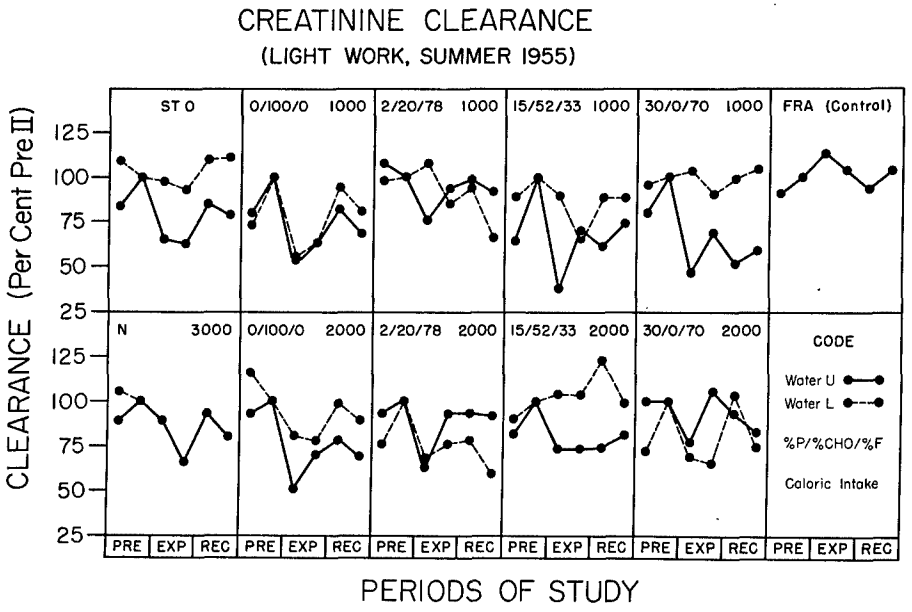


FIGURE III. 82. RESTING CREATININE CLEARANCE: LIGHT WORK

c. Urea Clearance

Resting Urinary Urea Nitrogen Excretion. According to our measurement, the post-absorptive subject excretes urea nitrogen at the rate of some 10 mg/min (Table III. 224). The coefficient of variation, the index of inter-individual variability, is about 25%. When pre-periods are compared there is no consistent trend. Furthermore, there are no significant differences between flights.

Experimental regimen produces marked changes in the urinary urea nitrogen (Tables III. 225). The output is low (less than 10 mg/min) among men on low protein intakes (0/100/0, 2/20/78, and 15/52/33 1000) for men doing hard work and greater than 10 mg/min for men on high protein intakes (15/52/33 3000 and 30/0/70). The output is also high for men on starvation. Water intake has no regular effect on the urea nitrogen output.

Among the men doing light work (Table III. 225), the minute urinary excretion of urea nitrogen tended to be lower than that for men doing hard work. Furthermore, fewer regimens caused the rate of excretion to exceed 10 mg/min, and the effect of regimen was not clearly evident until EXP II. In fact, the 30/0/70 2000 regimen was the only one which clearly increased the urea nitrogen. These observations suggest that hard work is a factor which markedly augments urea nitrogen output even when the subject is measured in a post-absorptive condition.

Resting Urea Clearance. In calculating urea clearance, we have used throughout the equation $C = UV/P$. Peters and Van Slyke (1946) recommend that when the urine flow is less than 2 ml/min, one should use the equation $C = U\sqrt{V}/P$. They term the former, "maximum clearance" and the latter, "standard clearance." According to data detailed in a previous section, most of the subjects urinated at a rate of less than 2 ml/min (Section III E1). As a matter of fact, during exercise most of the subjects urinated at a rate less than 1 ml/min. We have never been quite clear as to just what the physiological meaning of the square root is; consequently, we have used a straightforward calculation in preparing our observations for analysis.

The resting clearance of our subjects averaged only slightly greater than 60 ml/min (Table III. 226). The values agree quite well with the data for standard clearance quoted by Peters and Van Slyke (1946, p. 847): mean, 54 ml/min; range, 41-65 ml/min. We note that the coefficient of variation is of the order of 25%. There were no consistent changes in urea clearance from PRE I to PRE II, and there are no significant differences between groups (Tables III. 227).

Regimen and resting urea clearance: When we make a careful study of the effect of various experimental regimens on urea clearance, we find that while alterations in clearance did occur, they were most erratic and did not follow the trends which we have recently observed in the case of the creatinine clearance (Table III. 228). The marked decrease in creatinine clearance among subjects on ST 0, 0/100/0, and 2/20/78 is completely absent. The impression

one gets from a scrutiny of these data is that at least insofar as urea clearance is a measure of renal function, no significant functional alterations occurred. This finding supports a feeling we have had for some time regarding the significance of the creatinine clearance. It is more probable that the marked changes in creatinine clearance are caused by the effect of the regimen on serum level and rate of excretion than it is an effect of the regimen on the ability of the kidney to handle these nitrogenous wastes. In other words, we are inclined to raise the question of whether the marked decrease in creatinine clearance does, in fact, reflect a functional impact of regimen on the kidney.

Exercise Urinary Urea Nitrogen. Pre-period data on urinary output of urea nitrogen during exercise are summarized in Table III. 229. During PRE I the values tend to be of the same order of magnitude as those observed during resting. In PRE II, however, we find that the output of urinary urea nitrogen is considerably decreased. Every one of the five groups of subjects excretes less urea nitrogen in PRE II than in PRE I, and every one of the five groups of subjects excretes less urea nitrogen during exercise than during resting in PRE II. Exercise was associated with some increase in inter-individual variance. We note that the coefficient of variation increases from 25% to a value around 35%.

When we come to examine the effect of regimen on the excretion of urinary urea (Table III. 230), the first significant observation is that throughout the test; pre-period, experimental period, and recovery period; the exercise urinary urea nitrogen tended to be lower than the resting urinary urea nitrogen. Furthermore, in a general sort of way, the subjects doing hard work tend to eliminate more urea nitrogen than do the subjects doing light work. The only noteworthy exceptions are ST 0 L, 0/100/0 1000 L, 0/100/0 2000 L, 15/52/33 1000 U, and 30/0/70 1000 L. In these cases the light work subjects excrete somewhat more urea nitrogen than do the hard work subjects. In a general sort of way, the effect of nitrogen intake is also evident. The subjects on low protein rations tend to put out less urea nitrogen than do the subjects on high protein rations. Starvation, insofar as exercise urea nitrogen is concerned, does not provoke the large output of the urea nitrogen that is characteristic in the resting state. Limitation of water has no effect on urinary urea nitrogen.

Exercise Urea Clearance. Exercise caused a general decrease in creatinine clearance (Table III. 231 and III. 232). The effect of exercise was more pronounced in PRE II than in PRE I. The mean urea clearance for PRE I was 51±21 ml/min; PRE II was 40±15 ml/min. By the "t" test this difference was significant. The coefficients of variation tended to be somewhat greater for resting than for exercise, suggesting that in resting, insofar as urea clearance is concerned, exercise augmented individual differences among subjects.

In contrast to the resting data, exercise data suggest that regimen had an effect on urea clearance (Table III. 233). In a general way, the urea clearances tend to be higher among the men whose intake of protein was large than among the men whose protein intake was low. This trend we have seen pre-

viously in the case of the creatinine clearance and in the case of the osmotic clearance. Work per se had no consistent effect upon creatinine clearance, and there is no evidence that limitation of water caused any real differences in the values for clearance.

TABLE III. 224

PRE-PERIOD DATA ON RESTING URINARY UREA NITROGEN
(mg/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	11.4	2.7	23.8	21	13.6	3.8	28.0
2	21	10.4	3.0	28.7	21	10.0	2.1	21.0
3	20	12.4	1.8	14.5	21	10.8	2.2	20.4
4	21	9.4	2.3	24.5	22	9.5	2.9	30.5
FRA	12	10.4	3.5	33.6	10	15.9	4.5	28.3

TABLE III. 225

RESTING URINARY UREA NITROGEN EXCRETION
(mg/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	9.7	9.2	12.9	7.2	12.9	14.2	11.4	13.3	9.2	6.1	13.3	18.8
	L	8.9	8.9	12.6	11.0	13.8	12.4	10.4	7.3	9.2	6.0	15.2	11.2
0/100/0	U	14.2	15.7	11.2	4.9	24.1	24.7	11.3	11.2	6.5	4.1	13.7	15.8
1000	L	11.4	10.0	9.4	7.5	11.7	10.4	9.0	6.9	9.6	5.1	12.2	11.4
0/100/0	U	7.8	10.6	8.6	1.9	15.7	17.0	11.2	9.0	5.7	2.7	14.3	9.2
2000	L	11.6	7.8	7.8	4.9	7.6	10.9	10.0	12.4	7.3	2.9	12.3	11.1
2/20/78	U	12.2	16.2	7.0	7.5	18.1	16.5	13.0	10.0	10.4	7.5	11.1	11.8
1000	L	9.0	11.4	9.7	6.8	10.0	14.2	10.3	10.0	10.9	8.2	12.7	7.8
2/20/78	U	14.6	19.0	4.4	3.5	7.4	----	13.4	9.4	8.2	4.2	9.3	10.0
2000	L	9.2	11.4	9.8	4.0	11.4	15.2	9.4	10.6	11.4	5.6	15.4	9.6
15/52/33	U	13.2	13.4	8.7	9.4	8.6	18.4	12.6	10.1	6.1	8.0	9.5	12.8
1000	L	13.0	10.4	8.0	8.3	----	----	8.2	10.6	13.4	7.5	15.0	14.7
15/52/33	U	10.6	12.0	9.7	11.1	16.0	7.0	13.5	7.6	10.0	8.0	11.0	10.8
2000	L	12.4	9.7	12.0	10.4	10.2	16.6	6.4	8.4	11.0	8.4	13.1	7.8
15/52/33	U	12.0	13.2	10.4	11.9	13.2	14.4	11.5	10.1	13.0	10.6	17.4	11.0
3000	L	9.0	10.7	11.7	13.4	11.4	11.6	12.9	11.2	----	----	----	----
30/0/70	U	8.8	11.6	14.0	15.0	15.6	11.6	12.1	10.3	9.0	7.1	12.6	12.3
1000	L	11.2	12.8	13.0	16.5	11.2	18.7	9.0	9.1	18.4	10.0	10.2	9.8
30/0/70	U	12.4	18.2	16.4	18.5	21.2	17.0	12.4	13.0	16.6	14.4	12.6	15.0
2000	L	10.0	8.0	17.8	19.2	8.8	8.2	7.4	7.2	9.3	15.0	11.6	10.2
FRA		10.4	15.9	11.4	12.8	11.8	11.6	10.4	15.9	11.4	12.8	11.8	11.6

TABLE III. 226

PRE-PERIOD DATA ON RESTING UREA CLEARANCE
(ml/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	57	16	27.7	21	70	19	26.6
2	21	55	12	22.6	21	52	13	25.8
3	20	76	21	27.6	21	71	14	20.1
4	21	60	19	31.2	22	52	15	28.9
FRA	11	61	16	26.0	10	76	20	26.9

Subjects on 5-in-1:
P I = 62±19; P II = 61±18
Means not significantly different by "t" test.

TABLE III. 227

FREQUENCY DISTRIBUTION OF RESTING UREA CLEARANCE
PRE-PERIODS, 5-IN-1 RATION

Class Intervals	P I		P II	
	Number	Per Cent	Number	Per Cent
20-29	1	1.19	1	1.18
30-39	10	11.90	11	12.98
40-49	15	17.85	14	16.52
50-59	17	20.23	19	22.42
60-69	16	19.04	16	18.88
70-79	12	14.28	6	7.08
80-89	7	8.33	14	16.42
90-99	3	3.57	1	1.18
100-109	1	1.19	3	3.54
110-120	2	2.38	0	0.00
Total	84	99.96	85	100.20

TABLE III. 228

RESTING UREA CLEARANCE
(ml/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	44	53	52	38	69	92	72	88	49	31	98	102
	L	55	45	47	51	71	84	74	42	54	48	76	65
0/100/0	U	58	66	68	26	91	126	59	58	48	26	72	71
1000	L	60	50	45	54	56	61	57	38	75	38	65	56
0/100/0	U	32	55	67	20	77	112	50	66	50	31	94	47
2000	L	63	37	44	37	44	71	43	63	74	38	74	50
2/20/78	U	60	88	42	68	99	96	84	69	94	87	92	68
1000	L	45	58	42	45	62	62	64	63	66	61	66	49
2/20/78	U	77	82	36	50	29	---	97	61	80	56	61	57
2000	L	43	59	44	31	61	79	59	69	80	61	66	41
15/52/33	U	65	76	49	55	48	110	93	70	57	51	42	68
1000	L	61	52	37	56	--	---	57	58	73	51	94	85
15/52/33	U	53	60	52	58	77	45	99	54	69	60	56	60
2000	L	54	53	39	52	62	98	43	41	51	50	78	43
15/52/33	U	72	62	60	67	65	84	82	65	76	52	111	55
3000	L	44	57	45	56	75	82	77	61	--	--	--	--
30/0/70	U	59	80	64	73	91	88	67	60	56	36	64	48
1000	L	59	69	46	64	54	173	46	40	58	44	60	39
30/0/70	U	62	97	67	77	92	84	62	83	80	64	68	72
2000	L	64	45	51	56	63	72	59	42	32	64	89	46
FRA		61	76	65	71	62	62	61	76	65	71	62	62

TABLE III. 229

PRE-PERIOD DATA ON EXERCISE URINARY UREA NITROGEN
(mg/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	10.0	2.2	22.0	21	6.6	2.5	37.8
2	21	11.5	3.1	27.0	21	9.2	2.9	31.5
3	20	7.2	3.2	44.4	20	6.2	2.5	40.3
4	21	8.4	3.4	40.3	22	7.6	2.7	35.8
FRA	12	11.9	4.0	33.6	11	11.5	3.9	33.9

TABLE III. 230

EXERCISE URINARY UREA NITROGEN
(mg/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	8.2	5.3	4.4	5.5	9.3	7.1	5.4	3.4	2.5	5.8
	L	11.5	7.3	5.2	6.6	8.1	7.2	5.6	5.8	6.8	5.2
0/100/0	U	12.4	6.0	5.7	7.7	8.1	6.9	6.6	4.2	1.2	6.6
1000	L	10.8	10.0	4.7	10.0	9.6	7.6	6.7	5.0	7.2	10.0
0/100/0	U	28.1	8.7	10.9	7.1	8.2	6.7	4.6	1.6	5.0	5.4
2000	L	11.0	7.0	3.2	3.9	7.0	3.6	7.7	4.8	7.9	6.5
2/20/78	U	9.8	9.6	5.8	8.9	11.9	5.2	5.8	6.6	4.0	8.9
1000	L	7.6	6.8	6.8	6.0	8.1	10.0	11.0	4.2	10.3	6.6
2/20/78	U	8.1	6.8	6.4	---	---	6.2	5.0	3.3	3.6	3.8
2000	L	11.3	10.2	7.8	6.4	11.7	11.0	9.2	4.4	7.0	16.3
15/52/33	U	6.3	6.6	4.0	3.4	21.6	9.8	8.4	7.4	6.8	6.8
1000	L	17.4	10.6	8.2	---	---	11.5	7.8	6.6	8.4	9.2
15/52/33	U	7.5	6.1	5.7	---	---	7.5	7.4	5.2	3.7	4.1
2000	L	12.0	7.8	14.2	4.9	11.3	8.0	5.8	6.4	8.0	11.8
15/52/33	U	8.4	8.8	8.7	5.2	7.2	12.4	7.2	7.6	8.5	10.8
3000	L	9.3	9.2	13.2	7.1	13.2	12.7	7.7	---	---	---
30/0/70	U	6.4	5.0	12.2	5.8	7.9	5.6	5.8	7.8	3.6	7.2
1000	L	10.4	9.8	10.0	5.7	---	6.3	5.6	11.6	6.6	6.0
30/0/70	U	6.6	4.8	20.9	7.6	8.6	3.9	6.9	8.8	5.2	6.8
2000	L	13.5	11.6	21.7	6.8	6.5	7.9	10.8	8.2	10.5	7.7
FRA		11.9	11.5	10.9	8.4	10.5	11.9	11.5	10.9	8.4	10.5

TABLE III. 231

PRE-PERIOD DATA ON EXERCISE UREA CLEARANCE
(ml/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	21	43	12	27.9	21	34	12	35.3
2	21	62	21	33.9	20	45	13	28.9
3	20	46	22	47.8	20	40	14	35.0
4	21	54	22	40.7	22	42	18	42.8
FRA	12	69	22	31.9	11	56	25	44.6

Men on 5-in-1
P I = 51±21; P II = 40±15
t = 3.79 P<0.001

TABLE III. 232

PRE-PERIOD DATA ON FREQUENCY DISTRIBUTION OF EXERCISE UREA CLEARANCE: MEN ON 5-IN-1 RATION
(ml/min)

Class Intervals	Number	Per Cent	Number	Per Cent
0-9	1	1.20	0	0.00
10-19	0	0.00	2	2.40
20-29	8	9.60	18	21.60
30-39	19	22.80	26	31.20
40-49	19	22.80	17	20.40
50-59	10	12.00	10	12.00
60-69	11	13.20	7	8.40
70-79	6	7.20	2	2.40
80-89	4	4.80	0	0.00
90-99	2	2.40	1	1.20
100-109	1	1.20	0	0.00
110-119	2	2.40	0	0.00
Total	83	99.60	83	99.60

TABLE III. 233

EXERCISE UREA CLEARANCE
(ml/min)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	REC I	REC II	Light Work PRE I	PRE II	EXP I	REC I	REC II
ST 0	U	37	29	17	29	32	42	35	18	19	32
	L	72	36	22	34	24	51	32	31	32	28
0/100/0	U	49	24	36	29	41	36	35	32	6	30
1000	L	58	47	22	48	56	48	39	42	38	49
0/100/0	U	62	45	86	34	55	41	33	11	32	27
2000	L	60	33	18	24	46	15	38	48	48	29
2/20/78	U	47	51	35	49	70	34	42	60	33	51
1000	L	39	34	24	37	34	62	70	27	54	40
2/20/78	U	42	30	58	--	--	44	32	46	24	21
2000	L	57	52	34	34	60	67	44	28	30	13
15/52/33	U	32	34	23	19	45	74	55	72	30	36
1000	L	86	58	38	--	--	75	52	36	50	52
15/52/33	U	38	32	34	--	--	53	44	36	18	24
2000	L	54	42	46	30	66	54	28	28	48	24
15/52/33	U	50	43	50	25	42	83	46	44	54	54
3000	L	44	49	50	46	94	74	42	--	--	--
30/0/70	U	44	34	59	32	58	31	34	48	18	28
1000	L	56	50	34	28	--	32	26	74	38	24
30/0/70	U	33	26	88	30	40	22	45	42	30	33
2000	L	86	64	68	48	57	64	63	28	81	35
FRA		69	56	62	41	50	69	56	62	41	50

d. Effect of Exercise on Clearance

In order to evaluate the effect of exercise on clearance, we selected paired (resting and exercise) data for 44 men who in EXP I were existing on low protein regimens (ST 0, 0/100/0, and 2/20/78). These regimens were selected since they probably caused little if any change in serum concentration or urinary excretion of total osmoles, creatinine, and urea between morning and afternoon of the same days; i.e., it was assumed that the noon meal provoked little change in the subject's post-absorptive condition with regard to nitrogenous and osmotically active substances. Comparative data were derived from 11 FRA subjects. The mean data together with appropriate statistical analyses are summarized in Table III. 234. Examination of this table brings out several significant findings. First, there was a uniform decrease in the clearance measured during exercise among the subjects on the low protein regimens. The decrease was statistically significant and ranged in magnitude from 15% to 44%. In each case, none of the control subjects exhibited this decrease. According to our data the magnitude of the decrease ranged from 74% for the creatinine clearance to 91% for the urea clearance. In general, therefore, the greater the degree of decrease, the more consistent was the reaction among these subjects. In contrast, exercise had no significant effect on the clearances measured in the 11 FRA subjects. We are inclined to attribute the absence of significant change to the fact that these men ate a high protein meal just an hour or two prior to participating in the exercise test, and to the fact that the increased output of nitrogen and other osmoles obscured the effect of exercise on the renal function. Thus it is evident that an effect of exercise is demonstrable, provided other conditions can be properly controlled.

Comment: The effect of exercise on clearance has been investigated. Peters and Van Slyke (1946) state that urea clearance is not altered unless the exercise is strenuous. Kattus et al. (1949) studied 13 subjects who marched on a treadmill at 3.0 m.p.h. The work load did not affect the blood lactate. Glomerular filtration rate was not altered. There was, however, a retention of sodium and chloride which was attributed to either a reduction in the proportion of filtered sodium excreted or an increase in tubular reabsorption of sodium. The excretion of potassium and phosphate were not influenced. These results allow the inference that osmotic clearance may have decreased. Asa and Blegan (1949), using exhausting work, found, in two females, that the creatinine clearance was dramatically reduced at the point of exhaustion. A similarly tested male, however, did not become exhausted. The GFR was reduced, but not as greatly as in the case of the females. Radigan and Robinson (1949) reported that men exercising in a cool environment maintained their glomerular filtrate rate at resting levels. When they were exposed to heat, the filtration rate fell. Resting in heat caused the rate to fall from 108 ml/min to 84 ml/min; exercise caused a further decrease to 70 ml/min. Kenney (1952 b) has also recorded a fall in the glomerular filtration rate of men working in moist heat.

Our own observations indicate that osmotic clearance, urea clearance, and glomerular filtration rate (creatinine clearance) were reduced by exercise which

consisted of walking 3.75 m.p.h. for one hour during hot weather. Our data thus agree with other reports in the technical literature.

TABLE III. 234

EFFECT OF EXERCISE ON OSMOTIC, CREATININE, AND UREA CLEARANCES

A. Mean Values

Clearance	Low Protein* Resting	Low Protein* Exercise	Δ%	FRA Resting	FRA Exercise
Osmotic	1.33±0.47	0.93±0.35	30	2.98±0.77	2.46±0.74
Creatinine	134 ± 31	114 ± 33	15	204 ± 46	231 ± 67
Urea	55 ± 21	21 ± 19	44	65 ± 17	62 ± 14

*ST 0, 0/100/0, and 2/20/78

B. Statistical Analysis

(Number, a; "t", b; P, c: % subjects showing decrease, d)

Clearance	Low Protein a	Low Protein b	Low Protein c	Low Protein d	FRA a	FRA b	FRA c
Osmotic	44	4.44	<0.001	84	11	1.55	<0.20
Creatinine	43	2.88	<0.01	74	11	0.96	———
Urea	43	5.39	<0.001	91	11	0.40	-----

F. FUNCTIONS OF ENDOCRINE GLANDS

1. Adrenal Cortex

Urinary 17-Ketosteroids. Urinary 17-ketosteroids were measured on the urine collected during the three-hour test. The specimens were analyzed for 17-ketosteroids by means of the Vestergaard method of hydrolysis and extraction and the Zimmerman color reaction (Sargent et al., 1954).

The mean 17-ketosteroid values during P I and P II for the five groups of subjects are summarized in Table III. 235. The subjects excreted approximately 1.5 mg/2 hrs. There was, of course, considerable individual variability and also there were some differences between the five groups. The values for each of the groups were slightly lower in PRE II than in PRE I, but in view of the large individual variability these differences are not significant.

FRA subjects: The 17-ketosteroid values of the subjects subsisting on Field Ration A changed relatively little during the course of the summer test (Table III. 236). Lowest values were observed during EXP II. During the recovery period, the values rose to levels equivalent to that observed in EXP I. This downward trend during the first four periods of the summer test suggests that the stress of the trial in general had a small, but measurable, effect upon the function of the adrenal glands. Whether or not this reflects the acclimatization that was occurring is impossible to say. These data, in general, support the recent finding of Bass et al. (1955). Those investigators reported that exposure of five normal young men for a period of 14 days to a hot atmosphere was associated with a slight but rather constant downward trend in the rate of excretion of 17-ketosteroids. A reduction in the urinary output of 17-ketosteroids might mean either that the rate of production of adrenal corticoids is decreasing or that the rate of utilization of the corticoids by the tissues is increasing. We have no independent evidence on which to make a judgement between these two possibilities.

Experimental subjects: The mean values for 17-ketosteroids were significantly reduced by some of the experimental regimens (Table III. 236; Figures III. 83 and III. 84). The greatest decrease occurred among the subjects on starvation. Similar, but less marked decreases took place among those men subsisting on 1000 Cal/day. At 2000 Cal/day the reduction was less sharp, and, in the case of the 3000 Cal/day regimen, the trend was of the same order of magnitude as that shown by the FRA subjects. Among the subjects doing hard work (Figure III. 83), the minimum values were reached in EXP II in all cases except 2/20/78 2000 U, 15/52/33 2000 L, 15/52/33 3000 L, and 30/0/70 1000 L. The reverse was true for men doing light work (Figure III. 84). The majority of values were lowest in EXP I. Exceptions were ST 0, 2/20/78 1000 L, 2/20/78 2000 L, 15/52/33 3000 U, and 30/0/70 1000 L. As we have observed previously (Sargent et al., 1954, 1955), the 15/52/33 regimen, especially at 2000 and 3000 Cal/day provoked the least change in urinary 17-ketosteroid excretion.

Water intake had no consistent effect on the alterations of 17-ketosteroids. Work load did, however, seem to influence the values. During the

experimental period, men doing hard work tended to excrete a lesser amount of 17-ketosteroid than did men doing light work. The effect of work was especially evident among men on the 15/52/33 regimens. A similar observation was made in the 1954 winter test.

Recovery: In the majority of instances 17-ketosteroid excretion in recovery did not return to pre-period values. It is possible that failure to return to control levels is another manifestation of the non-specific reaction noted among the FRA subjects. Whether or not exposure to heat was responsible cannot be stated with certainty. The theoretical implications of the trend which is similar to that reported by Bass et al., (1955) are great and an effort should be made to confirm it and identify the mechanism. In the 1954 winter test, most of the subjects, in contrast, did return to control values during recovery. As in that test, we note that among the men whose outputs did return to pre-period levels, there were no significant rebounds.

Serum Sodium, Potassium, and Chloride. Pre-period data for serum sodium, potassium, and chloride are summarized in Table III. 237. The mean values for each of these electrolytes are entirely normal, and there is remarkably little variation from group to group. The measures of variance are small and likewise quite constant from group to group. Serum sodium and serum potassium reveal no significant changes from PRE I to PRE II. Serum potassium, on the other hand, falls in the case of each of the five groups. From the physiological point of view, the fall is small and unimportant functionally. From the statistical point of view, each of the differences are significant at least at the 2% level.

Serum sodium: The serum sodium of men doing hard work (Table III. 238) is generally remarkably constant from period to period and regimen to regimen. Careful examination of the data, however, reveals that in EXP I subjects on limited water tend to have higher serum sodium than do subjects on unlimited water. This tendency can be seen in the case of the following regimens: 0/100/0 1000 and 2000, 2/20/78 2000, 15/52/33 2000, and 30/0/70 1000 and 2000. In EXP II this effect of water restriction is markedly diminished.

In EXP I there was a large difference in the water intakes between Flight 1 and Flight 2. Because of anhidrosis late in this period, it was necessary to increase the water intake of Flight 2 substantially. This reduced the dehydration and, consequently, tended to lower the level of serum sodium.

Much the same remarks can be made about variations in serum sodium among the men doing light work (Table III. 238). The only significant variable is again water, but among the light working subjects the effect of dehydration is much less marked insofar as sodium was concerned. The differences between the U and L regimens is more evident in EXP II than in EXP I and is particularly notable in the case of men subsisting on diets high in osmotic activity, notably, 30/0/70 1000 and 2000.

The over-all impression that one gets from examination of Table III. 238 is a remarkable effort on the part of the organism to maintain a constant

serum sodium in the face of markedly deficient sodium intake and an augmented sodium loss via sweating. Certainly we have here striking evidence that serum sodium is a closely guarded constituent of the internal environment.

Serum potassium: Serum potassium was by no means as constant as serum sodium (Table III. 239). Among the men doing hard work, the reduction in serum potassium, which began in PRE II, continued in EXP I in 16 of the 20 regimens. Only 15/52/33 2000 U, 15/52/33 3000 U, 30/0/70 1000 U, and 30/0/70 2000 U failed to show this continued fall. The drop in serum potassium continued into EXP II in the case of five regimens: 0/100/0 1000 U and L, 0/100/0 2000 U, and 2/20/78 2000 U. In all the other regimens there was a rise in serum potassium toward pre-period values. The serum potassium for the recovery periods was normal. The only general phenomenon that could account for this wide-spread decrease in serum potassium was sweating. The experimental subjects lost considerably more potassium in sweat than did the FRA subjects (Sec. III. B). We notice that during the experimental periods the serum potassium of the FRA subjects did not decrease. It is possible then that excessive sweating brought about a depletion of bodily potassium stores.

When we inspect serum potassium values for subjects doing light work, we find that this tendency to develop hypokalemia is much less evident. The best examples of it are seen in the cases of men on 0/100/0 1000 U, 0/100/0 2000 L, 2/20/78 2000 L, and 30/0/70 2000 L. Again the effect continues into PRE II, but only in two of these regimens, 0/100/0 1000 U and 2/20/78 2000 L. In the case of a few other regimens we find that minimum values for potassium develop in EXP II: viz., ST 0, 0/100/0 2000 U, and 2/20/78 2000 U. Presumably this is a manifestation of the same phenomenon mentioned above. Subjects doing light work, in general, would not be expected to have perspired to the same extent as those doing hard work. Therefore, it is not unreasonable that we should find less striking evidence of a hypokalemia among the former.

Serum chloride: A number of the subjects developed low serum chloride values during the experimental periods (Table III. 240). None of the low values, however, were pathological, and none were associated with heat cramps. Among the men doing hard work, the lowest values were reached in EXP II, and the hypochloremias were generally limited to those men who were on low osmotic intakes. The low values for serum chloride completely disappeared in the recovery periods. An identical trend is observed in the case of men doing light work. Again, it is those regimens which were low in osmotically active material which were correlated with low values for serum chloride.

In neither the hard work groups nor the light work groups is there any striking evidence that dehydration alters the serum chloride. Furthermore, there is no evidence that work output in any way significantly modifies the concentration of chloride in the serum.

General Comments on Adrenocortical Function. Marotta (1957) made an extensive study of the urinary excretion of a number of adrenocortical steroids in addition to 17-ketosteroids as related to diet and salt intake. His general conclusions were first that caloric depletion alone has a depressing effect

upon the excretion of several of these substances, and second that ingestion of sodium chloride, but not protein ameliorates this depression. Therefore, no matter what hypothesis one may adopt about the mechanism of this phenomenon (whether decreased production, increased metabolism, decreased renal excretion or a combination of these), he concludes that there is a nutritional correlate with steroid excretion.

With respect to serum sodium as a correlate of adrenal function, the discovery of a large "skeletal reserve" of sodium would suggest that serum concentrations might be maintained even when the total body sodium is severely depleted. If one of the functions of the adrenal were to cause the skeleton to retain sodium, one could argue that nutritional depletion of sodium might lead to a total decrease of adrenal activity even though the serum sodium remained normal. Only in severe hypofunction of the adrenal would one expect then to find a diminution of serum sodium.

TABLE III. 235

PRE-PERIOD DATA ON URINARY 17-KETOSTEROID EXCRETION
(mg 2 hr)

	P I		P II	
Flight	Mean	Range	Mean	Range
1	1.48	0.82-2.54	1.38	0.85-1.87
2	1.21	0.82-1.94	1.15	0.62-1.98
3	1.62	0.74-2.89	1.34	0.80-2.33
4	1.58	1.04-3.68	1.31	0.86-2.50
FRA	1.61	0.94-2.59	1.58	0.92-3.65

TABLE III. 236

URINARY 17-KETOSTEROID EXCRETION
(mg/2 hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	2.10	1.46	0.76	0.59	1.00	1.31	1.45	1.14	0.68	0.51	0.74	1.07
	L	1.08	0.89	0.50	0.42	0.82	0.77	1.60	1.55	0.56	0.48	1.36	1.56
0/100/0	U	1.58	1.45	0.63	0.52	0.92	1.45	1.79	1.45	0.61	0.87	0.92	1.53
1000	L	1.14	1.12	0.72	0.65	0.82	1.11	1.52	1.24	0.59	0.60	1.19	1.08
0/100/0	U	1.13	1.18	0.64	0.58	0.90	0.88	1.44	1.40	0.69	0.90	1.12	1.22
2000	L	1.51	1.49	0.78	0.72	1.01	1.20	2.50	1.98	0.96	1.57	0.87	1.13
2/20/78	U	1.38	1.79	0.86	0.62	0.70	1.62	1.60	1.29	0.81	0.95	1.16	1.32
1000	L	1.14	1.46	0.58	0.52	0.85	1.10	1.48	1.17	0.69	0.64	0.76	1.17
2/20/78	U	1.08	1.21	0.84	0.84	0.67	----	2.03	1.55	0.92	1.12	0.97	1.38
2000	L	0.91	0.92	0.71	0.50	0.79	1.04	2.18	1.18	0.62	0.59	1.08	1.14
15/52/33	U	1.39	1.17	1.01	0.67	0.66	1.57	1.34	1.13	0.74	0.78	0.88	0.82
1000	L	1.43	1.18	0.95	----	----	----	1.22	1.12	0.68	0.78	0.96	1.22
15/52/33	U	0.99	1.08	1.10	0.95	1.47	0.83	2.12	1.54	1.40	1.44	1.06	1.56
2000	L	1.16	0.94	0.90	0.95	0.85	1.27	1.42	1.38	0.94	1.16	1.76	1.58
15/52/33	U	1.83	1.19	1.22	0.97	1.02	0.92	2.67	1.88	1.82	1.76	1.80	1.64
3000	L	1.30	1.26	0.86	0.96	0.86	1.15	1.16	1.03	----	----	----	----
30/0/70	U	1.53	1.48	0.92	0.84	1.05	0.98	0.95	0.80	0.49	0.77	0.65	0.80
1000	L	1.32	1.49	0.54	0.67	0.96	1.11	1.76	1.12	0.65	0.55	0.75	0.93
30/0/70	U	1.14	1.46	1.08	0.74	1.34	1.16	0.92	1.33	0.89	0.93	0.99	1.18
2000	L	1.40	1.06	0.96	0.91	0.92	1.12	1.28	1.04	0.63	0.67	0.95	0.90
FRA		1.61	1.58	1.34	1.11	1.39	1.30	1.61	1.58	1.34	1.11	1.39	1.30

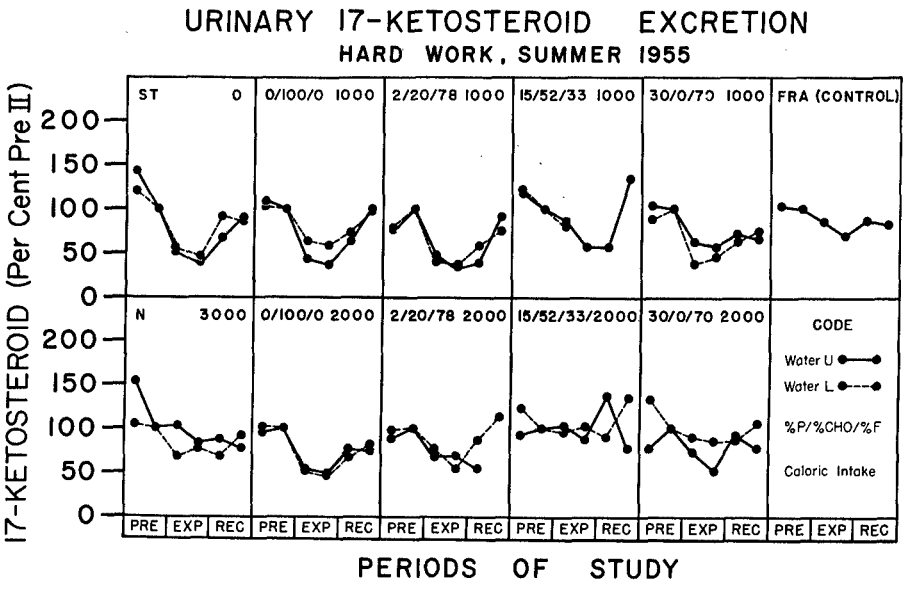


FIGURE III. 83. URINARY 17-KETOSTEROID EXCRETION: HARD WORK.

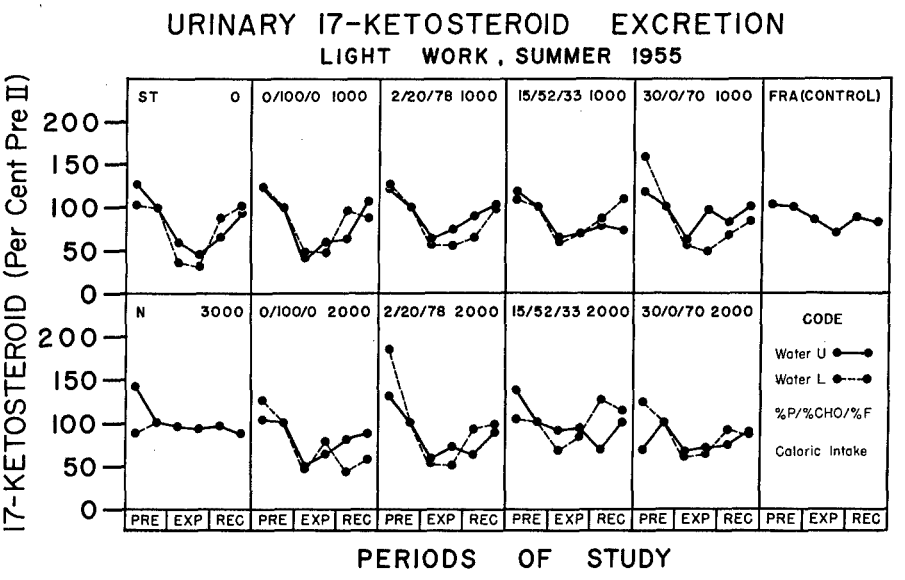


FIGURE III. 84. URINARY 17-KETOSTEROID EXCRETION: LIGHT WORK.

TABLE III. 237

PRE-PERIOD DATA ON SERUM SODIUM, POTASSIUM, AND CHLORIDE
(mEq/L)

Flight	P I N	P I M	P I s.d.	P I C.V.	P II N	P II M	P II s.d.	P II C.V.
				A. Serum Sodium				
1	22	136	4	2.9	21	136	9	6.6
2	21	134	4	3.0	21	134	2	1.5
3	21	135	3	2.2	21	135	4	3.0
4	21	136	4	2.9	22	134	1	0.7
FRA	12	134	2	1.5	11	132	2	1.5
				B. Serum Potassium				
1*	22	4.5	0.4	9.0	21	4.2	0.3	7.1
2*	21	4.8	0.6	12.5	21	4.4	0.4	9.1
3**	21	4.8	0.4	8.3	21	4.4	0.3	6.8
4**	21	4.8	0.4	8.3	22	4.0	0.1	2.5
FRA**	12	4.9	0.2	4.1	11	3.9	0.4	10.2
				C. Serum Chloride				
1	22	102	4	3.9	21	100	2	2.0
2	21	102	1	1.0	21	102	1	1.0
3	21	103	4	3.9	21	104	2	1.9
4	21	102	2	2.0	22	103	2	1.9
FRA	12	103	3	2.9	11	101	2	2.0

"t" test on P I vs. P II

*P less than 0.02

**P less than 0.001

TABLE III. 238

SERUM SODIUM
(mEq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	134	134	136	133	134	136	132	135	131	132	140	133
	L	134	136	132	133	134	134	136	132	131	134	138	136
0/100/0	U	135	134	134	130	132	140	133	137	135	132	140	138
1000	L	138	134	140	134	131	135	135	133	130	134	140	137
0/100/0	U	135	132	136	132	136	137	135	133	136	133	136	130
2000	L	132	133	137	136	131	135	135	135	131	132	140	137
2/20/78	U	135	140	138	132	133	143	138	135	131	143	134	133
1000	L	133	134	132	133	134	137	135	133	132	134	134	135
2/20/78	U	142	138	134	135	137	---	135	135	132	132	136	133
2000	L	132	134	140	135	131	130	134	134	133	135	140	137
15/52/33	U	134	140	137	133	132	136	135	135	134	132	136	134
1000	L	133	134	135	132	---	---	136	134	133	135	140	132
15/52/33	U	135	138	133	133	130	130	139	136	131	131	140	130
2000	L	138	133	140	132	132	140	140	136	136	135	140	134
15/52/33	U	140	133	134	136	131	137	135	135	133	131	138	132
3000	L	137	133	134	132	132	137	139	133	---	---	---	---
30/0/70	U	135	132	132	130	132	136	143	135	133	130	138	133
1000	L	133	136	136	133	132	140	133	133	133	135	138	137
30/0/70	U	135	137	132	132	134	135	133	135	131	132	136	139
2000	L	133	135	142	136	131	138	135	135	131	135	139	133
FRA		134	132	133	136	139	136	134	132	133	136	139	136

TABLE III. 239

SERUM POTASSIUM
(mEq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	4.6	4.4	4.2	4.5	4.5	4.7	4.5	4.5	4.9	4.4	4.5	4.7
	L	5.0	4.6	4.0	5.0	4.7	4.4	4.6	4.0	4.6	4.6	4.5	4.5
0/100/0	U	4.4	4.0	3.8	3.2	4.2	4.2	4.5	4.5	4.1	3.9	4.4	4.2
1000	L	4.6	4.6	4.0	3.7	4.6	4.0	4.8	4.1	4.1	4.7	4.8	4.8
0/100/0	U	4.3	4.4	4.0	3.8	4.4	4.7	5.3	4.4	4.4	3.9	4.6	4.8
2000	L	4.6	4.6	3.3	3.8	4.4	3.9	4.6	3.9	3.8	4.4	4.7	4.2
2/20/78	U	4.2	4.1	4.1	4.2	5.5	4.4	4.8	4.5	4.8	5.0	5.3	5.0
1000	L	4.8	4.6	3.9	4.4	5.0	4.1	5.2	4.0	4.6	4.8	4.7	4.0
2/20/78	U	4.4	4.1	4.0	3.8	4.7	---	4.6	4.2	4.6	4.1	4.3	4.3
2000	L	4.5	4.3	3.9	4.1	4.7	4.0	5.0	4.4	4.1	4.0	5.0	4.4
15/52/33	U	4.4	4.6	4.2	4.5	4.6	4.6	5.0	4.2	4.8	4.4	4.6	4.8
1000	L	5.4	4.3	4.0	4.5	---	---	5.1	3.9	4.1	4.1	4.4	4.2
15/52/33	U	4.3	4.0	4.1	4.0	4.4	4.9	4.8	4.4	4.8	4.2	4.7	4.7
2000	L	4.8	4.2	3.8	4.8	4.7	4.7	4.9	3.9	4.3	4.3	4.6	3.8
15/52/33	U	5.2	3.9	4.1	4.5	4.8	5.0	4.7	4.4	5.2	4.3	4.7	4.5
3000	L	4.9	4.4	3.9	4.5	4.6	4.2	4.6	3.8	---	---	---	---
30/0/70	U	4.1	4.0	4.2	4.1	4.4	4.6	5.0	4.5	5.0	5.0	5.0	4.2
1000	L	4.8	4.2	3.9	4.0	4.9	3.8	4.6	3.8	4.2	4.6	4.6	4.2
30/0/70	U	4.7	4.2	4.2	3.9	4.8	4.8	5.2	4.4	5.1	4.5	4.7	4.8
2000	L	4.8	4.2	3.8	4.2	4.3	4.2	4.8	4.0	3.8	4.2	4.2	4.0
FRA		4.9	3.9	4.9	4.0	4.5	4.4	4.9	3.9	4.9	4.0	4.5	4.4

TABLE III. 240

SERUM CHLORIDE
(mEq/L)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	102	100	97	95	98	102	101	105	96	92	104	102
	L	101	102	99	93	103	103	102	101	100	96	104	102
0/100/0	U	104	104	97	91	107	108	103	106	100	94	104	104
1000	L	98	102	101	97	104	96	102	104	100	95	101	98
0/100/0	U	102	99	97	95	100	102	107	104	101	97	104	102
2000	L	104	102	103	97	102	99	101	103	100	96	104	99
2/20/78	U	102	100	98	99	104	101	104	106	100	100	105	102
1000	L	103	104	100	98	101	102	105	104	106	98	104	101
2/20/78	U	102	101	103	105	100	---	104	105	104	101	102	102
2000	L	101	102	104	104	100	100	102	104	105	102	103	102
15/52/33	U	102	100	98	103	102	103	104	104	96	100	104	99
1000	L	98	102	104	96	---	---	102	102	97	99	103	100
15/52/33	U	100	100	102	99	102	100	102	104	102	101	105	100
2000	L	104	102	103	97	103	102	102	104	108	101	104	103
15/52/33	U	101	100	100	103	102	104	105	106	103	102	107	102
3000	L	101	102	104	102	102	104	102	104	---	---	---	---
30/0/70	U	104	102	95	98	104	103	104	104	101	97	105	103
1000	L	103	102	102	99	101	105	104	104	95	98	105	102
30/0/70	U	102	98	100	100	105	102	102	102	102	101	104	98
2000	L	103	102	104	102	103	102	102	103	102	101	104	100
FRA		103	101	102	104	102	102	103	101	102	104	102	102

2. Parathyroid Glands

Serum Calcium and Serum Inorganic Phosphate. Pre-period data on serum calcium and serum inorganic phosphate are summarized in Table III. 241. The mean values for these minerals for the five groups of subjects are similar one with another and represent normal data. In the case of calcium, the interindividual variability is small and remarkably uniform from group to group. The interindividual variability for serum inorganic phosphate is somewhat larger than that for calcium, but again we note a relative uniformity from group to group.

Serum calcium: During the several periods of the study the serum calcium exhibited variations which have not been heretofore observed by us (Table III. 242). For the hard work flights, we can detect appreciable increases in 11 averages in EXP I and II. Such changes were absent only in the case of the "0/100/0 2000" regimen. In a number of subjects the increase was maintained during both experimental weeks. Study of Table III. 242 indicates that among the subjects doing light work there were significant increases in 10 of the mean values in EXP I and 9 of the mean values in EXP II. Notable changes did not occur in the case of 15/52/33 3000, 30/0/70 1000, and FRA.

This elevation of serum calcium appears to be independent of nutrient mixture, water intake, and work output. It probably, however, is related in some way to the experimental conditions for subjects subsisting Field Ration A do not show the change. The cause of this variation is quite unknown to us at the present time. In the recovery periods the values of the serum calcium are quite comparable to those for the pre-periods.

Serum inorganic phosphate: Data on serum inorganic phosphate for the three phases of the summer test are presented in Table III. 243. Inspection of the mean values given in those tables indicates that there were no changes which could be consistently related to nutrient mixture, water intake, or work load. As a matter of fact, the most remarkable thing about these two tables is the constancy of the serum inorganic phosphate.

TABLE III. 241

PRE-PERIOD DATA ON SERUM CALCIUM AND INORGANIC PHOSPHATE
(mg/100ml)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
				A. Serum Calcium				
1	22	10.6	0.4	3.8	21	10.4	0.5	4.8
2	21	10.2	0.4	3.9	21	10.4	0.3	2.9
3	21	10.2	0.5	4.9	21	10.5	0.4	3.8
4	21	10.2	0.7	6.9	22	10.5	0.5	4.8
FRA	12	10.2	0.4	3.9	11	10.5	0.4	3.8
				B. Serum Inorganic Phosphate				
1	22	4.2	0.6	14.3	21	4.1	0.8	19.5
2	21	4.2	0.9	21.4	21	4.2	0.5	11.9
3	21	4.0	0.6	15.0	21	4.0	0.5	12.5
4	21	4.2	0.6	14.3	22	4.0	0.6	15.0
FRA	12	4.6	0.2	4.4	11	4.3	0.5	11.6

TABLE III. 242

SERUM CALCIUM
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	10.2	10.2	10.7	11.3	9.8	10.1	10.3	10.5	11.0	11.0	9.9	10.0
	L	10.3	10.1	10.7	11.2	9.9	10.5	10.2	10.4	10.8	10.3	10.4	10.5
0/100/0	U	10.4	10.7	10.6	10.7	10.7	10.5	10.0	10.8	11.5	10.8	10.3	10.8
1000	L	10.6	10.6	11.0	11.2	10.4	10.4	10.3	10.2	10.9	10.8	10.5	10.6
0/100/0	U	10.9	10.4	11.0	9.9	10.6	10.9	10.4	10.6	11.5	10.9	9.7	10.7
2000	L	10.0	10.8	10.6	11.0	10.1	10.1	10.8	10.2	11.1	10.5	11.0	10.6
2/20/78	U	10.3	10.6	11.4	10.9	10.9	10.5	10.0	10.5	10.3	10.2	10.6	10.1
1000	L	10.0	10.7	11.1	11.1	9.8	10.6	9.8	10.4	11.2	11.2	10.6	10.4
2/20/78	U	10.4	9.7	11.1	11.2	10.5	----	10.8	10.2	11.2	10.9	10.0	10.0
2000	L	10.4	10.6	10.7	10.1	10.2	10.8	9.9	10.4	10.6	11.2	10.4	10.4
15/52/33	U	11.0	10.6	11.3	11.2	10.2	10.9	10.0	10.2	10.2	11.0	10.8	10.1
1000	L	9.8	10.2	11.0	10.4	----	----	10.0	10.7	10.2	10.6	10.1	10.2
15/52/33	U	10.8	10.9	11.8	11.2	9.9	11.1	10.0	10.2	11.2	10.8	10.6	10.6
2000	L	10.4	10.6	10.6	11.4	10.1	11.4	10.3	11.5	11.2	10.6	10.2	10.0
15/52/33	U	10.5	10.6	11.0	11.2	11.2	10.7	10.2	10.4	10.0	10.6	10.0	10.2
3000	L	10.1	10.8	10.8	11.2	10.2	10.8	9.6	10.6	----	----	----	----
30/0/70	U	10.5	10.6	10.3	10.4	10.0	10.3	10.1	10.3	10.9	10.8	10.6	10.3
1000	L	10.0	10.0	11.2	11.3	10.1	11.2	11.0	10.4	10.8	10.8	10.4	10.2
30/0/70	U	10.8	10.2	10.2	10.4	10.4	10.3	10.4	10.6	11.1	11.4	10.4	10.0
2000	L	10.5	10.4	11.2	11.0	10.2	11.0	10.0	10.6	10.9	9.9	10.5	10.1
FRA		10.2	10.5	10.9	10.4	10.4	10.3	10.2	10.5	10.9	10.4	10.4	10.3

TABLE III. 243

SERUM INORGANIC PHOSPHATE
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	4.0	3.8	4.2	3.9	4.3	4.0	4.2	4.1	4.3	4.0	4.5	4.6
	L	4.2	3.9	4.2	3.9	4.2	4.2	4.1	3.8	3.6	3.6	4.0	4.5
0/100/0	U	4.1	3.8	4.0	4.6	3.5	3.7	4.0	4.0	4.4	4.0	4.4	4.6
1000	L	4.0	4.2	4.4	4.2	4.4	5.0	4.3	4.2	4.7	4.0	3.8	4.5
0/100/0	U	4.0	4.0	4.5	4.4	4.5	4.0	4.2	3.6	3.9	3.8	4.4	4.5
2000	L	4.2	4.6	4.6	3.8	3.8	4.3	4.1	3.8	3.2	3.7	3.8	4.2
2/20/78	U	4.4	4.1	4.3	4.6	4.4	4.5	3.8	4.0	3.7	3.6	4.5	4.4
1000	L	4.2	4.8	4.4	3.7	4.3	5.0	4.6	3.8	3.8	3.6	4.2	4.4
2/20/78	U	4.6	4.7	4.4	4.1	3.7	---	4.2	4.2	4.2	4.2	4.7	4.6
2000	L	4.7	4.0	4.6	4.2	4.5	4.6	4.4	4.5	4.3	3.3	4.5	4.8
15/52/33	U	4.2	4.4	4.8	4.6	4.1	4.2	3.9	4.3	4.0	4.2	4.6	4.6
1000	L	4.4	4.0	5.0	3.7	---	---	4.5	4.0	4.0	4.2	4.4	4.3
15/52/33	U	4.4	4.3	3.8	4.7	4.3	4.5	4.2	4.3	4.8	4.4	4.6	5.1
2000	L	4.0	4.0	4.7	4.5	4.3	4.3	4.7	4.3	4.4	3.8	4.2	4.5
15/52/33	U	4.6	4.2	4.6	4.6	4.6	4.6	3.8	3.9	4.2	4.0	4.0	4.6
3000	L	4.2	4.2	4.1	4.0	4.6	4.4	3.8	4.0	---	---	---	---
30/0/70	U	3.5	3.6	3.5	3.7	3.8	3.9	3.9	3.8	3.8	3.6	4.7	4.5
1000	L	3.9	3.8	4.3	3.5	3.8	5.5	3.8	3.8	3.6	3.5	4.0	4.4
30/0/70	U	4.2	4.2	3.9	4.0	4.1	3.8	3.7	3.8	4.0	4.0	4.1	4.2
2000	L	4.2	4.2	4.3	4.2	4.1	4.6	4.1	4.2	3.9	3.5	3.7	3.8
FRA		4.6	4.3	4.3	4.6	4.5	4.5	4.6	4.3	4.3	4.6	4.5	4.5

3. Thyroid Gland

Thyroid function was again evaluated as in previous studies by measuring resting oxygen consumption and urinary excretion of creatine under standardized conditions. The data on oxygen consumption will be dealt with in a subsequent section (Section G. 4).

Resting Creatinuria. Pre-period data for minute urinary creatine excretion (Table III. 244) agree closely in order of magnitude with values reported from the 1954 winter test. The variances are also comparable. Noteworthy is the general increase in creatinuria from P I to P II in groups on the 5-in-1 ration. The FRA's did not change.

Insofar as regimen was concerned, there is no evidence that diet or water intake had a significant differential effect on creatinuria (Table III. 245). Work load did, however, have a marked effect. In general, men doing hard work excreted greater amounts of creatine than paired-fed controls doing light work (Table III. 245). The effect of work load is evident in both experimental periods, but most marked in EXP II.

We also deal with a general trend. Creatinuria tends to fall from P II to EXP I and then rise to maximal levels in EXP II or REC I for hard work groups and REC II for light work groups. Such a trend is also evident among the FRA subjects.

The effect of work on creatinuria is also evident in the 1953 winter data. There, however, the most clear cut differences are limited to men on regimens providing substantial amounts of protein (15/52/33 2000 and 3000 and 30/0/70 1000 and 2000). Peters and Van Slyke (1946) point out that increased creatinuria may be associated with greater physical activity.

Exercise Creatinuria. Turning to the data on exercise creatinuria, we find that during the pre-periods (Table III. 246), creatinuria in P I was indeed larger among men who had been exercising than among the same men when resting. In P II, however, resting and exercise creatinuria are not significantly different. This inconsistency is difficult to explain.

The problem becomes even more complex when we study the changes in the exercise creatinuria during the five marches (Table III. 247). Inspection of the data as a whole clearly indicates that exercise creatinuria was maximal among both hard work and light work groups in EXP I. In the recovery period, creatinuria fell to low levels, in most cases to levels lower than P II. The FRA subjects fail to show a significant increase in EXP I and creatinuria varies little after the high value for P I. These trends tend to be the reverse of those noted for the resting state and suggest that insofar as creatine metabolism is concerned, environmental or situational factors operated differently on the resting subject than on the working subject.

Regimen had a marked effect on exercise creatinuria. High protein diets caused increased creatinuria; e.g., 30/0/70 1000 and 2000. The other diets

per se were associated with no consistent trends. The effect of the high protein diets may, however, merely represent a post-prandial excretion, for all of the subjects had eaten their noon meal prior to marching. The surprising thing is that such a post-prandial reaction is completely lacking in P II and REC I and II.

The clearest data on the effect of exercise per se are those observations on men whose diets were low in protein (ST 0, 0/100/0, and 2/20/78). In EXP I there tends to be a greater creatinuria during exercise than during rest. Regrouping the data and combining all flights, we find the following:

	Creatinuria, mg/min	
Regimen	Rest	Exercise
ST 0	0.20	0.25
0/100/0	0.09	0.23
2/20/78	0.09	0.23

TABLE III. 244

PRE-PERIOD DATA ON RESTING URINARY CREATINE EXCRETION
(mg/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.13	0.09	69	21	0.30	0.09	30
2	21	0.18	0.22	122	21	0.20	0.17	85
3	21	0.18	0.18	100	21	0.21	0.17	81
4	21	0.12	0.12	100	22	0.38	0.07	18
FRA	11	0.11	0.09	82	10	0.09	0.10	111

TABLE III. 245

RESTING URINARY CREATINE EXCRETION
(mg/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.03	0.32	0.19	0.39	0.24	0.17	0.18	0.09	0.24	0.05	0.44	0.41
	L	0.05	0.26	0.35	0.64	0.47	0.08	0.15	0.40	0.01	0.08	0.02	0.30
0/100/0	U	0.15	0.25	0.13	0.27	0.49	0.21	0.00	0.11	0.06	0.00	0.00	0.28
1000	L	0.10	0.27	0.00	0.27	0.40	0.04	0.18	0.39	0.18	0.08	0.04	0.22
0/100/0	U	0.15	0.33	0.14	0.32	0.44	0.06	0.01	0.00	0.10	0.10	0.10	0.27
2000	L	0.12	0.44	0.00	0.25	0.52	0.20	0.26	0.48	0.15	0.00	0.00	0.42
2/20/78	U	0.24	0.41	0.18	0.24	0.57	0.18	0.25	0.23	0.16	0.00	0.00	0.37
1000	L	0.07	0.20	0.00	0.35	0.44	0.12	0.06	0.36	0.00	0.08	0.02	0.22
2/20/78	U	0.20	0.38	0.17	0.38	0.35	----	0.22	0.20	0.27	0.10	0.06	0.36
2000	L	0.33	0.04	0.00	0.49	0.58	0.24	0.18	0.40	0.00	0.00	0.00	0.27
15/52/33	U	0.14	0.26	0.16	0.30	0.30	0.28	0.21	0.34	0.08	0.02	0.03	0.22
1000	L	0.73	0.10	0.00	0.45	----	----	0.00	0.28	0.00	0.03	0.00	0.36
15/52/33	U	0.06	0.25	0.10	0.45	0.42	0.20	0.42	0.44	0.13	0.06	0.00	0.29
2000	L	0.20	0.09	0.31	0.36	0.58	0.03	0.03	0.31	0.00	0.06	0.12	0.38
15/52/33	U	0.09	0.27	0.17	0.46	0.30	0.14	0.40	0.34	0.00	0.02	0.02	0.36
3000	L	0.0	0.04	0.00	0.12	0.35	0.06	0.18	0.42	----	----	----	----
30/0/70	U	0.18	0.25	0.30	0.53	0.42	0.13	0.07	0.10	0.16	0.11	0.06	0.33
1000	L	0.22	0.28	0.00	0.30	0.38	0.30	0.08	0.40	0.00	0.06	0.09	0.06
30/0/70	U	0.16	0.23	0.39	0.56	0.68	0.20	0.00	0.40	0.16	0.08	0.14	0.27
2000	L	0.07	0.24	0.07	0.66	0.49	0.14	0.08	0.30	0.00	0.19	0.05	0.24
FRA		0.11	0.09	0.00	0.05	0.30	0.29	0.11	0.09	0.00	0.05	0.30	0.29

TABLE III. 246

PRE-PERIOD DATA ON EXERCISE CREATINE EXCRETION
(mg/min)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.37	0.15	40.6	21	0.12	0.09	75.0
2	21	0.36	0.21	58.3	20	0.16	0.15	93.8
3	20	0.18	0.16	88.8	20	0.21	0.09	23.4
4	21	0.25	0.18	72.0	22	0.17	0.11	64.7
FRA	12	0.41	0.14	34.1	11	0.11	0.07	63.6

TABLE III. 247

EXERCISE CREATINE EXCRETION
(mg/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	0.44	0.13	0.16	0.18	0.52	0.24	0.29	0.20	0.01	0.18
	L	0.23	0.05	0.45	0.04	0.12	0.13	0.22	0.13	0.06	0.07
0/100/0	U	0.34	0.18	0.32	0.00	0.17	0.08	0.22	0.34	0.00	0.06
1000	L	0.36	0.13	0.22	0.00	0.17	0.16	0.12	0.16	0.13	0.11
0/100/0	U	0.38	0.10	0.00	0.00	0.10	0.09	0.16	0.29	0.00	0.16
2000	L	0.32	0.06	0.16	0.02	0.06	0.12	0.18	0.44	0.07	0.08
2/20/78	U	0.59	0.28	0.22	0.00	0.09	0.18	0.18	0.43	0.07	0.32
1000	L	0.38	0.06	0.20	0.10	0.00	0.16	0.20	0.14	0.00	0.14
2/20/78	U	0.36	0.08	0.30	----	----	0.14	0.18	0.33	0.04	0.14
2000	L	0.34	0.21	0.24	0.02	0.08	0.34	0.20	0.16	0.28	0.00
15/52/33	U	0.28	0.12	0.16	0.10	0.34	0.19	0.12	0.45	0.00	0.09
1000	L	0.60	0.28	0.47	----	----	0.24	0.24	0.38	0.42	0.23
15/52/33	U	0.24	0.10	0.18	----	----	0.26	0.26	0.26	0.00	0.04
2000	L	0.38	0.39	0.38	0.14	0.20	0.39	0.10	0.27	0.24	1.04
15/52/33	U	0.51	0.13	0.24	0.03	0.10	0.38	0.14	0.20	0.00	0.11
3000	L	0.21	0.36	0.60	0.01	0.12	0.52	0.12	----	----	----
30/0/70	U	0.22	0.08	1.18	0.07	0.11	0.12	0.23	0.82	0.07	0.18
1000	L	0.26	0.08	0.59	0.00	----	0.14	0.10	0.62	0.14	0.08
30/0/70	U	0.24	0.04	1.16	0.02	0.18	0.05	0.22	0.54	0.04	0.24
2000	L	0.64	0.12	0.58	0.00	0.03	0.14	0.24	0.07	0.10	0.13
FRA		0.41	0.11	0.14	0.14	0.12	0.41	0.11	0.14	0.14	0.12

4. Pancreas

Fasting whole sugar was the only measurement made which bore on the function of the pancreas. The pre-period data are presented in Table III. 248. The values are consistently lower than observed during the 1954 winter study and there is a strong trend toward lower values in P II than in P I. The question arises, are we dealing with a seasonal variation and an effect of hot weather on blood glucose? Some of the literature on seasonal variation in blood glucose has been reviewed by Sargent (1954). Although there is no unanimity on the matter, the weight of evidence points to higher sugar levels in the winter and lower levels in the summer. Our observations are thus supported by work of other investigators.

Regimen and Blood Glucose. The measurements on blood glucose are summarized in Table III. 249 and Figures III. 85 and III. 86. Inspection of those summaries indicates that a general trend, independent of regimen is present. Among the FRA subjects we note an elevation of glucose in EXP I and again the recovery periods. A comparable trend is evident in all the experimental subjects. This long-term trend may have been a reaction to the prolonged period of moist heat experienced by all subjects.

Regimen per se had much less effect on blood glucose than we have previously observed. Starvation and the high fat diets (2/20/78 and 30/0/70) in the temperate and cold weather studies, provoked a large fall in blood glucose. The data in Figures III. 85 and III. 86 indicate that the same tendency was present. The decline in sugar, however, was relatively very small. Variations in glucose among the other regimens are consistent with the general trend alluded to above. Water and work do not appear to be significant factors.

If we assume that the high fat regimens are capable of provoking hypoglycemia, we can argue that, in the light of our data, man exhibits a seasonal variation in susceptibility to hypoglycemia. He is more susceptible to hypoglycemia in the winter than in the summer. This question has not been directly investigated by other workers. Data from rats and rabbits (Sargent, 1954) suggest that there is reduced glucose tolerance and decreased utilization of glucose in the summer; hypoglycemia can be provoked more easily in summer than in winter. The diabetic requires less insulin in the summer than in the winter (Sargent, 1954). While our observations point to a conclusion opposite to that which can be induced from the literature, the basic fact remains that a summer-winter rhythm in carbohydrate metabolism does exist. It may be that different experimental conditions account for the variable manifestations. The observations are worthy of further detailed investigations.

TABLE III. 248

PRE-PERIOD DATA ON WHOLE BLOOD GLUCOSE
(mg/100 ml)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	60	7.3	12.3	21	56	6.2	11.0
2[1]	21	59	5.2	8.9	21	54	5.6	10.2
3[2]	21	62	6.2	9.8	21	56	5.1	9.3
4[3]	20	57	3.7	6.5	22	49	5.6	11.3
FRA[3]	12	65	7.6	11.6	11	54	5.3	9.8

P I vs. P II
1. $P < 0.02$
2. $P < 0.005$
3. $P < 0.001$

TABLE III. 249

WHOLE BLOOD GLUCOSE
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	55	54	52	60	66	76	65	57	54	49	79	82
	L	61	58	66	51	71	69	58	52	45	48	76	81
O/100/O	U	63	61	76	61	72	75	59	58	75	64	78	84
1000	L	58	54	76	66	76	68	61	56	70	66	81	84
O/100/O	U	52	50	65	60	68	68	64	58	75	65	75	80
2000	L	60	57	86	74	69	77	56	47	72	62	78	80
2/20/78	U	60	53	53	46	72	60	60	60	57	55	73	75
1000	L	64	55	72	54	74	76	54	48	49	50	75	81
2/20/78	U	62	54	58	55	70	—	64	56	66	58	74	78
2000	L	56	48	69	57	65	70	56	48	61	60	77	73
15/52/33	U	64	56	60	56	66	62	60	54	69	59	74	80
1000	L	58	54	72	57	--	--	56	48	62	57	77	76
15/52/33	U	64	56	76	66	62	66	67	54	72	68	74	86
2000	L	58	52	84	67	82	87	55	46	66	59	78	78
15/52/33	U	72	61	82	66	74	70	60	48	72	59	80	70
3000	L	54	50	91	64	68	72	56	46	--	--	--	--
30/0/70	U	58	62	54	46	71	66	58	55	81	52	73	84
1000	L	54	54	74	48	75	70	62	55	52	48	76	82
30/0/70	U	52	56	58	48	64	64	61	58	71	59	79	80
2000	L	60	60	83	56	76	74	56	44	57	55	77	81
FRA		65	54	79	67	74	75	65	54	79	67	74	75

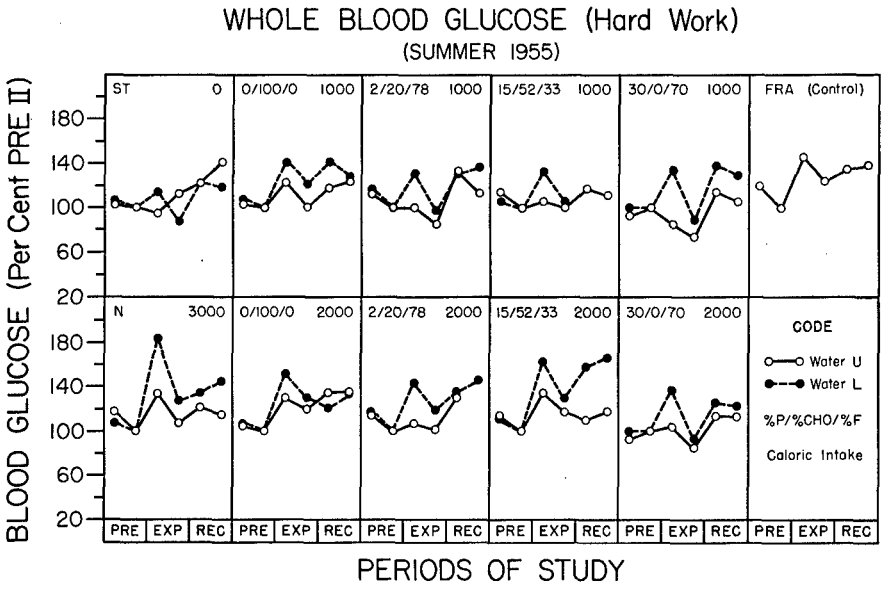


FIGURE III. 85. WHOLE BLOOD GLUCOSE: HARD WORK

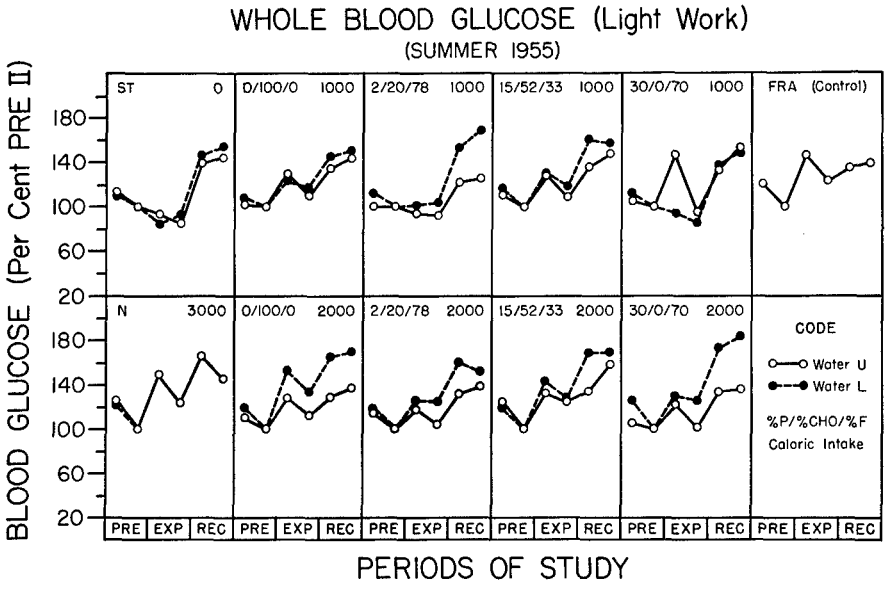


FIGURE III. 86. WHOLE BLOOD GLUCOSE: LIGHT WORK.

G. OTHER ORGAN AND SYSTEM FUNCTIONS

1. Liver Function

Serum Cholinesterase. Pre-period data on serum cholinesterase are summarized in Table III. 250. The mean value of this enzyme was close to 0.70 units. None of the several groups showed significant differences between the periods. It is of special interest to point out that the values for the summer trials average lower than those observed during the winter trials (WADC TR 53-484, Part 2). The only relevant report of which we are familiar is a study by Lackey and Slaughter (1942) who showed that the serum cholinesterase averaged higher in Texas than it did in Minnesota. These authors, together with Vorhaus and Kark (1953) have not observed, however, a seasonal variation. The available evidence thus indicates that in warm regions the serum cholinesterase may be higher than it is in cool regions. This reference, however, does not support our findings, and we cannot offer an explanation at this time.

During the experimental and recovery periods there were surprisingly very few significant trends in serum cholinesterase (Table III. 251) and Figures III. 87 and III. 88). In the winter tests, we observed a constant decrease in serum cholinesterase during EXP II and REC I. If it is granted that changes in serum cholinesterase reflect changes in liver function, we are led to the conclusion that the nutrient mixture would not significantly alter the liver function of heat-exposed subjects. Why this difference between hot and cold weather? At the present time we have no speculations to offer.

TABLE III. 250

PRE-PERIOD DATA ON SERUM CHOLINESTERASE
(ΔpH/hr.)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	0.72	0.16	22.3	22	0.63	0.10	15.9
2	22	0.74	0.19	25.7	21	0.69	0.18	26.1
3	22	0.63	0.15	23.8	22	0.70	0.08	11.5
4	22	0.79	0.13	16.5	22	0.69	0.14	20.3
FRA	12	0.65	0.07	10.8	11	0.65	0.06	9.2

TABLE III. 251

SERUM CHOLINESTERASE
(ΔpH/hr)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0.69	0.59	0.72	0.83	0.50	0.68	0.61	0.67	0.76	0.68	0.51	0.65
	L	0.75	0.79	0.82	0.71	0.61	0.66	0.86	0.70	0.80	0.59	0.64	0.60
0/100/0	U	0.90	0.87	0.86	0.66	0.57	0.74	0.58	0.64	0.69	0.62	0.52	0.64
1000	L	0.61	0.64	0.64	0.54	0.49	0.53	0.76	0.69	0.80	0.75	0.70	0.69
0/100/0	U	0.68	0.53	0.68	0.54	0.54	0.62	0.88	0.77	0.85	0.75	0.77	0.83
2000	L	0.73	0.67	0.72	0.66	0.59	0.62	0.61	0.50	0.62	0.46	----	----
2/20/78	U	0.73	0.70	0.78	0.66	0.56	0.60	0.71	0.70	0.77	0.66	0.66	0.71
1000	L	0.77	0.76	0.77	0.65	0.64	0.72	0.79	0.73	0.78	0.70	0.67	0.66
2/20/78	U	0.76	0.60	0.71	0.64	0.62	----	0.66	0.75	0.92	0.81	0.88	0.92
2000	L	0.75	0.58	0.67	0.54	0.58	0.61	0.68	0.63	0.69	0.55	0.58	0.65
15/52/33	U	0.71	0.55	0.83	0.71	0.69	0.71	0.71	0.75	0.73	0.78	0.69	0.67
1000	L	0.68	0.61	0.66	0.51	----	----	0.78	0.75	0.72	0.67	0.64	0.76
15/52/33	U	0.67	0.56	0.67	0.46	0.43	0.50	0.69	0.67	0.78	0.73	0.69	0.75
2000	L	0.67	0.61	0.72	0.68	0.58	0.70	0.75	0.73	0.74	0.65	0.71	0.75
15/52/33	U	0.77	0.65	0.77	0.69	0.77	0.79	0.70	0.75	0.81	0.78	0.74	0.81
3000	L	0.67	0.72	0.78	0.70	0.63	0.68	0.73	0.66	----	----	----	----
30/0/70	U	0.62	0.45	0.60	0.47	0.47	0.53	0.60	0.57	0.61	0.53	0.52	0.58
1000	L	0.74	0.69	0.81	0.71	0.66	0.64	0.89	0.74	0.89	0.78	0.70	0.74
30/0/70	U	0.82	0.79	0.85	0.78	0.72	0.78	0.71	0.76	0.89	0.77	0.70	0.74
2000	L	0.73	0.75	0.82	0.68	0.66	0.70	0.75	0.63	0.93	0.81	0.78	0.81
FRA		0.65	0.65	0.64	0.66	0.66	0.71	0.65	0.65	0.64	0.66	0.66	0.71

FIGURE III. 87. LIVER FUNCTION. SERUM CHOLINESTERASE: HARD WORK.

FIGURE III. 88. LIVER FUNCTION. SERUM CHOLINESTERASE: LIGHT WORK.

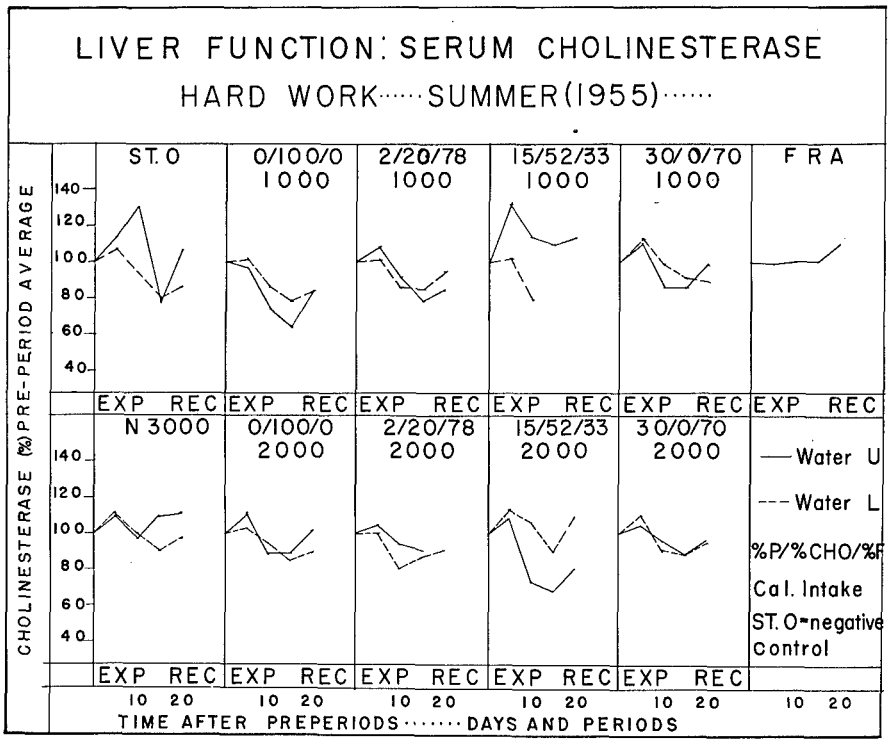


FIGURE III. 87

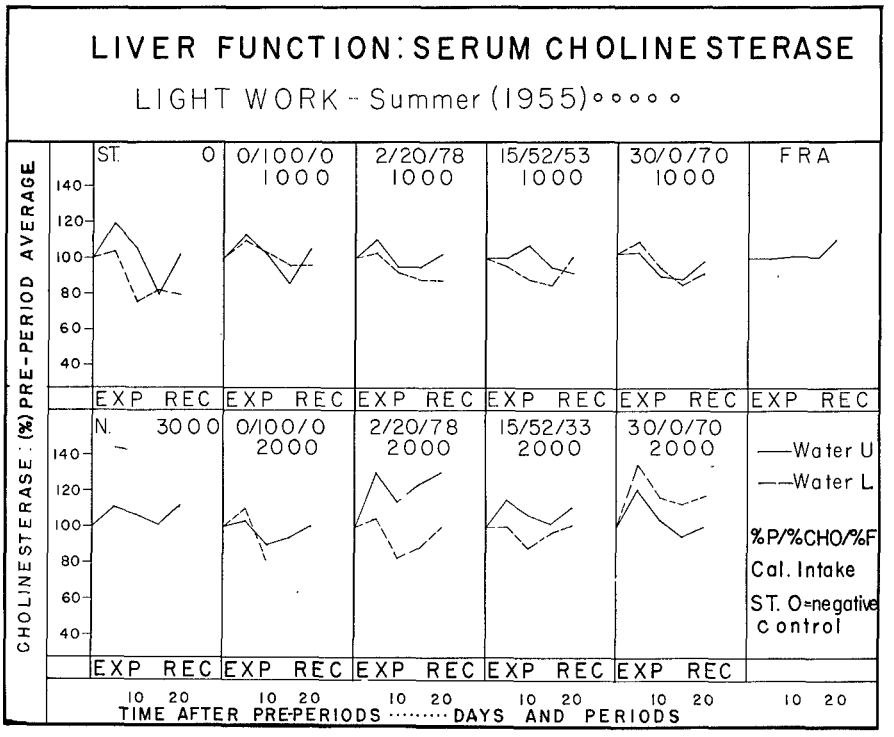


FIGURE III. 88

Serum Total Cholesterol. Serum collected during the summer of 1955 was analyzed for total cholesterol by a method similar to that used in the 1953 temperate study. This modification was made because the anthrone method used in analysis of serum collected in the winter of 1954 was quite unsatisfactory. Technically the older analytic procedure was very satisfactory, and consequently we have much more confidence in the data contained in the present report.

The pre-period data, together with measures of variance, are summarized in Table III. 252. In general, there were no significant differences within groups between periods; that is, none of the differences were significant at the 1% level. The means for the various groups are somewhat lower than those observed for the 1953 temperate study and the 1954 winter study. The measures of variance, however, are of the same order of magnitude. The values agree very well with the mean of 152 mg/100 ml and the range 105-109 reported by Albritton (1951, p. 92).

The dietary regimens which we were studying provoked some changes in the total serum cholesterol in the 100 young men studied in a 36-day period. The data are summarized in Table III. 253 and Figures III. 89 and III. 90. Because there was a certain amount of individual variability, the data in the figures have been expressed as per cent of the mean value for each subject in PRE II. In the case of the men who performed hard work during the experimental periods (Figure III. 89), we observed that starvation and 30/0/70 1000 and 2000 were associated with substantial increase in the level of total serum cholesterol. In the case of the men on 0/100/0 1000 and 2000, there were substantial decreases of the serum cholesterol. The subjects on 2/20/78 1000 and 2000 did not show consistent changes. The subjects on the three 15/52/33 mixtures showed surprisingly little variation in serum total cholesterol; they were remarkably similar to the FRA subjects. There was no consistent effect of water intake or of caloric intake. These results strongly suggest that a fat-free diet will cause a very rapid drop in serum cholesterol, and that a pemmican diet will cause an increase in cholesterol.

In the case of the men doing light work (Figure III. 90), we find some confirmation of these trends. The subjects on starvation and 30/0/70 1000 and 2000 again show a substantial increase in serum cholesterol. Among the light work subjects, however, we also find increases in the groups that subsisted on 2/20/78 1000 and 2000 and 15/52/33 1000 and 2000. The subjects on 15/52/33 3000 showed very little change. Men on 0/100/0 1000 likewise showed little change, while those subsisting on 2000 Calories of this same regimen exhibited a substantial decrease, especially in EXP II. In general, the largest increase occurred among the subjects on 30/0/70 and starvation; this fact strongly supports the results described for the hard work group.

These various trends confirm the observations which were reported from the 1953 temperate study. There it was shown that there was a statistically significant increase in serum cholesterol among the subjects subsisting on meat bar (30/0/70), and regimens containing meat bar as a component.

Comment: Keys et al., (1955) have reviewed some of literature on diet and serum cholesterol. There is general agreement that a high fat diet will cause an increase in serum cholesterol, a low fat diet a decrease. A similar observation has more recently been reported by Epstein et al., (1956). The cholesterol content of the diet is apparently not the significant factor (Keys et al., 1956). The source of the fat, however, does seem to be involved.

Diets rich in vegetable fat provoke a prompt and sustained decrease in serum cholesterol (Kinsell et al., 1952, 1953). Our results (Sargent et al., 1954 and present report) do not confirm this observation. The 2/20/78 regimen contains 78% fat, all of which is derived from oleomargarine (an hydrogenated vegetable oil). We have observed, among men on this regimen, either no change in serum total cholesterol or an increase. The only regimen which is consistently associated with a decrease in serum cholesterol is 0/100/0.

Mann (1955) recently reported that two subjects maintained for 15 days on a 2626-Calorie diet of 16% protein, 17% carbohydrate, and 57% fat did exhibit an increase in serum total cholesterol. The diet consisted of pemmican, oranges, soda crackers, and milk. The fat was chiefly derived from animal sources. The increases were not statistically significant when compared to control data obtained when the men were on their customary diets which contained 40% fat. When all the calories are derived from pemmican, as in our studies, the serum cholesterol regularly exhibits a prompt elevation. In some cases we have seen a rise when men subsist on 15/52/33, a major component of which is pemmican. We thus can conclude that a diet high in animal fat will increase serum cholesterol. The results further suggest that pemmican per se may contain a factor which elevates serum cholesterol even when the fat content of the diet is only 33%. From the work of Keys et al., (1956) it would appear that cholesterol itself is not the factor. In this connection, it is of interest to note that Kinsell et al., (1952, 1953) found that fat of dairy origin (egg yolk), when fed in large amounts, would not increase serum total cholesterol above levels characteristic of subjects fed customary mixed diets. When such fat replaced isocalorically vegetable fat, the low serum cholesterol values promptly return to control levels and were maintained there.

It has been suggested that the iodine number of the fat is controlling in this phenomenon. Saturated fat tends to raise the cholesterol, unsaturated fat tends to lower it. Because meat bar contains almost entirely saturated fat, we should expect it to raise the serum cholesterol.

TABLE III. 252

PRE-PERIOD DATA ON SERUM TOTAL CHOLESTEROL
(mg/100 ml)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	156	42	27.6	21	159	35	22.0
2	21	141	34	23.4	21	165	39	23.6
3	21	165	38	23.0	21	150	31	20.6
4	21	155	32	20.6	22	141	27	19.2
FRA	12	158	25	15.8	11	137	22	16.1

TABLE III. 253

SERUM TOTAL CHOLESTEROL
(mg/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	137	132	156	232	112	179	159	149	238	180	189	170
	L	176	197	224	220	160	221	154	163	267	260	176	216
O/100/O	U	162	173	132	138	110	183	188	204	204	192	210	178
1000	L	152	172	82	118	92	106	194	152	184	170	164	157
O/100/O	U	124	140	96	96	89	120	182	154	159	94	156	162
2000	L	127	154	124	129	108	114	176	150	110	118	193	235
2/20/78	U	158	168	190	165	145	225	157	154	218	168	159	212
1000	L	152	202	165	162	131	175	171	162	189	207	152	162
2/20/78	U	143	163	154	125	119	---	144	126	130	85	136	136
2000	L	140	148	123	106	137	155	165	121	204	195	156	123
15/52/33	U	152	178	176	142	138	212	170	156	192	186	168	118
1000	L	98	144	115	106	---	---	158	154	220	156	158	156
15/52/33	U	128	152	154	157	70	121	190	128	198	172	182	138
2000	L	122	132	156	139	112	100	134	110	204	124	110	104
15/52/33	U	176	161	164	132	130	156	141	155	196	134	162	118
3000	L	128	162	160	130	152	136	131	152	---	---	---	---
30/0/70	U	119	151	150	172	117	176	215	125	260	225	238	192
1000	L	140	151	202	242	110	113	136	120	241	198	156	131
30/0/70	U	230	215	244	270	155	245	135	138	181	179	164	164
2000	L	140	152	174	172	114	150	137	122	260	217	121	156
FRA		158	137	126	149	128	152	158	137	126	149	128	152

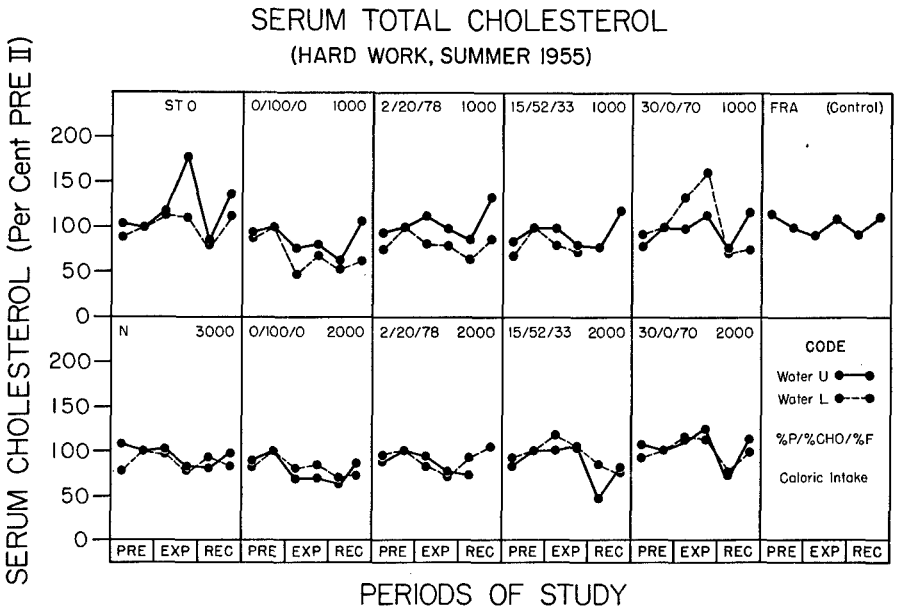


FIGURE III. 89. SERUM TOTAL CHOLESTEROL: HARD WORK.

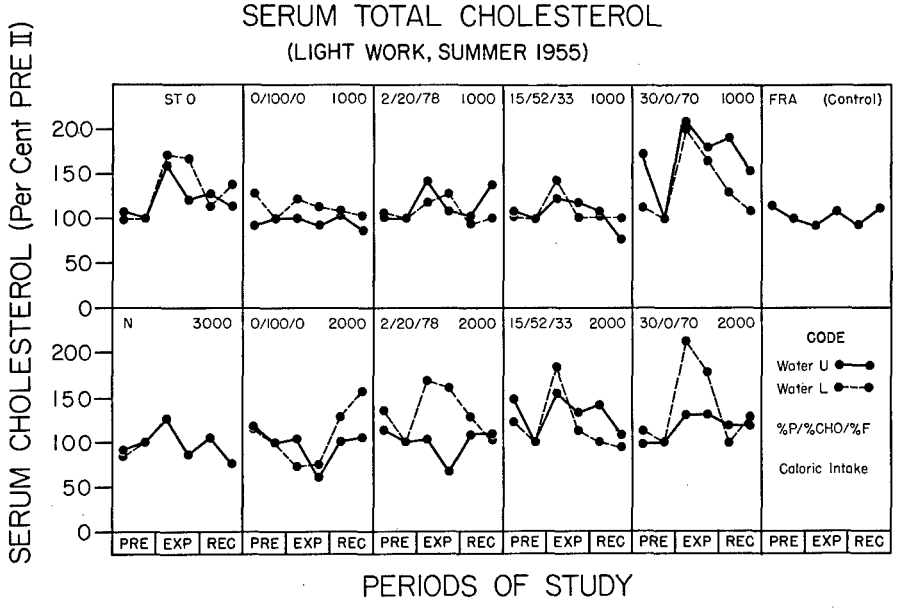


FIGURE III. 90. SERUM TOTAL CHOLESTEROL: LIGHT WORK.

2. Gastrointestinal Function

Fecal Wet Weight. The mean daily fecal excretion (wet weight) was calculated for each subject for each period, according to the equation: mean fecal excretion, gm/day, wet weight = (total excretion for period) (days in period). The data are summarized in Table III. 254, which presents means for all subjects on a particular regimen during a particular period.

The mode for the FRA subjects was 150 gm/day, with fluctuations from period to period amounting to ±20 gm. There was a tendency for the values of the experimental subjects to diminish from PRE I to PRE II, this diminution occurring in 31 of the 40 comparisons. Presumably the relatively low residue of the 5-in-1 ration explains this phenomenon.

With the onset of EXP I, there was an abrupt decrease in the production of feces by all subjects except those on the highest calorie intake, 15/52/33 3000. Even among these latter, EXP II was characterized by a small fecal production. Calories had a profound influence on fecal production. If we compare in EXP I the values for subjects on the same nutrient mixture, but at different calorie levels, increased calorie intake led to greater fecal production in 15 of the 20 comparisons, with no change in two and a decrease in three comparisons. In starvation, also, there was a small production of feces.

With the onset of rehabilitation in REC I, there was an abrupt increase of fecal production in all groups of subjects, and a further increase in REC II among 26 groups who had been on the 40 regimens, and a decrease in 11. REC II was greater than PRE I in 27 of the 36 comparisons that could be made. No doubt the explanation for this phenomenon lay in the greater calorie intake in REC II as compared with PRE I.

TABLE III. 254

FECAL WET WEIGHT
(gm/day)

Experimental Regimen		PRE I	PRE II	EXP I	EXP II	REC I	REC II	PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	86	59	15	0	161	173	135	100	35	33	144	191
	L	147	77	18	33	159	277	152	86	24	12	182	217
0/100/0	U	146	83	13	25	123	128	131	94	8	8	199	157
1000	L	145	87	33	33	147	199	126	69	15	15	167	213
0/100/0	U	160	125	45	73	209	203	175	79	41	41	125	193
2000	L	161	86	51	51	117	145	93	103	85	85	125	250
2/20/78	U	112	134	57	87	96	218	82	95	22	22	37	67
1000	L	103	94	43	43	103	139	151	69	47	47	119	154
2/20/78	U	135	103	43	29	146	---	102	116	77	81	113	121
2000	L	84	45	44	45	110	162	139	72	45	61	214	154
15/52/33	U	93	96	56	56	110	163	157	107	59	69	170	155
1000	L	109	102	76	--	---	---	173	72	59	83	223	199
15/52/33	U	97	104	75	66	200	99	117	105	27	43	187	195
2000	L	215	106	76	76	146	175	211	159	117	93	201	234
15/52/33	U	109	85	105	69	167	171	177	168	103	76	187	167
3000	L	162	106	124	71	198	192	134	156	171	--	---	---
30/0/70	U	133	100	37	53	135	213	94	105	34	42	123	118
1000	L	117	104	57	36	155	95	97	71	49	49	112	150
30/0/70	U	159	85	62	62	113	153	77	89	68	68	176	175
2000	L	147	127	57	73	145	191	127	123	55	47	186	310
FRA		127	149	125	150	153	165	127	149	125	150	153	165

Benzidine Dihydrochloride Reaction of Fecal Homogenates. Aliquots of the seven-day fecal pools were tested for the presence of occult blood or peroxidase-like compounds by means of the benzidine dihydrochloride reaction. The intensity of the reaction (depth of blue color) was graded from 0 to +4. The results of analyses conducted on 438 specimens are summarized in Table 1. During the pre- and recovery periods 65% and 68% of the stools collected from subjects subsisted on 5-in-1 ration yielded positive results. The majority of the reactions were trace or +1. There were no +4 reactions. During the experimental periods these same subjects passed fecal specimens of which only 10% were positive. All of the positive reactions were trace or +1. Two-thirds of these positive reactions occurred among men who were subsisted on the nutrient mixtures containing meat bar. There were no positive reactions among the stools from men who were starving. These reactions of the experimental period confirm the observations of 1953 and 1954.

An opportunity for comparing the 5-in-1 ration with the Field Ration A was possible since we had a number of subjects who subsisted on the latter ration throughout the period of study. Sixty-nine specimens were collected from men who were subsisted on Field Ration A. Only 31% of these specimens tested positive. The majority showed trace or +1 reactions. None of the stools tested +3 or +4. Inspection of the data in Table III. 255 suggests that the reactions were less intense for the men on Field Ration A than for men on 5-in-1. This difference is clearly brought out in Table III. 256. There we have calculated the percentage of the stools which showed the several degrees of intensity of the benzidine reaction. In the first place, we note that some 60% of the stools from men on Field Ration A were negative. Only half this number were negative in the case of men subsisted on 5-in-1 ration. In the second place, we note that the frequency of +1 reactions was between two and three times greater among the men on 5-in-1 ration, and roughly two times greater at the +2 level. At the +3 level no man showed a positive stool on the Field Ration A, whereas 0.6% and 3.5% of the stools were positive at this level in the case of men living on 5-in-1 ration. Previous studies (Sargent et al., 1953) have conclusively demonstrated that a positive reaction does not mean that the subject subsisting on 5-in-1 ration is bleeding from his gastrointestinal tract. A positive reaction indicates that some peroxidase-like compound is present in large amounts in the 5-in-1 ration components which contain beef. The data in Table III. 256 strongly support this previous finding. Whatever the substance is which causes these reactions, it was present in the 1951 procurement of 5-in-1 and is still present in the 1954 procurement.

The percentage of positive reactions in the pre- and recovery periods among specimens collected from men on the 5-in-1 ration was comparable to that observed in the 1953 and 1954 studies. The frequency of strongly positive reactions (+3 and +4) was much less than in previous studies. Two factors may have been responsible: (1) the somewhat greater dilution of the fecal pools in 1955 and (2) a reduction in the concentration in the substances causing the reaction in the 1954 procurement of the 5-in-1 ration.

Fecal Fibers. Microscopic analyses were conducted on 438 fecal homogenates. The number of meat fibers per high power field was counted and the

state of digestion of those meat fibers was appraised. Data on the number of meat fibers per high power field are summarized in Table III. 257. The only striking finding evident from a study of these data is that specimens collected from men subsisting on diets which did not contain the meat bar, rather consistently showed a marked decrease in the number of fibers in stools collected during the experimental period. Among the men who subsisted on nutrient mixtures containing the meat bar, this decrease was not evident.

Digestion of fecal muscle fibers: An appraisal was made of the degree of digestion of the muscle fibers in each of the 438 fecal homogenates. Several high-power fields were examined in making this appraisal. The conditions of the meat fibers were then assigned to one of four categories: (1) majority of fibers undigested, (2) approximately half the fibers undigested and half partially digested, (3) approximately half the fibers partially digested and half digested, and (4) majority of fibers digested. It will be noted that these categories divide the specimens according to an increasing degree of digestion of the meat fibers. The criteria used in evaluating the digestion of the meat fibers was the same as that of previous studies (Sargent et al., 1954). A fifth category was also used for classifying the specimens; some of them had no fibers.

The results of this analysis are summarized in Table III. 258. During the pre- and recovery periods, fecal specimens collected from men subsisted on the 5-in-1 ration contained meat fibers which were quite equally distributed between the categories "partially digested-digested" and "digested." A few of the specimens contained undigested fibers. In the experimental period the stools collected from the same subjects showed a large increase in the number of specimens containing "undigested," and "undigested-partially digested" fibers. This increase occurred almost entirely among the stools from men subsisted on nutrient mixtures containing meat bar.

As in the case of benzidine reaction, a comparative study was also made of the digestion of meat fibers in stools collected from men on Field Ration A and 5-in-1. Inspection of Table III. 258 indicates that the majority of specimens from the former group contained fibers which were classified as digested. The striking contrast between these two rations is more clearly brought out in Table III. 259. There we have indicated the percentage of the various fecal specimens falling into each of the five categories described above. Two facts are evident: (1) 81% of the specimens from men subsisting on Field Ration A contained "digested fibers," (2) about 50% of the specimens collected from men subsisted on 5-in-1 contained "partially digested-digested" fibers, and somewhat more than 2% contained "undigested-partially digested" fibers. This striking shift toward "undigested-partially digested" meat fibers in the fecal specimens from men eating the 5-in-1, strongly suggests that the animal-protein-containing foods of that ration are less digestable than similar foods in the Field Ration A. The 5-in-1 ration contains highly processed foods. Field Ration A contains fresh and frozen foods. Presumably then the difference in digestability, if we make the assumption that equally high quality foods are present in both rations, can be attributed to the processing and canning of the 5-in-1 ration.

In the case of meat bar, we have already discussed at some length in Section III. B3 the interesting mystery of the inability of this product to promote positive nitrogen balance even at very high nitrogen intakes. We have no real explanation for this phenomenon, but several factors may be involved. First, the stools from men subsisting on nutrient mixtures containing this item frequently contained incompletely digested meat fibers. This fact suggests incomplete digestion, even though the total fecal nitrogen was not excessive. Second, there is a possibility that essential amino acids are lacking in meat bar because of the processing. Available data (Table III. 18) do not support this hypothesis, except perhaps for lysine. Third, the biological value of meat bar appears to be of the order of 20%, as contrasted with the 65% for beef and 90% for egg albumin that have been reported by Allison as well as other workers. However, we are dealing with caloric deficits, and these will lower the "utilization index" of all proteins. We are left with the observed fact that meat bar has a deleterious effect on nitrogen balance and with several hypotheses that need experimental study.

TABLE III. 255

EFFECT OF 5-in-1, FIELD RATION A, AND EXPERIMENTAL RATION COMPONENTS ON FECAL BENZIDINE REACTION

Ration and Period	No. Stools Tested	Number of Stools Showing Given Intensity of Benzidine Reaction						% Positive
		0	tr	+1	+2	+3	+4	
Fasting	10	10	0	0	0	0	0	0
Jelly bar, spice drops, hard candy	11	10	1	0	0	0	0	9
Meat Bar	13	10	1	2	0	0	0	23
Crackers and oleomargarine	15	14	0	1	0	0	0	7
Meat bar, crackers, raisins, catsup, jelly	20	19	1	0	0	0	0	5
Total	60	54	3	3	0	0	0	10
5-in-1 (pre-periods)	155	54	59	31	10	1	0	65
5-in-1 (recovery)	144	46	49	37	7	5	0	68
Field Ration A								
1. Pre-periods	23	15	6	2	0	0	0	35
2. Experimental periods	11	5	3	2	1	0	0	55
3. Recovery periods	35	24	8	2	1	0	0	32
4. All periods	69	44	17	6	2	0	0	31

TABLE III. 256

FECAL BENZIDINE REACTION: COMPARISON OF 5-IN-1 RATION WITH FIELD RATION A

Ration and Period	No. Stools Tested	Per Cent Showing Given Intensity of Benzidine Reaction					
		0	tr	+1	+2	+3	+4
Pre-periods on 5-in-1	155	34.8	38.1	20.0	6.4	0.6	0.0
Recovery periods on 5-in-1	144	31.9	34.0	25.7	4.9	3.5	0.0
All periods on Field Ration A	69	63.8	24.6	8.7	2.9	0.0	0.0

TABLE III. 257

FECAL FIBERS (No./H.P.F.)

Experimental Regimen		Hard Work					Light Work				
		PRE		EXP	REC		PRE		EXP	REC	
		I	II	I	I	II	I	II	I	I	II
ST 0	U	3	2	0	4	3	8	7	4	6	3
	L	2	3	3	8	2	8	1	0	4	3
0/100/0	U	4	7	--	5	5	2	4	--	6	4
1000	L	4	4	4	7	6	3	2	1	3	1
0/100/0	U	5	10	3	5	4	4	8	2	5	4
2000	L	9	6	5	2	2	7	5	0	1	5
2/20/78	U	8	18	3	12	5	6	5	3	2	5
1000	L	3	5	2	8	4	5	1	3	4	2
2/20/78	U	4	4	0	--	--	3	3	0	2	2
2000	L	2	3	4	4	3	5	5	1	3	3
15/52/33	U	3	8	5	6	5	7	7	5	4	4
1000	L	2	3	1	--	--	5	4	5	3	2
15/52/33	U	4	7	5	7	5	2	7	2	4	2
2000	L	4	3	7	3	5	5	5	5	5	2
15/52/33	U	2	4	6	9	2	5	4	4	2	2
3000	L	7	4	9	4	3	5	5	--	--	--
30/0/70	U	6	--	3	7	4	4	5	3	1	2
1000	L	4	5	1	7	1	9	9	8	2	4
30/0/70	U	4	--	6	5	1	3	5	3	3	2
2000	L	5	9	9	7	4	4	2	3	5	5
FRA		3	4	3	3	2	3	4	3	3	2

TABLE III. 258

EFFECT OF 5-IN-1 RATION, FIELD RATION A, AND EXPERIMENTAL RATION COMPONENTS ON DIGESTION OF FECAL MUSCLE FIBERS

Ration and Period	No. of Specimens	Predominant Type of Fiber				
		Undigested	Undigested-Partially Digested	Partially Digested-Digested	Digested	Fibers Absent
Starvation	10	0	0	5	3	2
Spice drops, jelly bar, hard candy	11	0	0	5	4	2
Meat bar	13	1	3	8	1	0
Crackers and oleomargarine	15	1	0	3	9	2
Meat bar, crackers, catsup, raisins, jelly	20	1	7	9	2	1
Total	60	3	10	25	16	6
5-in-1 (pre-periods)	155	1	4	70	79	1
5-in-1 (recovery)	144	0	3	73	66	2
Field Ration A						
1. Pre-period	23	0	0	6	17	0
2. Experimental period	11	0	0	2	9	0
3. Recovery period	35	0	0	3	30	2
4. All periods	69	0	0	11	56	2

TABLE III. 259

FECAL MUSCLE FIBERS: COMPARISON OF EFFECT OF 5-IN-1 RATION AND FIELD RATION A ON DIGESTION

Ration and Period	No. of Specimens	Per Cent of Specimens Showing				
		Undigested Fibers	Undigested-Partially Digested Fibers	Partially Digested-Digested Fibers	Digested Fibers	No Fibers
Pre-periods on 5-in-1	155	0.6	2.6	45.2	51.0	0.6
Recovery periods on 5-in-1	144	0.0	2.1	50.7	45.8	1.4
All periods on Field Ration A	69	0.0	0.0	15.9	81.2	2.9

Fecal Fat. During the pre-periods, the subjects subsisting on 5-in-1 ration eliminated 2.0-5.0 gm/day of fecal fat (Table III. 260). These values are of the same order of magnitude as those recorded previously by Sargent et al., (1954, 1955). The subjects eating Field Ration A tended, on the average, to eliminate somewhat more fecal fat than did the subjects living on 5-in-1 ration. There was a tendency, which was hardly significant, however, for the fecal fat output to be smaller in PRE II than in PRE I. Undoubtedly this decrease reflects the diminution in the total consumption of food with the onset of hot weather.

During the several periods of the study there were a number of variations in the output of fecal fat. Among the subjects performing hard work (Table III. 261) there was a decrease in the output of fecal fat in the EXP I period for men subsisted on ST 0, 0/100/0, 2/20/78, and 15/52/33 1000. Subjects on 15/52/33 2000 and 3000 and 30/0/70 1000 and 2000 did not show a constant diminution of fecal fat. During the recovery periods, there was an increase in the output of fecal fat to levels which usually exceeded those observed in the pre-periods. In very few instances, however, did mean quantities reach such high levels as has been observed in previous studies. The smaller magnitude of the increase was most probably due to the fact that the men did not eat as voraciously during the summer recovery periods as they had during the winter recovery periods.

Among the subjects who performed light work, the reduction in fecal fat during EXP I involved many more of the nutrient regimens than was the case for men doing hard work. The only regimens which were not associated with a fall in fecal fat were 2/20/78 1000 L and 2/20/78 2000 U and L. In the recovery periods there was an increase in fecal fat which in many instances exceeded the values for the pre-periods.

The data in Table III. 261 confirm previous observations and indicate that the high fat content of some of the nutrient mixtures, for example, 2/20/78 and 30/0/70 had no ill effect on the digestibility of fat of these young men; furthermore, there was no indication that the functioning of the gastrointestinal tract was significantly impaired by the high fat diets.

Dietary protein and fecal fat: Magee and his associates (Magee, Kim, and Ivy, 1953; Magee, 1954) have reported that in the dog and rat iso-caloric substitution of carbohydrate by such purified proteins as casein, gelatin, and zein will significantly decrease the output of fecal fat. The mechanism of this phenomenon in the rat and dog has not been established (Magee, 1954). The data collected in 1953, 1954, and 1955 from our human subjects have been scrutinized in this respect (Table III. 262) and we find no evidence that isocaloric substitution of protein for carbohydrate significantly altered the daily output of fecal fat. During the first or second week of the experimental period, the fat content of the feces did not change appreciably when the composition of the diet was changed from 2/20/78 to 30/0/70. However, appreciably more fat was eliminated when the nutrient mixture contained 70 and 78% fat than when it contained 0% fat. A similar effect of dietary fat can be seen in the tabular data of Magee, Kim and Ivy (1953). These conflicting

results raise three questions: (1) Is the phenomenon characteristic only of rats and dogs? (2) Is the phenomenon provoked only by isocaloric substitution of purified proteins? (3) Is the interpretation given by Magee, Kim and Ivy (1953) correct?

TABLE III. 260

PRE-PERIOD DATA ON FECAL FAT
(gm/day)

	P I			
Flight	Mean	Range	Mean	Range
1	3.5	1.2-11.0	3.3	1.4- 6.3
2	3.8	1.5- 8.5	2.1	0.6- 4.2
3	5.1	1.6- 9.3	3.2	1.2- 7.9
4	4.6	1.4-12.3	2.7	0.8- 5.1
FRA	5.6	1.0-20.6	5.3	1.3-15.2

TABLE III. 261

FECAL FAT
(gm/day)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC I	Light Work REC II
ST 0	U	2.6	3.0	1.1	4.2	5.5	4.9	2.6	0.9	4.9	4.6
	L	5.2	2.4	0.4	4.2	5.6	7.6	3.0	1.4	4.5	6.1
0/100/0	U	2.6	2.6	0.6	3.5	4.7	4.8	3.0	0.4	5.0	4.1
1000	L	4.0	1.6	3.0	4.1	4.3	3.4	2.3	0.4	6.4	5.8
0/100/0	U	4.2	4.8	0.7	3.6	4.7	3.4	7.0	0.7	4.0	4.0
2000	L	2.5	1.8	0.6	3.5	1.7	8.1	2.7	0.6	2.2	6.2
2/20/78	U	6.1	4.1	3.8	3.4	4.9	5.0	1.8	1.5	1.0	2.6
1000	L	3.6	2.2	1.4	3.6	4.2	4.2	2.1	2.5	7.9	3.5
2/20/78	U	3.1	4.2	2.0	---	---	5.7	2.5	3.1	4.2	3.7
2000	L	2.5	0.8	2.2	3.6	3.8	2.8	1.2	1.4	4.5	2.3
15/52/33	U	2.1	4.4	1.6	5.0	4.6	6.2	2.2	1.3	3.9	2.8
1000	L	2.8	3.0	2.0	1.1	---	4.2	2.0	1.1	5.1	3.2
15/52/33	U	3.0	1.7	3.1	9.3	4.2	8.2	3.6	1.0	6.8	4.5
2000	L	3.8	2.6	5.7	3.5	4.1	4.6	4.0	1.7	4.1	3.4
15/52/33	U	4.2	2.1	2.6	6.0	3.6	6.4	4.7	2.6	3.9	3.9
3000	L	3.2	1.8	4.2	5.6	3.1	3.0	3.2	1.4	---	---
30/0/70	U	2.7	3.2	1.4	4.1	4.6	2.3	1.3	0.6	4.3	2.9
1000	L	4.0	2.1	2.0	3.8	2.7	4.0	3.2	1.8	3.3	6.8
30/0/70	U	6.0	3.6	1.8	4.4	6.8	2.8	3.4	3.1	4.1	2.7
2000	L	3.9	1.9	2.7	2.6	3.2	2.1	2.6	1.9	2.7	8.1
FRA		5.6	5.3	3.8	6.0	5.2	5.6	5.3	3.8	6.0	5.2

TABLE III. 262

PROTEIN CONTENT OF DIET VS. FECAL WEIGHT AND FECAL FAT IN EXPERIMENTAL PERIOD

Experimental Regimen	1953* Fecal Weight (gm/day)	1953* Fecal Fat (gm/day)	1954* Fecal Weight (gm/day)	1954* Fecal Fat (gm/day)	1955** Fecal Weight (gm/day)	1955** Fecal Fat (gm/day)
0/100/0 1000	50	1.4	46	0.9	17	1.1
2/20/78 1000	36	2.9	32	1.8	57	2.3
30/0/70 1000	72	3.4	62	1.8	46	1.6
0/100/0 2000	59	1.4	43	1.0	50	0.6
2/20/78 2000	41	3.1	50	2.1	52	2.2
30/0/70 2000	54	3.2	52	2.0	61	2.4

*EXP II
**EXP I

Serum Amylase. Pre-period data for serum amylase (Table III. 263) show two significant phenomena which we have noted in previous reports: (1) a large variation in the mean level of serum amylase from group to group and (2) a large variation from individual to individual. In order to establish a value with which to interpret the changes which occur from period to period, we calculated the mean serum anylase for the 199 measurements made in PRE I and PRE II. The mean value is 72 amylase units per 100 ml; the standard deviation, 29. Accordingly, serum values of the order of 159 are three standard deviations from the mean control value.

Marked variations in serum amylase were observed during the course of the summer test. In the case of the men doing hard work (Table III. 264) there was a regular increase in experimental periods among the subjects of Flight 2, all the subjects but the FRA's being on limited water. The increase was of the same order of magnitude among the FRA's as in the case of the other subjects. In contrast, all of the subjects in Flight 1 showed a marked decrease in serum amylase during the experimental periods; in fact, there was a tendency for the variations in Flight 1 to mirror inversely the variations in Flight 2 (Figure III. 91). Because the controls (FRA) showed the same type of variation as the experimental subjects, we are inclined to attribute the variation to a nonspecific factor or to a methodologic difference. Some of the mean values during the experimental periods rose to levels of the order of magnitude of 150 to 160 and thus probably represent significant changes. We are not prepared to speculate as to what this nonspecific factor may have been.

A variation was observed among the men in Flight 4 which was identical to that seen for Flight 2 (Figure III. 92). Practically all the subjects, including the FRA's, exhibited a marked increase during the experimental periods and in some cases the values were of the order of 150. Subjects on unlimited water (Flight 3), however, did not exhibit changes which resembled those of Flight 1. The period to period variations were for the most part small and rather

erratic so that it is difficult to make any generalizations. We are of the opinion that the increase of the serum amylase in the experimental periods is highly significant. We hope that some light will be cast on this mystery by further investigation.

TABLE III. 263

PRE-PERIOD DATA ON SERUM AMYLASE
(Amylase Units/100 ml)

	I				II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	59	17	28.8	21	86	23	26.8
2	21	57	14	24.6	21	90	24	26.7
3	21	55	27	49.1	21	61	13	21.3
4	21	85	33	38.8	22	70	35	50.0
FRA	12	70	24	34.3	11	84	40	47.6

TABLE III. 264

SERUM AMYLASE
(Amylase Units/100 ml)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	44	80	57	43	41	74	53	56	63	70	70	60
	L	69	98	104	62	90	111	93	77	166	124	90	70
0/100/0	U	53	91	56	44	106	98	35	41	46	50	54	66
1000	L	76	120	160	57	72	95	55	57	89	65	70	58
0/100/0	U	50	96	46	68	77	72	69	49	73	74	72	125
2000	L	62	104	73	73	78	76	67	53	126	68	50	65
2/20/78	U	56	94	47	75	100	100	35	67	76	68	78	85
1000	L	50	82	144	75	76	39	80	55	87	64	63	79
2/20/78	U	87	103	50	75	90	---	58	76	69	89	85	74
2000	L	60	86	143	74	84	73	101	65	120	76	93	105
15/52/33	U	75	100	81	50	83	67	39	66	61	59	55	54
1000	L	58	109	135	145	---	---	107	62	102	56	85	62
15/52/33	U	77	74	38	79	63	77	52	61	59	57	52	67
2000	L	58	84	183	43	50	49	72	53	75	69	58	50
15/52/33	U	54	57	50	57	52	53	120	60	74	71	53	60
3000	L	33	38	65	68	58	37	134	145	---	---	---	---
30/0/70	U	52	86	40	70	81	67	46	70	64	43	70	51
1000	L	54	105	144	85	70	65	78	61	85	72	74	56
30/0/70	U	55	85	51	72	76	77	44	74	74	80	60	88
2000	L	40	66	76	68	59	62	56	68	100	71	45	74
FRA	U	71	115	54	59	73	79	102	69	75	83	46	62
	L	68	98	124	124	76	61	89	59	116	71	56	43

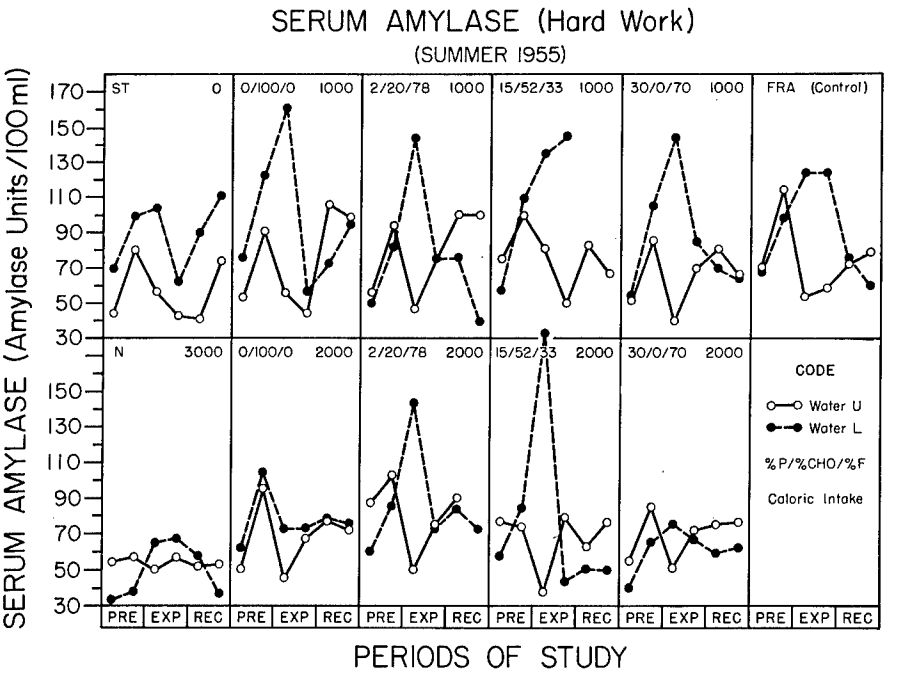


FIGURE III. 91. SERUM AMYLASE: HARD WORK.

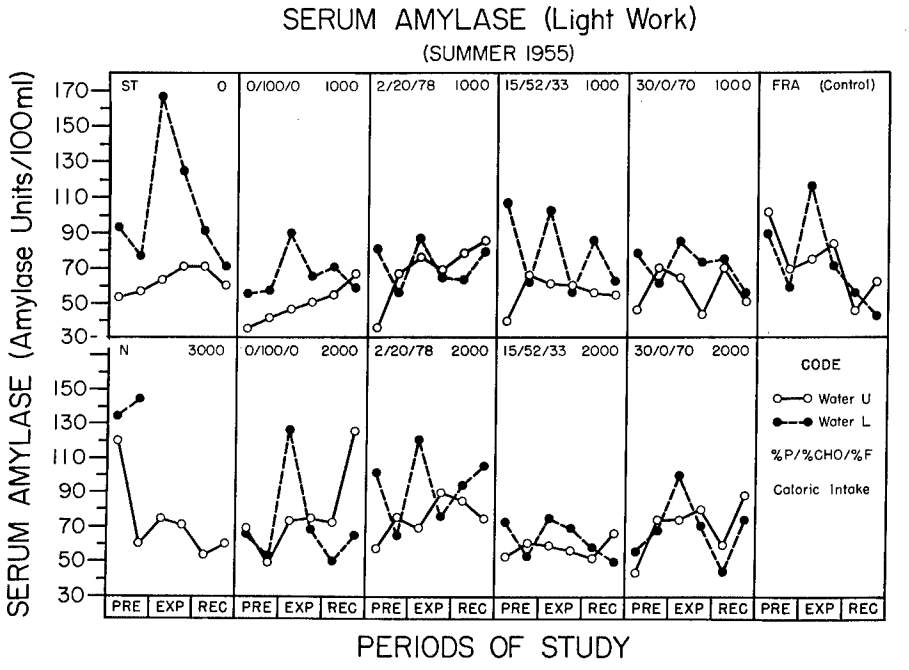


FIGURE III. 92. SERUM AMYLASE: LIGHT WORK.

3. Resting Oral Temperature

Oral temperatures were measured with standard clinical thermometers. The thermometers had been chilled in an ice-box prior to use. This procedure was adopted to obviate technical difficulties that would arise if the ambient temperature at the time of the three-hour test ever exceeded body temperature. The subjects rested in a reclining position 20-30 minutes before receiving thermometers. The thermometers were left in place for 5 minutes before a reading was made.

During the pre-periods the resting oral temperature averaged approximately 98°F (Table III. 265). Three groups showed a significant change in temperature when P I and P II were compared: Flight 1, a fall of 0.4°F; Flight 2, a rise of 0.7°F; Flight 4, a rise of 0.6°F. We do not attach any clinical significance to these variations principally because they are not all in the same direction. Of the two groups failing to exhibit statistically significant changes, Flight 3 showed a fall of 0.3°F and the FRA's a rise of 0.1°F. Furthermore, equally large differences were observed between groups.

During the experimental and recovery periods there was only one significant variation. In EXP II there was a uniform increase in the oral temperatures of the men in Flights 1 and 2 (Table III 266). A similar rise was not evident among the men of Flights 3 and 4. This rise was caused by the change in time of conducting the three-hour test. The men in Flights 1 and 2 were tested in the evening in EXP II instead of in the morning. It is well-known that evening temperatures average higher than morning temperatures (Kleitman, 1949). When the FRA data were separated into two groups (those tested in evening with Flights 1 and 2; and those tested in morning with Flights 3 and 4) it was found that the oral temperature of the former group averaged 98.6°F while the temperature of the latter averaged 97.4°F. Obviously then we are dealing with the diurnal cycle rather than some effect of the experimental regimen.

TABLE III. 265

PRE-PERIOD DATA ON RESTING ORAL TEMPERATURE
(°F)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1*	22	97.8	1.3	1.3	21	97.4	0.5	0.5
2**	21	97.3	1.0	1.0	21	98.0	1.2	1.2
3	21	98.1	1.0	1.0	21	97.8	0.9	0.9
4*	22	97.8	0.4	0.4	22	98.4	0.5	0.5
FRA	12	97.6	0.3	0.3	11	97.7	0.5	0.5

"t" test on P I vs. P II

*P less than 1%

**P less than 2%

TABLE III. 266

RESTING ORAL TEMPERATURE
(°F)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	98.2	97.5	97.8	97.7	97.7	97.5	98.5	97.9	97.5	97.9	97.9	97.5
	L	97.4	98.3	97.8	98.6	97.6	98.0	97.9	98.6	97.4	97.5	97.9	97.9
0/100/0	U	98.0	97.8	97.8	99.0	97.6	97.8	98.3	97.5	97.5	98.0	97.8	97.7
1000	L	97.4	98.1	97.8	98.8	97.9	97.9	98.0	98.4	97.3	97.7	97.7	97.4
0/100/0	U	97.7	97.2	97.1	98.9	97.3	97.2	97.2	97.7	97.6	97.9	97.8	97.4
2000	L	97.3	97.8	97.9	98.7	98.1	97.5	98.3	98.8	98.0	98.0	98.0	97.8
2/20/78	U	97.5	97.2	97.1	98.4	97.4	97.0	98.6	98.7	98.0	98.0	97.6	97.4
1000	L	96.5	98.0	97.5	98.7	97.9	98.0	97.5	98.4	96.6	97.1	97.2	97.5
2/20/78	U	97.2	97.2	97.4	99.4	100.2	----	98.0	97.6	97.5	97.6	97.2	97.2
2000	L	97.9	98.1	98.1	98.7	98.1	98.3	97.7	98.0	97.4	97.0	97.2	97.4
15/52/33	U	97.6	97.6	97.4	98.4	97.7	97.8	97.9	97.6	97.3	97.7	97.1	96.9
1000	L	97.0	98.0	----	----	----	----	98.0	98.4	97.9	97.8	97.9	97.9
15/52/33	U	97.7	97.4	97.3	99.0	97.8	99.2	98.5	97.6	97.3	98.3	97.4	96.8
2000	L	97.2	98.2	98.0	98.8	98.4	98.4	97.9	98.8	97.8	97.9	97.9	97.8
15/52/33	U	98.0	97.6	97.8	99.0	97.7	97.7	97.6	97.6	97.5	97.6	97.6	96.6
3000	L	98.0	97.6	97.4	99.4	97.7	97.6	97.6	98.2	----	----	----	----
30/0/70	U	97.7	97.5	97.2	98.9	97.7	97.6	98.0	97.6	97.4	98.0	97.6	97.2
1000	L	97.0	97.9	98.2	98.4	97.6	97.6	98.0	98.3	97.7	97.3	98.2	98.0
30/0/70	U	97.6	97.5	97.2	99.1	97.9	97.6	97.9	97.6	97.5	98.2	97.4	97.6
2000	L	97.2	98.4	97.3	98.7	98.2	98.1	97.4	98.4	97.6	97.0	98.4	97.6
FRA		97.6	97.7	97.6	98.0*	97.7	97.7	97.6	97.7	97.6	98.0*	97.7	97.7

*Men tested in P.M. 14 July: 98.6
Men tested in A.M. 15 July: 97.4

4. Respiratory Function

(This section was written by Corwin Mokler)

Respiratory function was studied under three separate conditions. During the three-hour test, respiratory rate at rest was counted by observation of movements of the chest. At the time of the specific respiratory studies, the voluntary ventilation capacity was measured. Finally, measurements were made with the "gas-meter machine" of respiratory rate, pulmonary ventilation, tidal volume, oxygen consumption, carbon dioxide production, and respiratory quotient. In the sections to follow, we shall discuss in order the results of these separate kinds of measurements of respiratory function.

a. Respiratory Rate at Rest (Three-Hour Test)

The resting respiratory rate was counted for one minute in the second hour of the three-hour test. During the pre-periods this function was remarkably constant from group to group and from period to period (Table III. 267). The standard deviation was of the order of ±3 breaths/min.

In the experimental and recovery periods the respiratory rate seldom deviated from the pre-period value by more than two standard deviations (±6 breaths/min). Certainly no very significant trends were evident (Table III. 268). However, ketotic subjects (30/0/70 2000, especially) did increase the rate in EXP II, and the pure carbohydrate diet at 2000 Calories tended to diminish the rate.

TABLE III. 267

PRE-PERIOD DATA ON RESTING RESPIRATORY RATE DURING THREE-HOUR TEST
(breaths/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	16	3	18.7	21	16	2	12.5
2	21	16	2	12.5	21	16	4	25.0
3	20	16	2	12.5	19	17	2	11.8
4	21	16	2	12.5	22	17	3	17.6
FRA	12	16	2	12.5	11	18	3	16.7

TABLE III. 268

RESTING RESPIRATORY RATE DURING THREE-HOUR TEST
(Breaths/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	18	17	17	14	18	20	16	15	22	16	14	15
	L	17	16	18	19	19	16	17	17	16	20	17	16
0/100/0	U	16	14	15	18	15	19	14	17	17	18	17	20
1000	L	12	18	16	15	16	16	14	18	12	14	13	16
0/100/0	U	16	14	18	16	13	18	14	16	17	14	20	16
2000	L	14	12	17	16	19	15	14	12	12	10	13	12
2/20/78	U	18	16	17	22	20	19	16	17	15	20	22	18
1000	L	14	16	14	18	12	14	17	20	16	18	16	18
2/20/78	U	15	14	14	19	14	--	16	18	15	17	20	20
2000	L	17	16	15	16	15	14	15	14	20	16	18	18
15/52/33	U	16	17	22	20	23	16	16	16	14	18	16	19
1000	L	16	18	18	--	--	--	17	17	25	18	16	16
15/52/33	U	14	16	16	17	18	13	16	18	13	16	18	18
2000	L	15	18	20	18	15	16	18	20	20	20	20	18
15/52/33	U	18	20	14	16	19	14	16	18	16	16	16	20
3000	L	17	16	15	25	20	16	14	16	--	--	--	--
30/0/70	U	17	18	20	24	17	20	17	17	19	20	15	17
1000	L	16	15	16	20	16	16	15	14	16	16	18	20
30/0/70	U	16	16	18	26	18	20	18	18	20	20	19	17
2000	L	16	16	18	23	18	16	17	20	21	26	26	18
FRA		16	18	19	17	17	17	16	18	19	17	17	17

b. Voluntary Ventilation Capacity

Recent investigators have made wide use of this test as a measure of pulmonary function. It was first proposed by Hermannsen (1933) and has been revised and refined by subsequent workers. Baldwin et al. (1948) and Gray et al. (1950) have established standard protocols for the test and determined normal values (Tables III. 269 and III. 270). By comparison, the values we obtained are slightly lower, but as Comroe (1950) has indicated, variations due to methodology are not uncommon and each investigator should determine his own normal values.

Each subject served as his own control, and PRE II values were usually considered normal for comparison with experimental and recovery values. The volumes obtained in PRE I and PRE II are summarized and analyzed statistically in Table III. 271. The existence of a learning factor is indicated, for in each flight the PRE II mean is at least 12% higher than the mean of the first trials in PRE I. Gray (1950) found a similar 12% mean improvement between a first and second trial. Only 23 of our subjects gave a better performance in PRE I than in PRE II and the PRE I volume is used as control for subjects 32, 45, 58, 82, 83, and 98 because it is significantly higher than the PRE II volumes of these subjects. The coefficients of variation obtained from our pre-period data (Table III. 271) and those shown by Gray (Table III. 269) are of the same order of magnitude and show remarkably little variation between the individuals tested.

Unfortunately, the metabolism runs had to be discontinued in the middle of the first day of EXP II testing period. Therefore, data are incomplete in EXP II in many cases. Also, some regimens lack data in this and other periods due to the widespread illness discussed elsewhere in this report. However, the data obtained exhibit some interesting features. It must be emphasized that each subject is his own control so that the best comparison to be made is between experimental and recovery periods, and the pre-period in each case.

The data show (Tables III. 272 and 273; Figures III. 93 and III. 94) that FRA controls behave much as would be expected from normal subjects according to the observations of Gray (1950). There is an initial rise between the first and second trials followed by only minor fluctuations in performance during the remainder of summer investigation. This initial "learning" period is observed in most experimental subjects, but their behavior varies considerably thereafter with no logical pattern apparent. Several trends with respect to water intake in the experimental period are noted. First, all but one of the groups showing a marked drop in the experimental period were on limited water. Secondly, the ventilation capacities of those subjects on limited water showed a marked tendency to remain lower than their better hydrated counterparts. It will be noted that some of these subjects were still in negative water balance during REC I (Section B2). Furthermore, those subjects having higher osmotic intakes (30/0/70 1000 and 2000 L and 15/52/33 1000 and 2000 L) tend to show a more marked decrease in ventilation capacity during the experimental period.

The caloric level of the diets may play a significant role here, especially in the limited water groups. Subjects receiving 1000 Calories in the 0/100/0 and 2/20/78 diets show a greater decrease in the experimental period than their 2000-Cal counterparts. This difference disappears in the 30/0/70 and 15/52/33 diets and is not apparent in the limited water groups.

Twenty-one of the 40 experimental groups showed a more or less marked increase in the recovery period over their experimental performance. This is evidently not correlated with previous diet or hydration. Of the 37 groups giving data, 28 exhibit this trend. Of the nine groups whose capacity continued to decrease, little can be said except that osmotic problems may account for this. Five of these nine groups were previously on limited water, and the subjects on the 30/0/70 diet, with high osmotic intake, constitute three of the nine groups. Comparisons with control values also show the dehydration effect. In the limited water groups, only six managed to exceed their control values in recovery by at least 10%---the FRA figure; thirteen of the unlimited water groups exceeded this level.

The work level seems at first glance to have made some difference in the extent of recovery. The hard work flights exceeded their control values by 22%, while the light work subjects rose only 13% over their PRE II figures in recovery. It must be remembered, however, that the limited water subjects of the hard work flight were given three canteens (2700 ml) of water per day in EXP II while the allotment of the limited water group doing light work was raised to only two canteens per day. Thus, hydration is again of apparent importance with respect to this test.

As Gaensler (1955) has indicated, each performance in the voluntary ventilation capacity test is dependent on several factors. These include the patency of airways, elasticity of lung tissue, responsiveness of neuromusculature of the thorax, and sensitivity of respiratory centers. We have seen in our data an apparent effect of dehydration in the results. Interpretation of this effect is difficult at best, but since water plays an important role in most metabolic processes, especially those concerned with energy release, it is possible that the kinetics of these processes have been effected. Another admittedly questionable hypothesis is that the psychological status of dehydrated humans is such that the extent of voluntary effort will be measurably decreased.

TABLE III. 269

NORMAL VALUES FOR VENTILATION CAPACITY
(From Gray, et al., 1950)

Author	Subjects No.	Sex	Vol. Vent. Cap. (liters/min.) M	s.d.	C.V.	Method Correction	Acapnia	Duration
Hermannsen	23	Both	99	24.8	25	?	Present	60 sec
Malamos	68	M	145	34.6	24	?	Present	10 sec
Zorn	40	M	128	25.7	20	?	?	?
Cournand	20	M	154	30.9	20	STP	Present	15-30 sec
Cournand	20	F	100	16.8	17	STP	Present	15-30 sec
Battro and Labourt	10	?	111	35.3	32	?	Present	60 sec
Dripps and Comroe	19	M	166	20.3	12	?	Present	30 sec
Gray et al.	283	M	167	21.0	13	STP	Absent	20 sec
Gray et al.	40	F	116	20.9	18	STP	Absent	20 sec
Mohler et al.	99	M	98	19.9	20	None	Absent	15 sec

TABLE III. 270

NORMAL VALUES FOR VOLUNTARY VENTILATION CAPACITY AND CORRELATIONS*

Subjects Type	Sex	No.	Normal Values (STP) M	s.d.	C.V.	Correlation With Age	With Surface Area
USAF Cadets	M	89	167.8	22.1	13.1		
Med. Students	M	194	166.8	20.5	12.3		
Both Combined	M	283	167.1	21.0	12.6	+0.094	+0.307
Nurses	F	40	115.8	20.9	18.0	+0.042	+0.301

*Adapted from Gray et al., (1950)

TABLE III. 271

VOLUNTARY PRE-PERIOD DATA ON VENTILATION CAPACITY
(L/15 sec)

Flight	P I N	M	s.d.	C.V.	P II N	M	s.d.	C.V.
1	22	20.32	4.61	22.9	21	23.44	4.60	19.6
2	21	18.35	4.07	22.4	22	24.03	6.31	29.2
3	21	20.41	5.48	26.8	21	23.11	4.96	21.5
4	21	21.57	3.88	18.1	21	26.29	6.46	24.6
FRA	12	19.72	5.17	26.2	11	23.32	3.85	16.5

TABLE III. 272

VOLUNTARY VENTILATION CAPACITY
(L/15 sec)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC II
ST 0	U	17.07	20.09	18.84	24.19	26.16	20.06	23.37	26.53	---	34.03
	L	16.58	24.08	21.42	17.37	29.25	19.05	28.40	23.44	---	25.68
0/100/0	U	20.26	22.03	26.12	24.42	28.54	18.33	24.14	30.96	---	29.01
1000	L	22.04	26.14	24.94	19.80	22.76	20.17	19.28	20.98	---	21.34
0/100/0	U	21.54	26.04	21.02	26.92	32.85	15.99	20.43	22.80	---	29.05
2000	L	17.49	20.60	23.93	20.87	25.38	23.96	27.44	30.60	---	35.53
2/20/78	U	19.46	23.94	25.28	---	25.57	19.72	26.00	26.79	---	23.61
1000	L	20.56	28.53	25.48	21.36	26.98	20.82	24.62	22.86	---	29.68
2/20/78	U	17.80	24.84	23.32	29.45	---	18.48	20.68	16.84	---	20.27
2000	L	18.22	22.76	29.32	25.04	34.28	22.96	28.30	32.77	---	31.89
15/52/33	U	21.76	29.40	32.67	24.06	30.32	19.62	19.34	21.65	---	34.51
1000	L	12.66	17.96	15.52	---	---	29.74	27.89	27.83	---	28.21
15/52/33	U	22.12	19.98	33.22	22.19	28.11	28.04	24.66	26.89	---	31.24
2000	L	19.00	24.63	27.73	---	40.58	18.04	29.25	28.57	---	31.31
15/52/33	U	22.90	21.02	25.04	---	30.34	20.10	20.92	28.35	---	23.94
3000	L	21.16	24.54	24.57	---	25.80	14.08	25.98	---	---	---
30/0/70	U	22.15	23.37	25.36	21.40	30.32	34.82	28.63	27.39	---	31.28
1000	L	21.36	23.06	20.60	---	20.25	15.88	21.26	21.22	---	27.20
30/0/70	U	21.42	27.06	29.54	---	36.01	16.68	25.28	26.52	---	24.49
2000	L	16.20	27.98	24.53	28.46	28.59	22.72	23.20	16.32	---	14.86
FRA		19.72	23.32	25.90	28.20	27.56	19.72	23.32	25.90	28.20	27.56

TABLE III. 273

VOLUNTARY VENTILATION CAPACITY AS PER CENT OF PRE II: HARD WORK

Diet		Water	Subject	PRE I	EXP I	EXP II	REC	Remarks
ST 0		U	1	54	82	72	136	
			2	103	38	---	FRA	
			3	91	116	142	130	
			4	86	143	---	141	
		L	23	79	103	91	178	
			24	50	78	69	---	
			25	70	113	---	119	
			26	81	67	---	97	
0/100/0	1000	U	5	88	113	108	FRA	
			6	96	124	---	133	
		L	27	76	100	82	102	
			28	91	91	---	75	
	2000	U	7	105	71	118	152	
			8	66	88	---	106	
		L	29	81	107	104	126	
			30	87	125	---	121	
30/0/70	1000	U	9	70	132	110	161	
			10	112	91	---	107	
		L	31	50	88	FRA	FRA	
			32	100	34	---	84	PRE I = 100%
	2000	U	11	73	139	---	167	
			12	83	91	---	112	
		L	33	70	86	120	113	
			34	49	76	---	94	
2/20/78	1000	U	13	81	136	---	---	
			14	81	80	---	98	
		L	35	75	90	82	128	
			36	69	89	---	67	
	2000	U	15	83	99	120	---	
			16	61	89	---	---	
		L	37	91	109	109	113	
			38	69	149	---	189	
15/52/33	1000	U	17	80	135	103	110	
			18	70	95	---	98	
		L	39	52	82	---	---	
			40	91	---	---	FRA	
	2000	U	19	113	165	104	132	
			20	108	168	---	---	
		L	41	75	---	---	FRA	
			42	78	87	---	127	
	3000	U	21	107	123	---	132	
			22	111	115	---	157	
		L	43	88	126	---	107	
			44	84	73	---	103	

TABLE III. 273 (Contd.)

VOLUNTARY VENTILATION CAPACITY AS PER CENT OF PRE II: LIGHT WORK

Diet		Water	Subject	PRE I	EXP I	REC	Remarks
ST O		U	54	77	89	140	
			45	115	194	200	PRE I = 100%
			46	61	102	125	
			47	89	115	118	
			48	104	85	156	
		L	67	44	84	93	
			68	78	77	---	
			69	82	73	66	
			70	61	102	118	
0/100/0	1000	U	49	65	127	119	
			50	90	130	122	
		L	71	102	111	136	
			72	106	107	95	
	2000	U	51	86	100	166	
			52	72	120	124	
		L	73	100	142	---	
			74	80	94	102	
30/0/70	1000	U	53	122	96	109	
		L	75	47	71	90	
			76	77	93	120	
	2000	U	55	45	100	111	
			56	85	110	83	
		L	78	92	87	79	
2/20/78	1000	U	57	55	77	68	
			58	119	---	FRA	PRE I = 100%
		L	79	96	77	144	
			80	77	103	104	
	2000	U	59	---	46	83	
			60	91	126	117	
		L	81	85	131	105	
			82	77	98	FRA	PRE I = 100%
15/52/33	1000	U	61	114	110	164	
			62	87	114	---	
		L	83	121	123	96	PRE I = 100%
			84	97	64	90	
	2000	U	63	107	126	135	
			64	119	97	121	
		L	85	74	104	101	
			86	50	92	112	
	3000	U	65	83	116	116	
			66	114	---	112	
		L	87	29	---	FRA	
			88	90	---	---	

TABLE III. 273 (Contd.)

VOLUNTARY VENTILATION CAPACITY AS PER CENT OF PRE II: FRA

Diet	Water	Subject	PRE I	EXP I	EXP II	REC	Remarks
FRA	U	90	42	80	101	134	
		91	107	131	116	130	
		92	89	124	---	119	
		94	50	76	95	125	
		95	81	94	---	116	
		96	76	116	---	139	
		97	94	126	---	88	
		98	100	94	---	92	PRE I = 100%
		99	78	120	---	104	
		100	90	117	---	146	
		101	93	99	---	81	
	These Subjects Changed To FRA During EXP II						
		2			---	89	See other
		5			---	141	parts of
		31			79	86	table for
		40			---	123	data pre-
		41			---	108	vious to com-
		58			---	100	ing off diet.
		82			---	106	
		87			---	54	

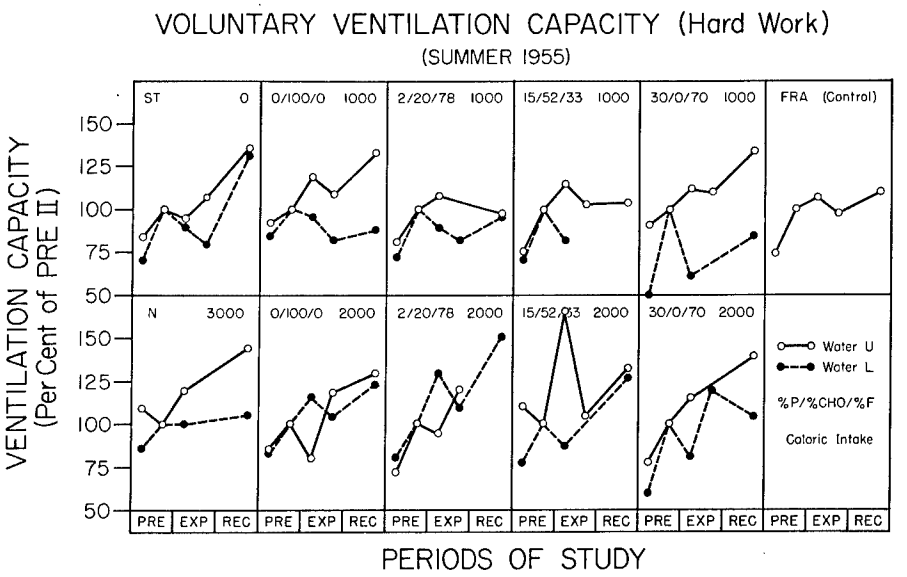


FIGURE III. 93. VOLUNTARY VENTILATION CAPACITY: HARD WORK.

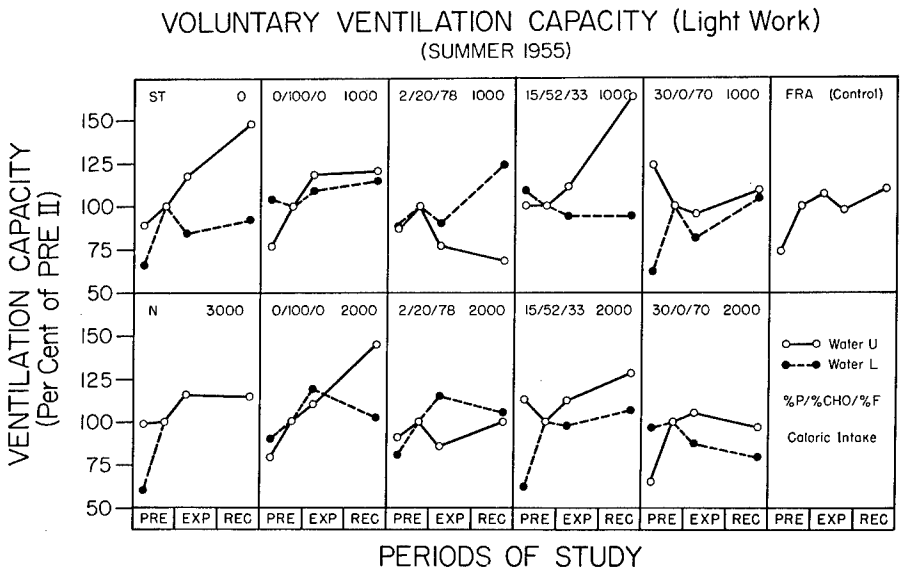


FIGURE III. 94. VOLUNTARY VENTILATION CAPACITY: LIGHT WORK.

c. Respiratory Metabolism

Pulmonary Ventilation. This is summarized for all subjects in Tables III. 274 and III. 275, and is diagrammed as percent of PRE II values in Figures III. 95 and III. 96. The concept of own control is again used and any differences due to variation in body weight, etc. are thereby eliminated.

Generally, it may be seen that pulmonary ventilation dropped in the experimental periods. Of the experimental subjects, only nine had a significantly increased pulmonary ventilation during EXP I (Subjects No. 21, 22, 32, 36, 42, 50, 53, 55, and 76), but no trend can be detected with respect to water intake, work level, caloric intake, or regimen. Increased protein intake seemed to have a slight effect in increasing this volume. Contrary to expectations, the diets from which ketosis resulted (ST 0, 2/20/78, and 30/0/70) did not cause a consistent increase in pulmonary ventilation. Only those light work subjects on 30/0/70 1000 exhibited this phenomenon while the other subjects on meat bar did not. The FRA controls did not follow the general decrease in EXP I, and the N 3000 subjects dropped nearly as much as the ST 0 subjects. Generally, the differences obtained by limiting the water intake were more marked in the hard work groups, but these differences were not consistent.

Recovery was generally satisfactory, most subjects tending to approach or exceed their PRE II volumes. Only the low calorie groups exhibited a different recovery pattern; the starvation and 1000-Calorie groups averaged 111% of their PRE II volumes, while the 2000-Calorie groups averaged 102%, and the six 3000-Calorie subjects averaged 98% in recovery. It is possible that this rebound reflects some sort of overcompensation of the undernourished organism when placed on an adequate diet. Variations with respect to work level, water intake, and regimen were apparently random in recovery.

Current concepts of the role of blood pH in activation of the respiratory center imply that a higher pulmonary ventilation is to be expected in those cases of metabolic acidosis associated with ketosis (Best and Taylor, 1955. p. 411). That such an increase did not occur cannot be readily explained. The increased recovery of the subjects on low calorie diets is also difficult to fit into known physiological mechanisms, and probably deserves further investigation. In the classical literature on respiration there is mention of changes in respiratory measurements occurring without detectable physico-chemical changes in blood. These changes have been attributed to alteration of sensitivity of the respiratory centers, and have been alluded to as an adaptive "change of set" of the organism. If such occurs, the lack of change, where change is expected (and vice versa), may be the result.

TABLE III. 274

PRE-PERIOD DATA ON PULMONARY VENTILATION
(L/min, STP)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	7.00	1.14	16.6	22	7.48	1.48	19.8
2	21	6.89	1.45	21.1	22	6.90	1.23	17.8
3	21	7.23	1.02	14.4	21	7.18	2.82	39.3
4	22	6.82	2.66	39.0	21	6.97	2.95	42.3
FRA	12	6.75	2.48	36.6	11	6.61	2.83	42.7

TABLE III. 275

PULMONARY VENTILATION
(L/min STP)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC II
ST 0	U	6.53	7.00	6.16	5.24	7.19	7.28	7.35	6.07	----	8.28
	L	7.23	7.36	5.76	5.20	9.31	6.76	7.56	6.54	----	8.51
0/100/0	U	7.70	6.70	6.27	6.29	8.30	6.72	6.29	6.38	----	7.42
1000	L	7.18	6.64	5.22	5.23	7.34	6.78	6.82	5.54	----	7.66
0/100/0	U	7.22	9.89	8.28	8.40	9.36	8.12	7.74	7.48	----	7.62
2000	L	7.00	6.96	5.34	5.29	6.84	7.14	6.90	6.66	----	6.37
2/20/78	U	7.58	9.42	6.73	----	7.66	7.72	7.46	6.49	----	8.75
1000	L	5.56	4.80	6.02	4.79	5.93	6.34	6.20	5.21	----	6.04
2/20/78	U	5.17	6.66	5.72	5.27	----	7.28	7.09	6.00	----	7.04
2000	L	7.42	6.20	5.85	6.43	6.17	6.79	6.56	4.74	----	7.14
15/52/33	U	6.78	6.98	6.06	7.09	8.90	7.26	6.96	6.20	----	6.16
1000	L	6.21	6.54	5.72	----	----	6.41	5.73	5.25	----	6.38
15/52/33	U	7.32	6.27	5.92	5.63	6.84	6.55	6.57	6.36	----	7.00
2000	L	6.56	7.95	11.60	----	7.89	7.50	7.08	6.42	----	7.04
15/52/33	U	8.22	7.88	8.93	----	8.14	8.08	8.15	6.86	----	7.04
3000	L	6.50	7.48	6.19	----	7.48	6.88	6.88	----	----	----
30/0/70	U	6.40	7.21	6.88	5.08	7.49	4.79	5.59	6.55	----	6.23
1000	L	8.00	7.60	8.32	----	7.88	6.92	6.54	7.95	----	7.45
30/0/70	U	7.52	7.23	6.88	5.98	7.65	7.22	7.58	7.88	----	8.83
2000	L	6.94	7.00	7.40	7.46	6.88	7.71	8.56	9.01	----	10.60
FRA	U	6.75	6.61	6.90	7.84	7.10	6.75	6.61	6.90	7.84	7.10

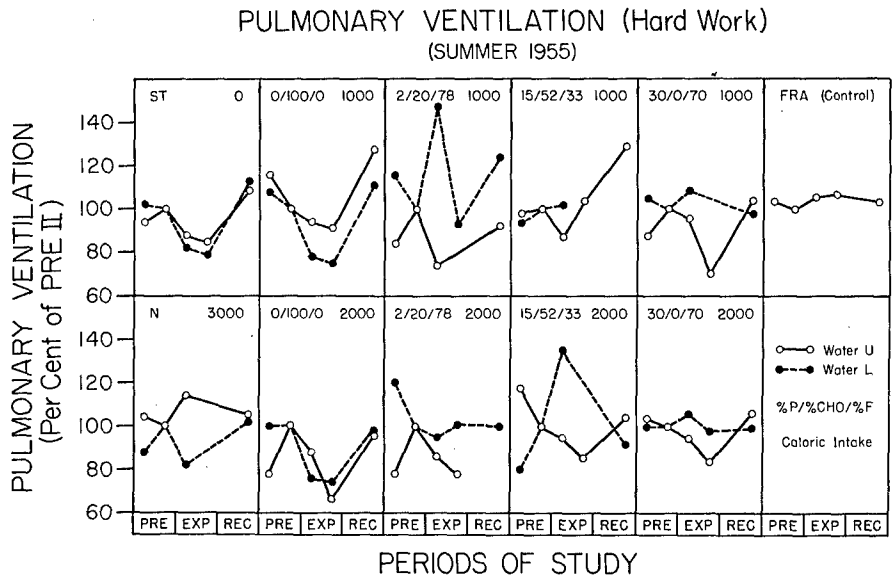


FIGURE III. 95. PULMONARY VENTILATION: HARD WORK.

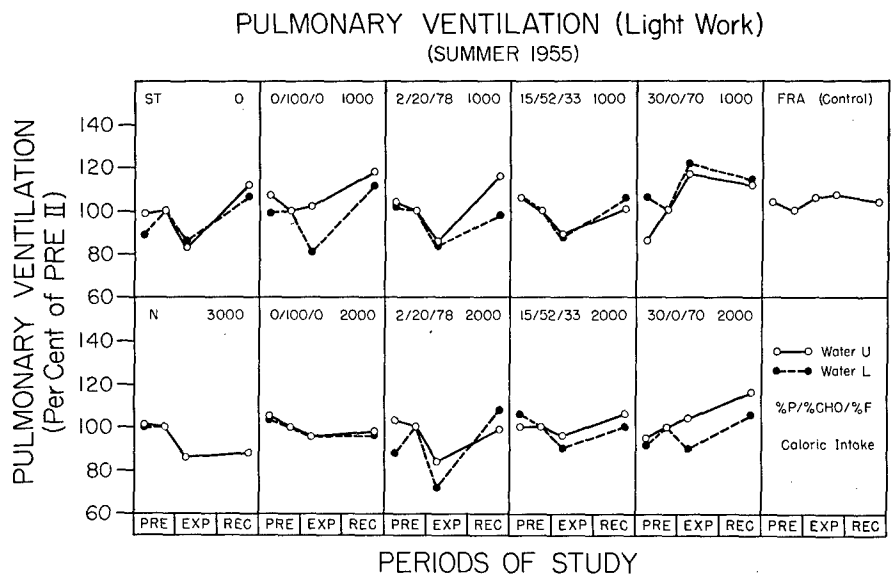


FIGURE III. 96. PULMONARY VENTILATION: LIGHT WORK.

Tidal Volume. The classical works of Hering and Breuer in 1868 and of other investigators since have firmly established that the depth (and therefore the rate) of respiratory movements is mediated by sensory endings of the vagus nerve in the lung and respiratory passages. The fibers from these receptors run to the respiratory centers in the brain stem where the respiratory movements are reflexly regulated. Therefore, tidal volume is governed not only by these centers but also by the sensitivity of the vagus receptors and of the motor portion of the arc. Deviations of tidal volume from normal are therefore due to dysfunction of one or more elements of the reflex arc and not directly to changes in blood pH, pCO_2, etc. However, since these elements are subject to influences from other systems, the whole picture is quite complex and permits no easy interpretation of results.

Tidal volumes of all subjects are summarized in Tables III. 276 and III. 277, and are plotted as mean per cent of PRE II values in Figures III. 97 and III. 98. Again, the latter figures are used for discussion purposes and the own-control concept is thereby employed.

Here, as in other respiratory measurements, a general decline is noted during the experimental periods. Only nine subjects (No. 2, 23, 31, 11, 36, 42, 21, 50, and 76) had an appreciable increase over their PRE II values, and these follow no apparent pattern. Deviations seen in the hard groups (Figure III. 97) are due to individual variations and reflect no recognizable trend. No specific trends can be seen with respect to water intake, work level, or regimen. Work level seems to have influenced the extent of the experimental decline in the starvation groups and in the N 3000 groups (Figure III. 99). Statistical analysis using Fischer's "t" test shows these differences to be significant even with the small numbers involved. The decline is usually continued into EXP II where measured. FRA controls gave a similar though less pronounced decrease.

Recovery period brought a general return to PRE II values. Thirty-three subjects exceeded their control figures (110% of PRE II) and seventeen remained significantly below them (90% of PRE II). Only eleven subjects failed to show an increase over experimental volumes. The only detectable trend was found in the hard work groups, where those previously on inadequate (caloric) rations exhibited more pronounced recovery than their better-fed companions. This is a result of comparing mean figures, and the ranges of each group overlap extensively.

It should be emphasized that while tidal volumes are reflected in total pulmonary ventilation, the two sets of data cannot be compared directly because of the different neurological control mechanisms involved. There is no ready means of explaining the differences seen at different work loads except by a possible conditioning influence found in greater exercise among the hard work groups.

TABLE III. 276

PRE-PERIOD DATA ON TIDAL VOLUME
(ml STP)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	462	131	35.2	22	516	182	35.3
2	21	516	171	33.2	22	485	132	27.2
3	21	483	66	13.6	21	441	137	31.1
4	22	458	119	26.1	21	451	120	26.6
FRA	12	454	65	14.7	11	484	116	24.1

TABLE III. 277

TIDAL VOLUME
(ml STP)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC II
ST 0	U	402	490	432	396	578	493	451	335	---	491
	L	503	369	396	302	504	483	486	364	---	580
0/100/0	U	493	448	405	351	503	624	526	524	---	430
1000	L	612	464	460	270	538	467	455	440	---	560
0/100/0	U	412	574	534	483	572	509	470	402	---	470
2000	L	622	516	416	429	538	504	544	468	---	585
2/20/78	U	422	674	440	---	455	493	397	308	---	474
1000	L	357	414	568	286	454	343	368	284	---	338
2/20/78	U	465	497	356	367	---	430	396	394	---	448
2000	L	676	600	505	339	650	624	470	421	---	586
15/52/33	U	446	490	426	394	648	438	433	386	---	425
1000	L	496	485	327	---	---	362	407	302	---	447
15/52/33	U	536	384	316	316	428	530	550	429	---	723
2000	L	444	521	580	---	462	345	378	354	---	350
15/52/33	U	647	660	601	---	463	531	528	488	---	564
3000	L	541	601	390	---	474	529	407	---	---	---
30/0/70	U	378	410	371	350	454	273	397	280	---	322
1000	L	560	605	451	---	477	594	691	676	---	555
30/0/70	U	476	510	489	443	467	389	378	364	---	442
2000	L	358	396	394	452	377	307	273	269	---	400
FRA		454	484	454	515	473	454	484	454	515	473

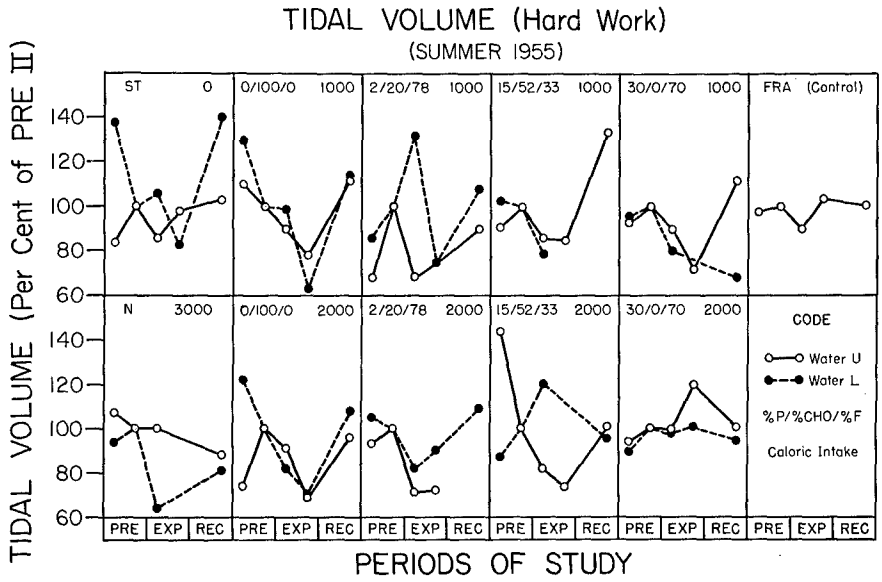


FIGURE III. 97. TIDAL VOLUME: HARD WORK.

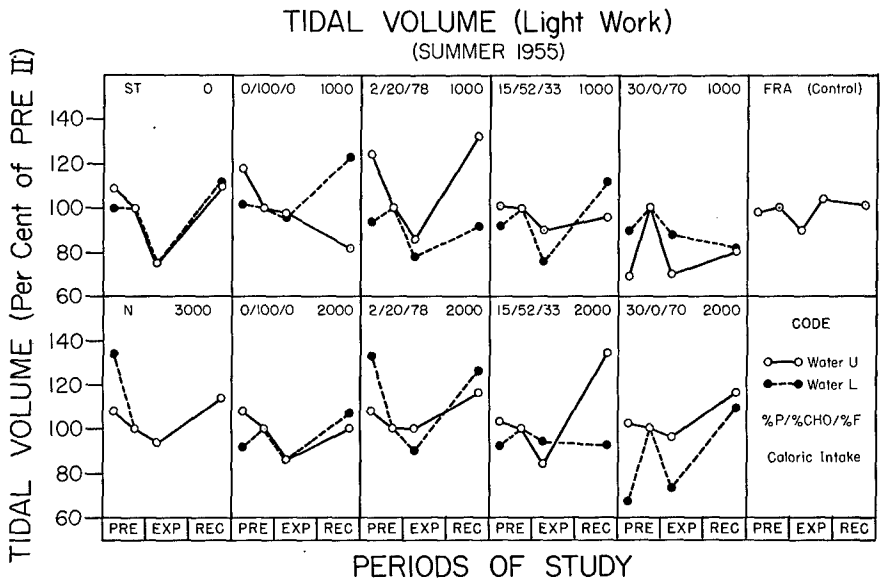


FIGURE III. 98. TIDAL VOLUME: LIGHT WORK

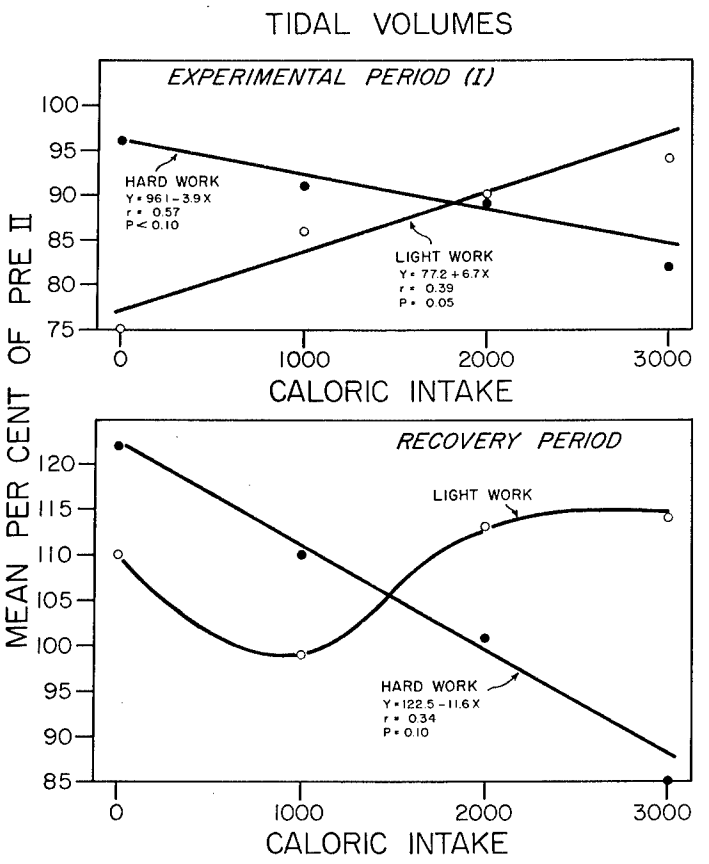


FIGURE III. 99. TIDAL VOLUME AND CALORIC INTAKE.

Resting Respiratory Rate. In scrutinizing these data, the same methods of comparing the subject with himself were applied as before (Tables III. 278 and III. 279). In the main it was felt that comparisons of percentages were somewhat less valid here than in the volume measurements of tidal volume and pulmonary ventilation, for a change in respiratory rate from 12/min to 13/min involves a change of 8%. However, with this in mind, the experimental and recovery rates were calculated as percentage of PRE II rates in the interests of uniformity, and compared (Figures III. 100 and III. 101).

The experimental period was marked by considerable variation in all groups. The trends noted with respect to work level in tidal volumes were reversed here, the hard work groups showing a low respiratory rate on the low caloric intake (75% of PRE II) and the light work low calorie groups breathing at higher rates (115%) than in PRE II. Thus it would appear that the changes seen in tidal volume were compensated by those of respiratory rate. It should be remembered that pulmonary ventilation of nearly all groups was lower in EXP I than in PRE II. Figure III. 102 shows these relationships. Note that many subjects had decreased tidal volume and increased rates in the period, but

that the exceptions are numerous. One other trend worthy of notice is that the respiratory rate increased with increasing protein intake in EXP I, especially in the hard work groups. Tidal volumes do not show a compensating decrease. The ketogenic nature of the diets is the first suspect in this tendency, but since the respiratory rate of those on the normal (15/52/33) diet was higher than that of those subjects on either the ST 0 or the 2/20/78 regimens (See Table III. 279), this argument will not stand up.

The recovery period was not marked by any outstanding trends. The return to normal rates was erratic, and many subjects failed to show any tendency to approach the pre-period levels.

Current theories concerning the regulation of the respiratory rhythm (which are well substantiated by experimental evidence) postulate an intimate relationship between rate control and depth control. (Best and Taylor, 1955. pp. 400-405). In view of this, one would predict good correlation between these measures, as was obtained (Figure III. 102). It must be recalled that only two runs of ten minutes each were made at any one time, and the extrapolation of data thus obtained to the actual state of each subject involves the questionable but necessary assumption of a steady state.

TABLE III. 278

PRE-PERIOD DATA ON RESPIRATORY RATE DURING METABOLISM TEST
(breaths/min)

	P I				P II			
Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
1	22	16	3	21.2	22	16	4	26.0
2	21	14	4	27.2	22	15	5	35.9
3	21	16	3	18.8	21	16	3	21.0
4	22	16	4	26.9	21	17	7	43.2
FRA	12	15	3	20.8	11	14	7	50.0

TABLE III. 279

RESPIRATORY RATE DURING METABOLISM TEST
(breaths/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC II
ST 0	U	17	15	14	14	13	15	16	18	--	17
	L	15	18	15	17	19	14	16	18	--	15
0/100/0	U	16	15	14	18	16	11	12	12	--	17
1000	L	12	14	12	20	14	14	15	14	--	13
0/100/0	U	18	17	16	18	18	16	16	19	--	16
2000	L	12	14	14	12	13	15	13	14	--	11
2/20/78	U	18	14	16	00	17	15	19	21	--	18
1000	L	16	12	13	17	16	19	17	18	--	18
2/20/78	U	12	14	16	14	--	18	18	15	--	16
2000	L	12	12	14	19	11	10	15	12	--	14
15/52/33	U	16	14	15	18	14	16	16	16	--	14
1000	L	12	14	18	--	--	18	16	18	--	14
15/52/33	U	14	17	20	18	19	14	15	15	--	12
2000	L	14	16	20	20	18	23	19	18	--	20
15/52/33	U	16	17	18	--	20	16	16	14	--	13
3000	L	13	14	18	--	16	13	18	--	--	--
30/0/70	U	18	16	19	14	18	18	14	24	--	20
1000	L	16	13	20	--	16	12	10	16	--	14
30/0/70	U	18	16	14	14	16	18	20	22	--	20
2000	L	20	18	20	17	19	24	34	35	--	27
FRA		15	14	17	16	16	15	14	17	16	16

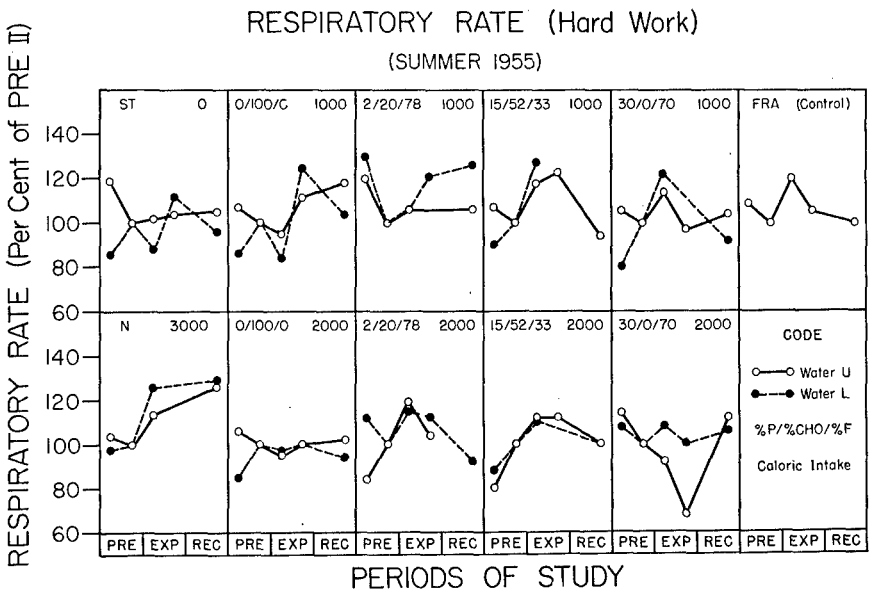


FIGURE III. 100. RESPIRATORY RATE: HARD WORK.

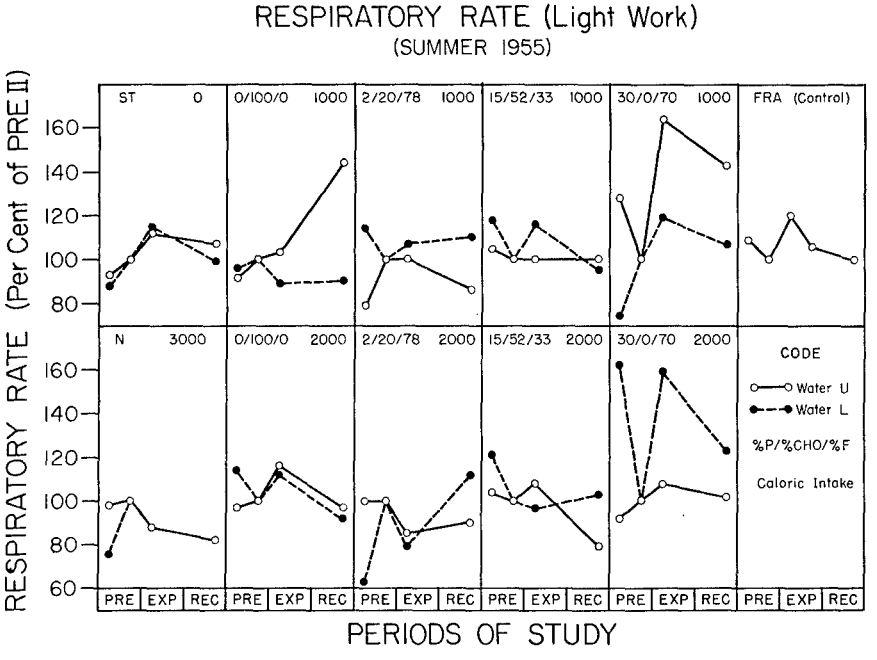


FIGURE III. 101. RESPIRATORY RATE: LIGHT WORK.

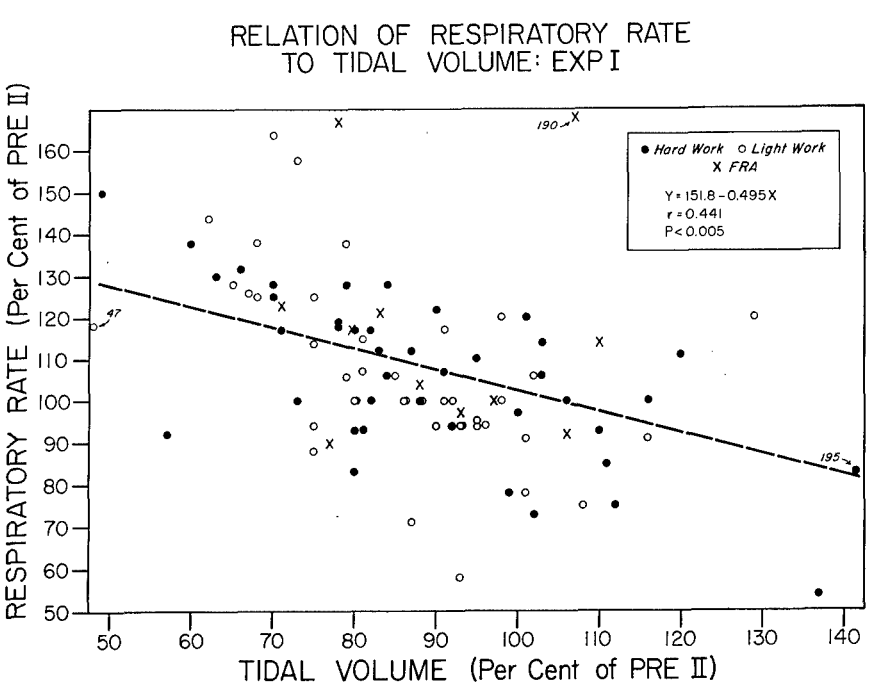


FIGURE III. 102. RELATION OF RESPIRATORY RATE TO TIDAL VOLUME IN EXP I.

Oxygen Consumption, CO_2 Production, and the Respiratory Quotient. The study of these quantities under temperate conditions and light work with dietary regimens identical to those of the 1955 study yielded the following results (Sargent et al., 1955; Boyd, 1954):

a) A diminished CO_2 excretion in diets which deviated markedly in protein/carbohydrate/fat ratios from the average diet of the North American population.

b) A decreased pulmonary ventilation simultaneous with CO_2 "retention."

c) A lowered oxygen consumption on all low calorie diets. This reduction was greatest in the high carbohydrate regimens and least in the high protein regimens.

d) No effect of chronic dehydration.

The data from the hot weather studies were scrutinized for like results and comparisons were as follows:

a) Generally, CO_2 excretion was reduced in those diets which deviated from a "normal" distribution of carbohydrate, protein, and fat, especially in the light work flights. However, the decrease was not regular enough to permit the broad generalization made in 1953.

b) Pulmonary ventilation was correlated with CO_2 excretion. Comparison of the mean percent deviation from PRE II of the two variables is favorable, with $r = 0.532$ ($P<0.01$), and it was concluded that the two measures are closely interdependent. In view of the known sensitivity of the respiratory center to CO_2, this would indicate (1) a real decrease in the rate of CO_2 production, or (2) an actual CO_2 retention which is masked by concomitant changes in acid-base balance. If the latter was the case, the tissues themselves would have to be the site of retention, for urinary pH and titrable acidity (Section III. B.10) indicate an acidosis in almost all subjects. Therefore only two explanations avail themselves to the situation: (1) There was a decreased production of CO_2 or (2) the respiratory centers had become partially desensitized to the CO_2 stimulus. The former is probably the case.

c) The decreased oxygen consumption with decreased caloric intake (also observed by Keys et al., 1950) is not confirmed by our data. However, one should recall that our experimental data is limited to EXP I. Man has been shown to increase his O_2 consumption during the first days of starvation (Benedict, 1915), and we may have missed a decrease after the first week.

d) Contrary to the results of Boyd (1954), dehydration had a marked effect on the oxygen consumption. There was a definite increase in those subjects on unlimited water over their PRE II values. Carbon dioxide production was apparently not affected by dehydration. These effects were most pronounced in the hard work flights. They are not necessarily at variance with the results of the temperate and cold weather studies since neither of these experiments dealt with the extreme conditions of dehydration seen at Camp Atterbury. Comparison of these studies with our light work flights and the hard work, unlimited water group is quite favorable, and only where dehydration was most marked among the hot weather subjects is there seen any real difference.

Calculations: The gasmeter apparatus used at Camp McCoy was extensively modified and tested, and was giving satisfactory results before the summer phase. However, scrutiny of the data obtained at Camp Atterbury revealed some apparently aberrant results. Therefore the following steps were employed in calculating the data:

Oxygen

a) The FRA control subjects were assumed to be normal.

b) From the age of each FRA, basal O_2 consumption was calculated from Boothby-Sandiford standards (Consolazio et al., 1951. p. 340)

and a more or less arbitrary 20% was added to account for non-basal conditions.

c) A factor was then calculated for each machine for each week which would bring the FRA's mean O_2 consumption to the mean theoretical consumption.

d) These same machine factors were then applied to the experimental subjects.

e) This procedure was repeated for each period.

f) All data were then tabulated as percent of PRE II consumption for each subject, and the means of these percentages are shown in Table III. 280 and Figures III. 103 and III. 104.

Carbon Dioxide

a) The FRA controls were assumed to have an R.Q. of 0.85 for all periods. This is valid since Rahn and Otis (1949) have shown that the steady state R.Q. is between 0.8 and 0.9 whether basal or resting.

b) The theoretical CO_2 production was then calculated, and the same method applied as for oxygen to obtain FRA correction factors for each period.

c) These factors were applied to experimental subjects.

d) The subjects' CO_2 production was then tabulated as percent of PRE II and the percentages averaged and tabulated. (See Table III. 281 and Figures III. 105 and III. 106.)

Respiratory Quotient

a) CO_2 and O_2 figures from the above calculations were used to calculate the R.Q. of each subject in each period of study.

b) These were then expressed as percent of PRE II for each subject, the percentages averaged for each regimen, and graphed (Table III. 282 and Figures III. 107 and 108).

c) The mean O_2 and CO_2 figures were also used to arrive at an R.Q. for each regimen (Table III. 283).

The very considerable variations in PRE I data indicate a probably "training effect" as seen in other respiratory measurements, and this period is not used for statistical analysis. EXP II was also eliminated because the manner of handling the data required more information from FRA subjects than was obtained.

Oxygen consumption: The outstanding feature of data on O_2 consumption is

a definite increase in most subjects on unlimited water intake (unlimited = 113%, limited = 99%) over their PRE II values. This was especially noticeable in those diets giving highest protein intakes (except N 3000). ST 0 subjects also conform to this trend. This is seen more regularly in the hard work flights. In the 30/0/70 diets there was either no change from PRE II or a marked increase. Specific dynamic action of the diet will not explain all these changes, as discussed below:

Inspection of dietary composition reveals a consistent decrease of oxygen consumption with increasing carbohydrate intake. This agrees with the classic literature and can be attributed to the fact that the burning of carbohydrate as an energy source requires less oxygen than does an isocaloric amount of fat or protein.

The specific effect of dehydration seen above is not known, but one might speculate that (as in the case of maximal breathing capacity) normal metabolic processes are grossly effected by a water shortage within the organism in some unknown manner.

CO_2 production: In contrast to the effect on oxygen consumption, no significant effect of water limitation or nitrogen intake appeared in the data for CO_2 production. No trend could be seen with respect to diet composition other than that already noted above. The decreased metabolism of starvation caused a much lower CO_2 excretion than was seen in other groups. Increased caloric intake reduced the extent of experimental decrease in all flights, but only in flight one was this proportional to the caloric increase. Work load alone did not significantly effect the resting CO_2 production.

In the 1953 study, significant differences in CO_2 excretion did not appear until EXP II. Analysis of the limited data obtained in EXP II during this study does not reveal a continuance of trends, either of CO_2 production or O_2 consumption. No EXP II data were obtained for the light work flights.

Respiratory quotient: The method of calculation introduces an element of autocorrelation between CO_2 and R.Q., but the latter represents a coordinated view of O_2 and CO_2 data and is worthy of examination in that light. The hard work flights show much more variability than the light work groups. This is also apparent in oxygen and CO_2 data. The effect of water seen in the oxygen consumption is duplicated here. Clearly no general conclusions can be reached from the respiratory quotient concerning the "metabolic mixture" of the subjects during EXP, because of the variability of the data.

Specific Dynamic Action. Since none of the subjects were tested in the post-absorptive state, the specific dynamic action (SDA) of the various diets must be taken into account. The relative effect of SDA on oxygen consumption and CO_2 production, normally of considerable magnitude, is accentuated when the diet is calorically inadequate (Mason, 1927) as in most of the subjects here. The changes due to chemical regulation of heat production to compensate for environmental temperature cannot easily be estimated. Rubner's experiments

have shown that the SDA effect is most pronounced at elevated environmental temperatures, and, since most of our subjects were tested when room temperature was 86°F and above, the SDA exerted considerable influence on the heat production and therefore on oxygen consumption.

The average changes in O_2 consumption between PRE II and EXP I due to change of SDA alone were calculated from intake figures and are shown in Table III. 284. Two simplifying assumptions were made for purposes of calculation: (1) The SDA effect was evenly distributed over a six-hour interval and (2) the daily caloric intake was equally divided between the three meals. These assumptions introduce some slight error into the figures given, but must be made. If the average oxygen consumption of each regimen is corrected for the calculated oxygen consumed due to SDA, it can be seen that increases in EXP I over PRE II are exaggerated while decreases are not so apparent (Table III. 285). This is due to the fact that there was a larger or smaller decrease in caloric intake in all groups when the experimental period began.

Resting heat production is considered as the sum of the basal heat production and the heat produced by SDA. As the latter factor is reduced by decreasing caloric intake, the resting subject is nearer the basal state. However, this does not explain the results obtained with ST 0 subjects who would be "basal" if this concept is to hold. It is important to distinguish between post-absorptive and starvation conditions, for in the former the organism is deriving energy from previously ingested carbohydrate, fat, and protein. In starvation it is well known that liver and muscle glycogen are rapidly exhausted. After this the organism can only be deriving its energy from fat and protein stores, the former being depleted first. The subjects of this study were physically hardened young men having a minimum amount of adipose tissue, so that a short period of starvation would exhaust this and the carefully guarded protein "reserves" would be expended. (See Nitrogen Balances, Section III. B. 3). This endogenous metabolism of fat and protein has been used to explain why actively starving subjects are consuming oxygen at a level somewhat higher than basal, for the amount of oxygen required to metabolize protein is larger than that required for an isocaloric amount of carbohydrate, whether these substances are of endogenous or exogenous origin. The decreased metabolism of starvation may partially mask this phenomenon.

The relation between dehydration and oxygen consumption in these experiments is not easy to explain. Two of the respiratory measurements were strongly effected by dehydration. The first was the voluntary ventilation capacity and the second was oxygen consumption. One can speculate that in dehydration the subjects were not able to perform muscular work, lost muscle tone, and did not expend as many calories as the hydrated subjects. Alternatively, one can postulate a cellular basis, in which normal enzymatic processes are inhibited by dehydration. Further investigation of the effects of dehydration on respiratory function is needed under carefully controlled laboratory conditions.

Working hypothesis integrating the effects of these various factors could explain most of our results. Schematically:

Total oxygen consumption = (specific dynamic action) + (food calories, less SDA) + (calories derived from tissues)

Two assumptions must be made in applying this scheme. First, in the subject who is in negative calorie balance, all food ingested is burnt. Second, in the subject who is in negative calorie balance, the oxygen consumption due to food is supplemented by oxygen consumption similar to that of a starving subject but at a reduced rate. It might be possible to calculate this "residual starvation" effect by calculating from net dry tissue weight loss. In terms of survival studies, the implication of this general scheme are several:

a) That ration would be best whose potential energy for muscular work is highest. In other words, rations of high specific dynamic action should be avoided and physical activity should be held to a minimum. In our experiments, deleterious effects of regimen were considerably accentuated in the hard work flights, in correlation with their greater output of calories in work. Therefore, in them the "residual starvation" metabolism would be higher than in the light work flights.

b) Some food is better than none. In all respects the starving subjects were measurably worse off than those subjects on even the worst experimental regimens. There is a close correlation between deterioration in organ function and total lack of external calories.

c) In hot weather the specific dynamic action of food is not useful to the body in any sense because it cannot be used for muscular activity. In cold weather it is of some use because, in maintaining body temperature, specific dynamic action can replace food calories which then become available for muscular work. In either hot or cold weather, however, the specific dynamic action should be kept at a minimum in order to make available maximal muscular work from those calories available.

d) In the undernourished subject, the survival ration should, within its possible range, keep at a minimum the "residual starvation." Therefore, it is necessary to have in the survival diet a certain amount of protein because pure carbohydrates and pure fat are not as effective in minimizing negative nitrogen balances as are the same nutrients supplemented with protein added isocalorically.

e) It is apparent in general that a compromise must be reached if we consider respiratory metabolism alone. The compromise must be between "residual starvation", minimal specific dynamic action, and food calories available for muscular work. If we accept this reasoning, we should reject the following nutrient mixtures: (1) pure carbohydrates, (2) pure fat, (3) high protein mixtures. At any given calorie level, a regimen containing moderate amounts of protein, carbohydrates and fat will fulfill the criteria of (1) moderate SDA and (2) least quantitative amount of "residual starvation." In other words, our metabolistic hypothesis leads to the concept that the "normal mixture" such as our 15/52/33 is the best compromise regimen for a survival ration.

TABLE III. 280

RESTING O_2 CONSUMPTION: MEAN PER CENT OF PRE II

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC II	Hard Work Rank in EXP I	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC II	Light Work Rank in EXP I
ST 0	U	99	100	107	94	14	124	100	109	108	13
	L	131	100	88	118	4	95	100	106	95	11
0/100/0	U	151	100	114	109	16	105	100	86	119	1
1000	L	113	100	63	88	1	111	100	96	91	6
0/100/0	U	98	100	93	123	7	137	100	87	101	2
2000	L	115	100	87	120	3	109	100	95	N.D.	5
2/20/78	U	99	100	91	111	5	98	100	114	108	14
1000	L	124	100	100	105	10	101	100	N.D.	96	--
2/20/78	U	110	100	178	N.D.	21	114	100	135	119	17
2000	L	113	100	97	131	9	95	100	91	95	3
15/52/33	U	118	100	120	85	18	107	100	100	108	8
1000	L	131	100	92	N.D.	6	105	100	103	89	10
15/52/33	U	137	100	118	163	17	109	100	117	121	15
2000	L	76	100	95	93	8	94	100	123	90	16
15/52/33	U	83	100	78	89	2	103	100	94	95	4
3000	L	111	100	101	129	12	164	100	N.D.	N.D.	--
30/0/70	U	143	100	127	112	19	84	100	164	86	19
1000	L	123	100	109	87	15	119	100	108	108	12
30/0/70	U	115	100	139	125	20	89	100	99	125	7
2000	L	124	100	105	138	13	91	100	143	120	18
FRA		100	100	100	100	10	100	100	100	100	8

TABLE III. 281

RESTING CO_2 PRODUCTION: MEAN PERCENT OF PRE II

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC II
ST 0	U	101	100	103	124	111	100	77	122
	L	100	100	72	100	94	100	85	84
0/100/0	U	133	100	75	119	103	100	89	119
1000	L	139	100	89	108	107	100	92	87
0/100/0	U	63	100	90	123	107	100	97	123
2000	L	96	100	95	91	111	100	93	93
2/20/78	U	107	100	94	138	99	100	109	105
1000	L	107	100	119	117	88	100	100	103
2/20/78	U	126	100	119	N.D.	107	100	87	124
2000	L	100	100	89	102	85	100	77	91
15/52/33	U	90	100	93	107	109	100	109	133
1000	L	97	100	137	147	113	100	104	117
15/52/33	U	123	100	89	158	99	100	114	135
2000	L	108	100	172	125	97	100	85	73
15/52/33	U	89	100	113	113	100	100	94	92
3000	L	71	100	93	101	101	100	N.D.	N.D.
30/0/70	U	104	100	108	146	102	100	111	113
1000	L	127	100	111	76	95	100	81	95
30/0/70	U	124	100	126	151	97	100	80	141
2000	L	97	100	106	99	109	100	84	125
FRA		100	100	100	100	100	100	100	100

TABLE III. 282

RESTING RESPIRATORY QUOTIENT: MEAN PER CENT OF PRE II

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC II
ST O	U	111	100	95	135	90	100	65	111
	L	78	100	83	86	101	100	81	90
0/100/0	U	87	100	65	108	100	100	103	101
1000	L	119	100	143	125	96	100	96	94
0/100/0	U	67	100	99	101	85	100	117	122
2000	L	87	100	114	77	96	100	99	93
2/20/78	U	139	100	105	126	100	100	97	97
1000	L	99	100	128	115	87	100	N.D.	107
2/20/78	U	114	100	71	N.D.	95	100	69	105
2000	L	87	100	95	85	89	100	85	89
15/52/33	U	114	100	77	101	101	100	112	123
1000	L	77	100	149	N.D.	112	100	102	130
15/52/33	U	89	100	75	97	91	100	98	113
2000	L	100	70	128	95	103	100	73	88
15/52/33	U	109	100	145	126	95	100	81	74
3000	L	64	100	93	77	68	100	N.D.	N.D.
30/0/70	U	73	100	85	130	124	100	69	132
1000	L	105	100	103	87	79	100	79	87
30/0/70	U	109	100	91	121	109	100	85	113
2000	L	77	100	102	75	119	100	59	103
FRA		104	100	108	101	104	100	108	101

TABLE III. 283

RESTING RESPIRATORY QUOTIENT*

Absolute Value

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work REC II
ST 0	U	0.83	0.78	0.75	1.05	0.82	0.93	0.56	1.04
	L	0.70	0.98	0.77	0.91	0.91	0.92	0.72	0.82
0/100/0	U	0.88	1.01	0.66	1.05	0.91	0.91	0.03	0.94
1000	L	0.82	0.67	0.96	0.78	0.80	0.83	0.79	0.78
0/100/0	U	0.69	1.08	1.05	1.08	0.63	0.82	1.00	1.02
2000	L	0.81	0.98	1.03	0.75	0.88	0.91	0.85	0.90
2/20/78	U	1.02	0.93	0.93	0.92	0.92	0.91	0.84	0.85
1000	L	0.67	0.73	0.87	0.85	0.64	0.74	----	0.80
2/20/78	U	0.88	0.65	0.42	----	0.81	0.85	0.58	0.90
2000	L	0.89	1.02	0.97	0.84	0.77	0.88	0.72	0.81
15/52/33	U	0.65	0.78	0.60	0.91	0.85	0.83	0.91	1.03
1000	L	0.54	0.73	0.94	----	0.68	0.65	0.65	0.83
15/52/33	U	0.91	1.02	0.76	1.00	0.70	0.77	0.74	0.87
2000	L	1.04	0.92	1.33	0.99	0.94	0.91	0.61	0.74
15/52/33	U	0.73	0.69	0.96	0.85	0.77	0.81	0.78	0.75
3000	L	0.61	0.94	0.87	0.73	0.86	0.86	----	----
30/0/70	U	0.51	0.71	0.61	0.93	0.88	0.71	0.48	0.94
1000	L	0.89	0.88	0.87	0.94	0.70	0.90	0.68	0.77
30/0/70	U	0.83	0.77	0.69	0.93	0.93	0.86	0.72	0.95
2000	L	0.76	0.99	1.00	0.73	0.89	0.75	0.39	0.68
FRA		0.85	0.85	0.84	0.85	0.85	0.85	0.85	0.85

*Calculated with aid of FRA factors.

TABLE III. 284

CHANGES IN OXYGEN CONSUMPTION DUE TO EXOGENOUS SPECIFIC DYNAMIC ACTION

Regimen		$ml O_2$/min, Protein Hard Work PRE II	EXP I	Δ	$ml O_2$/min, Protein Light Work PRE II	EXP I	Δ	(Table III. 57) $ml O_2$/min CHO All Flights PRE II	EXP I	Δ	(Table III. 58) $ml O_2$/min Fat All Flights PRE II	EXP I	Δ	μ Δ ml O_2/min Hard	Light
ST 0	U	29	0	-29	33	0	-33	19	0	-19	8	0	-8	-56	-60
	L	28	0	-28	36	0	-36	18	0	-18	8	0	-8	-54	-62
0/100/0	U	35	0	-35	37	0	-37	18	11	- 7	9	0	-9	-51	-53
1000	L	37	0	-37	34	0	-34	18	11	- 7	9	0	-9	-53	-50
0/100/0	U	37	0	-37	29	0	-29	21	22	+ 1	8	0	-8	-44	-36
2000	L	34	0	-34	27	0	-27	16	22	+ 6	7	0	-7	-35	-28
2/20/78	U	38	2	-36	24	2	-22	18	2	-16	8	6	-2	-54	40
1000	L	33	2	-31	32	2	-30	17	2	-15	8	6	-2	-48	-47
2/20/78	U	30	4	-26	26	4	-22	19	4	-15	8	12	+4	-37	-33
2000	L	34	4	-30	31	4	-27	18	4	-14	8	12	+4	-40	-37
15/52/33	U	29	9	-20	38	10	-28	18	6	-12	8	3	-5	-37	-45
1000	L	30	10	-20	37	10	-27	17	6	-11	8	3	-5	-36	-43
15/52/33	U	33	20	-13	34	20	-14	21	12	- 9	9	5	-4	-26	-27
2000	L	34	20	-14	36	20	-16	18	12	- 6	9	5	-4	-24	-26
15/52/33	U	34	29	- 5	44	29	-15	23	18	- 5	10	8	-2	-12	-22
3000	L	37	29	- 8	37	--	---	21	18	- 3	9	8	-1	-12	---
30/0/70	U	39	21	-18	26	19	- 7	20	0	-20	8	5	-3	-41	-30
1000	L	33	21	-12	31	21	-10	17	0	-17	8	5	-3	-32	-30
30/0/70	U	38	41	+ 3	35	41	+ 6	19	0	-19	9	10	+1	-15	-12
2000	L	30	41	+11	36	41	+ 5	17	0	-17	8	10	+2	- 4	-10

TABLE III. 285

RESTING O_2 CONSUMPTION, CORRECTED FOR SDA OF FOOD
(assuming S. A. = 1.8 M^2)

Experimental Regimen		Hard Work PRE II ml/M^2/min	Hard Work EXP I	Hard Work $\frac{\text{EXP I}}{\text{PRE II}} \times 100$	Light Work PRE II ml/M^2/min	Light Work EXP I	Light Work $\frac{\text{EXP I}}{\text{PRE II}} \times 100$
ST O	U	156	200	128	130	199	153
	L	134	145	108	150	195	130
0/100/0	U	124	173	139	141	147	104
1000	L	201	137	68	131	153	117
0/100/0	U	125	138	110	141	127	90
2000	L	128	128	100	140	165	118
2/20/78	U	117	132	113	130	157	121
1000	L	129	150	116	---	---	---
2/20/78	U	100	252	252	105	187	178
2000	L	118	130	110	147	150	102
15/52/33	U	130	175	135	117	139	119
1000	L	140	141	101	147	172	117
15/52/33	U	95	133	140	126	170	135
2000	L	137	156	114	144	199	138
15/52/33	U	194	152	78	154	156	101
3000	L	135	144	107	---	---	---
30/0/70	U	140	208	149	141	266	189
1000	L	139	172	124	121	175	145
30/0/70	U	126	200	159	145	147	101
2000	L	125	135	108	130	233	179

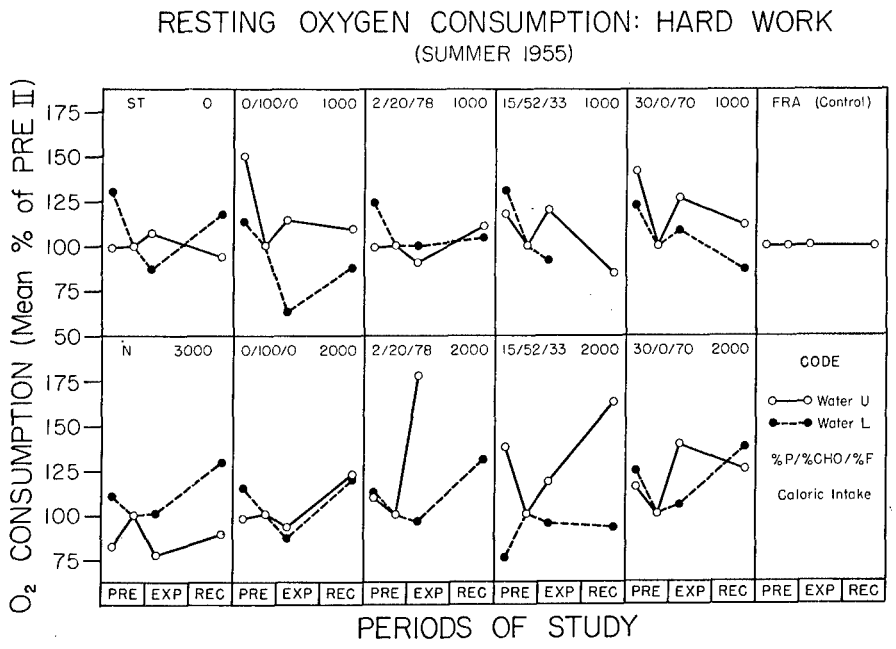


FIGURE III. 103. RESTING OXYGEN CONSUMPTION: HARD WORK.

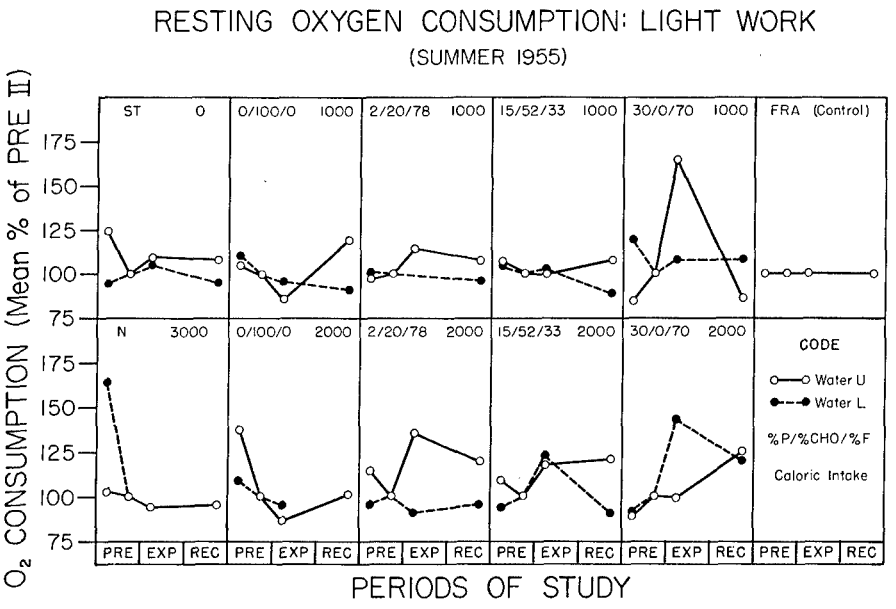


FIGURE III. 104. RESTING OXYGEN CONSUMPTION: LIGHT WORK.

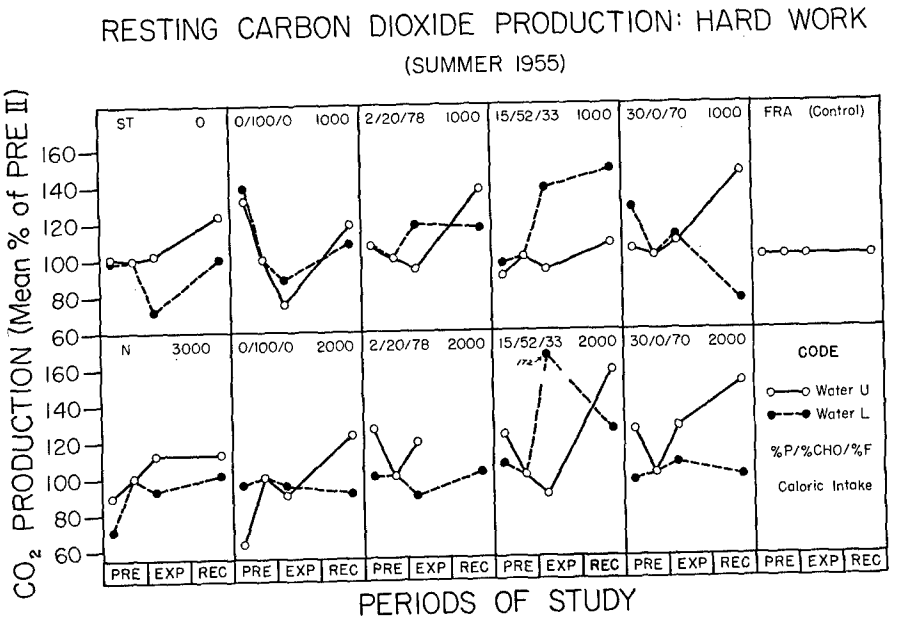


FIGURE III. 105. RESTING CARBON DIOXIDE PRODUCTION: HARD WORK.

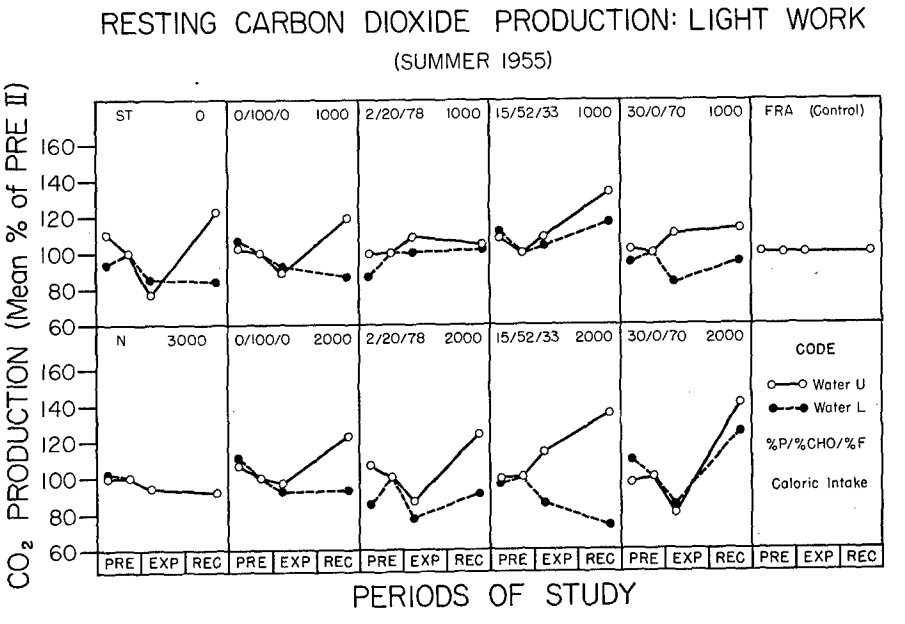


FIGURE III. 106. RESTING CARBON DIOXIDE PRODUCTION: LIGHT WORK.

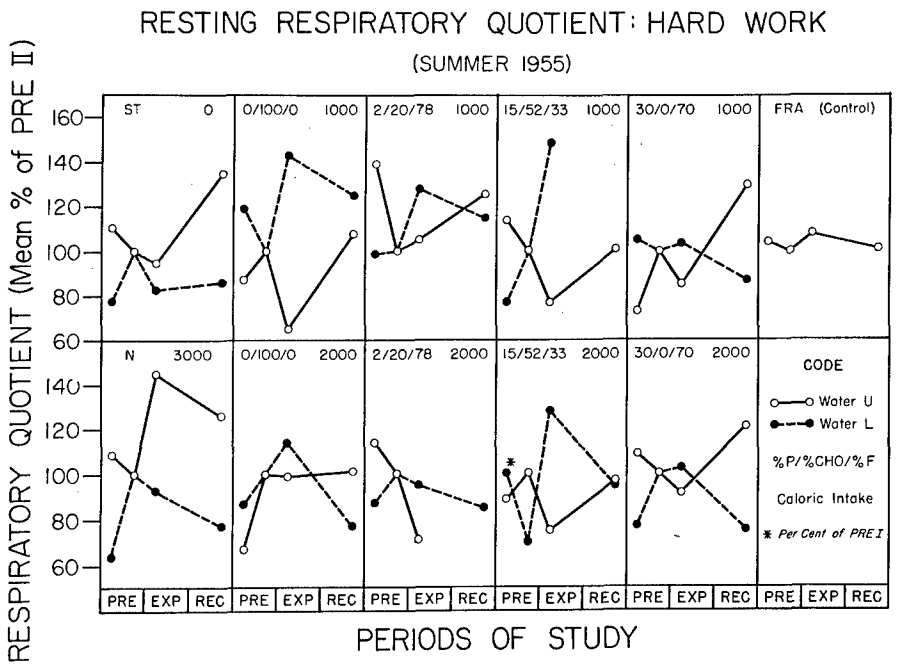


FIGURE III. 107. RESTING RESPIRATORY QUOTIENT: HARD WORK.

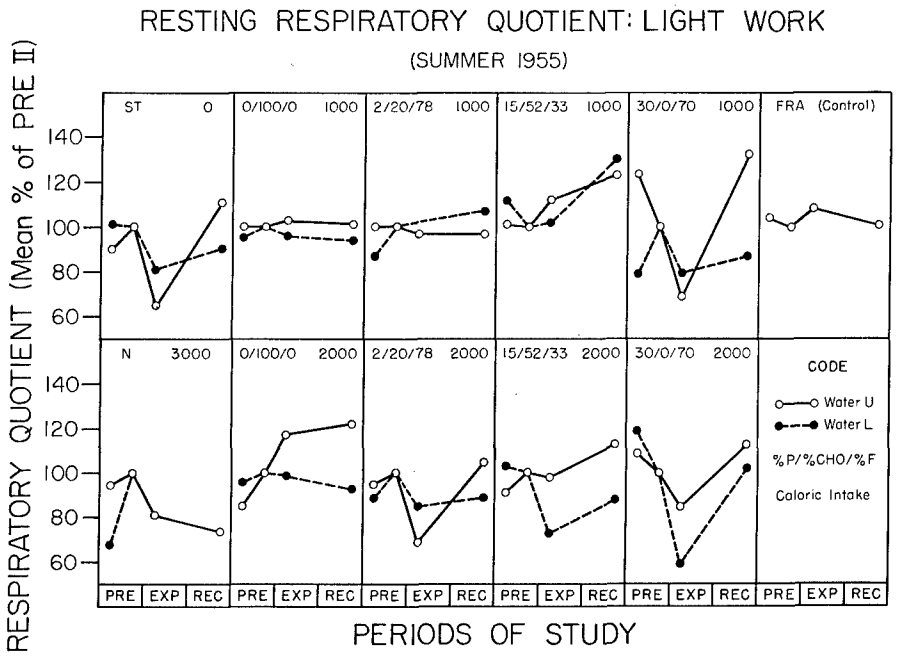


FIGURE III. 108. RESTING RESPIRATORY QUOTIENT: LIGHT WORK.

5. Cardiovascular Function

The systolic and diastolic blood pressure and the pulse rate of the subjects were measured both in the reclining position and in the standing position (Section II). For the sake of convenience we shall consider data on systolic pressure first; diastolic pressure, second; pulse pressure, third; and pulse rate, fourth. The effect of posture will be compared for each measurement as we proceed. Throughout we shall use as reference data, the comprehensive statistical investigations of Schneider and Truesdell (1922) and Emery (1955) on circulatory adjustments to changes of posture. Pertinent data from their papers are summarized in Table III. 286. These data are based on measurements on 2000 military personnel and 954 male medical students, respectively, made under conditions quite comparable to our own.

TABLE III. 286

CARDIOVASCULAR ADJUSTMENTS TO POSTURAL CHANGE

A. After Schneider and Truesdell, 1922*

	Systolic Pressure		Diastolic Pressure		Pulse Pressure		Pulse Rate	
Position	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Standing	120.3	11.8	79.7	9.1	41.6	11.1	92.0	12.6
Reclining	118.0	10.0	71.6	8.4	47.4	9.5	74.1	10.2

*From Table 2, p. 443; Table 3, p. 452; Table 4, p. 456; and Table 5, p. 459. (Values have rounded to nearest 0.1.)

B. After Emery, 1955**

	Systolic Pressure		Diastolic Pressure		Pulse Pressure		Heart Rate	
Position	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Standing	114.0	10.6	79.0	10.4	35.0	9.1	85.0	10.9
Reclining	114.0	9.0	74.0	9.0	40.0	9.2	72.0	9.5

**From Table 1, p. 24. (Values have been rounded to nearest 0.1.)

Systolic Blood Pressure. The pre-period data are presented in Table III. 287. The mean values for lying and for standing are very similar both from group to group and from period to period. The standard deviations for groups and periods are of the same order of magnitude as those reported by Schneider and Truesdell. Only in the case of the FRA subjects is there a significant change in systolic pressure from P I to P II.

On standing, the change of systolic pressure during the pre-periods was very small (Table III. 294). In general, there was a decrease which averaged 6 mm Hg (s.d. = ±16). In the case of the FRA subjects, there was a statistically significant decrease in the systolic pressure in P II ($P < 0.05$); all other postural changes in the systolic pressure were not significant.

These data agree in order of magnitude with those in the literature. Schneider and Truesdell observed a small increase while Emery found no change

(Table III. 286). Wald, Guerney, and Scott (1937) found that within ten seconds after assuming a standing posture the systolic pressure fell 5 to 40 mm Hg and then rapidly returned to, or even exceeded, recumbent levels within 30 seconds.

Reclining systolic pressure: During the six periods of study there were no remarkable changes of the systolic pressure while the subjects were in the reclining posture (Table III. 288). Work load, water intake, and nutrient mixture did not cause any wide deviations from the pre-period (control) levels.

Since there were no evident influences of the principal variables--diet, water, and work--we have averaged the data by flights and periods (Table III. 293 and Figure III. 109). Again it is evident that, in general, the lying systolic pressure was remarkably constant from phase to phase. The men of Flight 1 exhibited a sharp peak in EXP II. The rise was significant ($P<0.001$) when compared with EXP I. Flights 3 and 4 had decreases but the changes were not significant from period to period. Similar changes are present for the FRA subjects (Figure III. 110).

Standing systolic pressure: Study of the variations of standing systolic blood pressure during the several weeks of the summer trial (Table III. 289) indicates that during the experimental periods the systolic pressure was, in many cases, appreciably lower than in the pre-periods. For the flights doing hard work there were 14 mean values in the experimental periods which were more than 10 mm Hg less than the pre-period means; in the recovery periods there were only eight such low values. In the experimental period five means rose to more than 10 mm Hg above the pre-period means; there was only one such rise in the recovery periods.

For the men doing light work there were 17 mean values which were less than the pre-period mean by more than 10 mm Hg; only 7 in the recovery period. In the experimental period one value rose to more than 10 mm Hg above the pre-period mean; in the recovery period there were three such rises.

Of the 31 low values of standing systolic pressure, 18 occurred among men on limited water. Nutrient mixture and calorie deficit did not seem appreciably correlated with this hypotensive tendency. In order to examine more critically this observation, we have defined a level of standing systolic hypotension. We have done this in the terms of our own data. Among the 88 subjects on 5-in-1 ration there were no significant changes in systolic pressure between groups and between periods (PRE I and PRE II). A frequency distribution of the standing systolic pressures was calculated (Table III. 290). The results indicated that the range of pressures was from 80 to 142 mm Hg. No man had a pressure less than 80; only 5.36% of the 168 observations fell in the interval 80-89 mm Hg. The mode was at 100-109 mm Hg with 35.12% of the values falling in this class interval. The mean for the distribution was 107 mm Hg with a standard deviation of 11. Since during the control period only one man had a pressure of 80 mm Hg and since a pressure 85 mm was two standard deviations from the mean, a pressure of 80 mm or less was classified as orthostatic

systolic hypotension. This choice is supported by the fact that among 2000 male subjects of military age studied by Schneider and Truesdell (1922), none had a standing systolic pressure less than 85 mm Hg.

Twelve men had systolic hypotension on standing (Table III. 291). Nine were among subjects on limited water and only three among subjects on unlimited water. Four of the men had hypotensive levels twice. The great majority of these hypotensive levels occurred in the experimental periods, particularly in EXP II (Table III. 292 A). No man on Field Ration A developed standing systolic hypotension. Since the occurrence of this hypotension was largely independent of nutrient mixture and work load (Table III. 292 B) we can hypothesize that it represented an early stage of heat exhaustion brought on by the hot weather of the experimental periods and concurrent dehydration.

Not only did individual subjects exhibit marked orthostatic hypotension, but mean systolic pressures for the several groups of subjects also fell appreciably during the experimental periods (Table III. 293; Figures III. 109 and III. 110). The FRA's exhibited the fall in PRE II with the onset of heat; the experimental subjects in EXP I and EXP II. The decrease in the standing pressure for the FRA's was significant ($P<0.005$). The subjects in Flight 1 showed a marked fall in EXP ($P<0.005$) but in EXP II the standing pressure paralleled the reclining pressure and rose. The subjects of Flights 2, 3, and 4 exhibited a progressive decrease of standing systolic pressure; minimum values were reached in EXP II and in all cases the decreases from P II to EXP II were significant ($P<0.01$, $P<0.005$, and $P<0.001$, respectively). In the recovery periods the standing pressures returned toward pre-period values.

The point of outstanding physiological significance is the decrease of pressure on standing relative to that measured during reclining for the experimental periods. The postural changes in systolic pressure are detailed in Tables III. 294 and III. 295, and Figures III. 109 and III. 110). For the FRA subjects the postural decrement was maximal in PRE II: the standing pressure was significantly lower than the lying pressure (Table III. 296). During the remainder of the summer test, there were no other significant differences for these subjects. Among the subjects of Flight 1 the standing pressure was lower than the reclining pressure in EXP I and REC I (Table III. 296). For Flight 2, the standing decrement was significant in both experimental periods. The pressure did not fall appreciably for the men in Flight 4. Furthermore, the lying and standing values closely parallel one another (Figure III. 109). For Flight 4 the decrements were large and significant in both experimental periods (Table III. 296).

In summary, then, these changes in the flights as a whole support the observations made on individual men. Large and significant decrements of standing systolic pressure took place in the experimental periods among the subjects on limited water. The decrements were greater in EXP II than in EXP I even though extra water had been allowed these men. This is strong evidence of circulatory embarrassment. The subjects could not maintain systolic pressure on standing. This is an early sign of heat exhaustion. The fact that men in other flights exhibited a similar change but of small magnitude argues

that water restriction must have been an accentuating factor. The FRA's showed the decline in PRE II when the weather became hot. They presumably adjusted rapidly and in them the diagnosis might be sub-clinical heat syncope. The men of Flight 1 had a similar reaction in EXP I. In REC I, the decrement may be attributed to the presumative readjustments of rehabilitation.

TABLE III. 287

PRE-PERIOD DATA ON SYSTOLIC BLOOD PRESSURE
(mm Hg)

Flight	P I N	P I M	P I s.d.	P I C.V.	P II N	P II M	P II s.d.	P II C.V.
			A. Reclining					
1	22	109	13	11.9	21	108	15	13.9
2	21	105	11	10.5	21	106	11	10.4
3	21	112	15	13.4	21	107	11	10.3
4	21	109	13	11.9	22	106	17	16.1
FRA	12	117	13	11.1	11	112	15	13.4
			B. Standing					
1	22	111	8	7.2	21	111	13	11.7
2	19	103	10	9.7	21	103	10	9.7
3	21	108	9	8.3	21	111	13	11.7
4	21	106	12	11.3	22	104	7	6.7
FRA*	12	111	8	7.2	11	99	7	7.1

"t" test on P I vs. P II

*P less than 0.005

TABLE III. 288

RECLINING SYSTOLIC BLOOD PRESSURE
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	108	110	109	110	108	106	120	107	105	98	106	113
	L	108	110	102	108	100	110	114	100	106	113	108	97
0/100/0	U	108	111	99	116	132	113	100	99	94	97	103	98
1000	L	100	114	105	102	106	97	121	112	121	114	94	120
0/100/0	U	95	99	99	109	104	111	110	115	111	116	110	117
2000	L	108	107	105	103	102	106	120	125	120	114	106	128
2/20/78	U	98	116	110	120	108	116	112	113	109	108	98	106
1000	L	106	103	96	102	110	108	99	92	96	104	96	110
2/20/78	U	110	109	115	120	130	---	110	106	117	115	102	114
2000	L	109	106	101	109	108	105	102	98	119	114	102	108
15/52/33	U	128	99	115	125	113	110	107	95	105	100	108	109
1000	L	96	100	110	---	---	---	101	100	90	91	108	108
15/52/33	U	119	108	100	114	104	120	128	112	124	108	117	107
2000	L	98	102	104	112	108	98	108	108	111	98	102	124
15/52/33	U	123	90	97	122	97	107	105	112	107	100	103	104
3000	L	93	93	91	103	100	110	116	134	---	---	---	---
30/0/70	U	100	120	117	122	111	115	102	106	114	98	112	104
1000	L	105	105	122	110	90	94	109	101	123	112	107	108
30/0/70	U	102	115	115	120	109	110	102	108	110	96	106	104
2000	L	126	118	125	116	111	103	95	99	100	104	100	98
FRA		117	112	113	108	112	112	117	112	113	108	112	112

TABLE III. 289

STANDING SYSTOLIC BLOOD PRESSURE
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	112	110	103	105	96	102	119	123	98	92*	108	114
	L	102	106	92	90	93	103	101	104	90	84	98	104
0/100/0	U	110	135	110	116	116	135	95	104	83	98	86	97
1000	L	104	99	98	84	92	96	106	109	98	98	113	119
0/100/0	U	108	105	102	109	98	104	115	115	110	107	100	109
2000	L	108	116	98	86	110	106	127	111	110	93	126	126
2/20/78	U	108	111	93	118	105	118	109	96	102	97	118	106
1000	L	100	97	99	100	99	104	101	99	88	79	89	101
2/20/78	U	122	122	118	130	---	---	103	108	115	113	116	112
2000	L	88	109	105	111	99	105	102	97	109	105	100	108
15/52/33	U	112	110	91	91	104	91	106	106	93	97	105	101
1000	L	102	102	114	---	---	---	106	97	82	88	95	105
15/52/33	U	100	94	90	120	90	100	110	100	98	99	113	105
2000	L	119	106	96	110	100	112	108	102	109	95	107	109
15/52/33	U	109	101	95	116	108	104	101	115	119	94	119	110
3000	L	99	94	94	97	88	89	118	104	---	---	---	---
30/0/70	U	115	125	95	126	104	109	118	120	108	108	97	106
1000	L	104	108	98	78	106	96	106	109	101	96	104	108
30/0/70	U	110	103	90	121	91	94	94	109	105	84	111	96
2000	L	106	89	98	82	101	90	92	104	97	83	86	88
FRA		111	99	107	111	106	106	111	99	107	111	106	106

*One other man had undectable blood pressure.

TABLE III. 290

FREQUENCY DISTRIBUTION OF STANDING SYSTOLIC PRESSURES:
EXP SUBJECTS: BOTH PRE-PERIODS

Class Intervals	Number	Per Cent
70 - 79	0	0.00
80 - 89	9	5.36
90 - 99	28	16.67
100 - 109	59	35.12
110 - 119	50	29.76
120 - 129	13	7.74
130 - 139	6	3.57
140 - 149	3	1.79
Total	168	100.01

Mean = 107±11; Range = 80 (1) to 142 (1)

TABLE III. 291

SYSTOLIC BLOOD PRESSURES OF MEN WITH STANDING HYPOTENSION

Flight	Subject Code No.	Systolic Pressure, mm Hg P I	P II	E I	E II	R I	R II
1	18	105	110	90	92	104	78
2	26	92	90	85	78	78	84
	27	95	90	88	78	92	90
	29	114	110	96	78	110	106
	32	95	98	90	78	106	96
	34	105	80	85	76	106	85
	Mean P I =	100	(Entire Flight = 103±10)				
3	49	104	98	80	98	80	84
	56	85	120	118	80	124	109
	Mean P I =	94	(Entire Flight = 108±9)				
4	70	93	100	90	80*	94	96
	79	108	100	100	80	90	100
	80	94	98	75	78	88	102
	84	115	106	73	92	92	108
	Mean P I =	102	(Entire Flight = 106±12)				

*On rehabilitation diet.

TABLE III. 292

A. FREQUENCY OF STANDING HYPOTENSION: SYSTOLIC PRESSURE < 80 mm Hg

	Number of Subjects					
Flight	P I	P II	E I	E II	R I	R II
1	0	0	0	0	0	1
2	0	1	0	5	1	0
3	0	0	1	1	1	0
4	0	0	2	3	0	0
FRA	0	0	0	0	0	0
Total	0	1	3	9	2	1

B. EXPERIMENTAL NUTRIENT MIXTURES OF MEN WITH HYPOTENSION IN EXPERIMENTAL PERIODS

Nutrient Mixture	Number	
	Water U	Water L
ST 0	0	2*
0/100/0 1000	1	1
0/100/0 2000	0	1
2/20/78 1000	0	2
15/52/33 1000	0	1
30/0/70 1000	0	1
30/0/70 2000	1	1

*One subject rehabilitating from starvation.

TABLE III. 293

SYSTOLIC BLOOD PRESSURE: RECLINING VS. STANDING*
(mm Hg)

	Flight 1		Flight 2		Flight 3		Flight 4		FRA	
Period	Lying	Stand	Lying	Stand	Lying	Stand	Lying	Stand	Lying	Stand
PRE I	109±13	111± 8	105±11	103±10	112±15	108± 9	109±13	106±12	117±13	111± 8
PRE II	108±15	111±13	106±11	103±10	107±11	111±13	106±17	104± 7	112±15	99± 7
EXP I	108±10	99±11	106±15	98± 8	109± 9	102±14	109±14	97±11	113±12	107±12
EXP II	118± 6	114±12	107±10	93±12	104±12	98±10	106± 9	91± 9	108±11	111±10
REC I	110±11	101± 9	104±10	98± 9	106± 8	107±12	103± 9	101±12	111± 8	106± 9
REC II	111± 4	105±15	105± 8	100±10	109± 9	107±11	110±11	107± 9	112± 5	106±10

*Underlined values statistically significant by "t" test at 1% level.

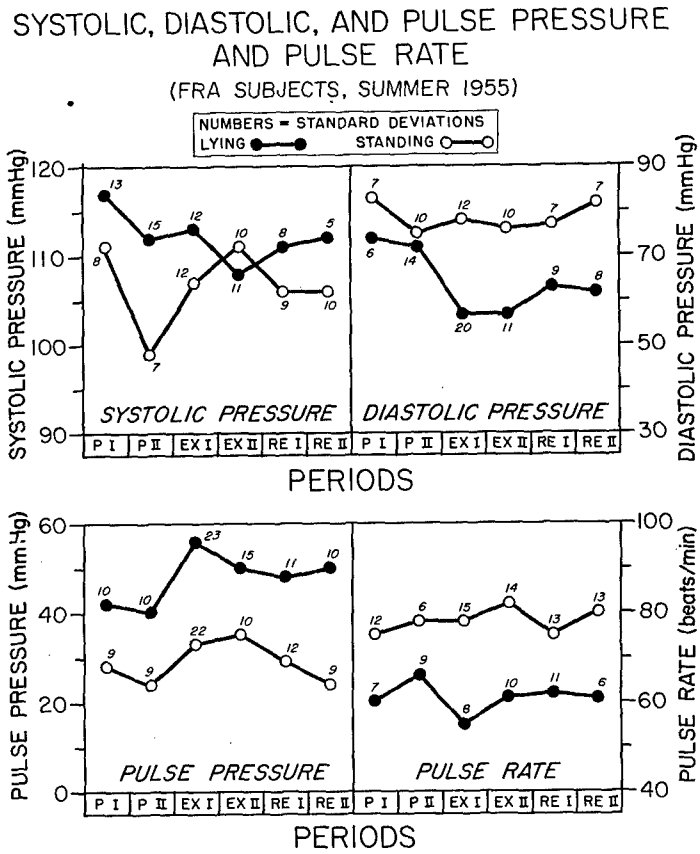


FIGURE III. 109. SYSTOLIC BLOOD PRESSURE: EXP SUBJECTS.

TABLE III. 294

PRE-PERIOD DATA ON POSTURAL CHANGE OF SYSTOLIC BLOOD PRESSURE
(mm Hg)

A. MEAN POSTURAL CHANGE

Period	Flight 1	2	3	4	FRA
P I	+2	-3	-4	-3	- 6
P II	+5	-4	+4	-2	-13

B. FREQUENCY DISTRIBUTION

Class Interval	No.	%
75-85	0	0.00
65-75	0	0.00
55-65	0	0.00
45-55	0	0.00
35-45	1	0.60
25-35	5	2.98
15-25	16	9.52
(+) 5-15	43	25.58
5-5	42	24.99
5-15	35	20.82
(-)15-25	15	8.92
25-35	5	2.98
35-45	4	2.38
45-55	1	0.60
55-65	1	0.60
65-75	0	0.00
Total	168	99.97
Mean	-6±16	

TABLE III. 295

SYSTOLIC BLOOD PRESSURE INCREMENT
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	+5	0	-7	+2	-12	-4	-1	+16	-7	-8*	-2	+5
	L	-5	-4	-10	-18	-5	-7	-13	+4	-16	-28	-10	+7
0/100/0	U	+2	+24	+11	0	-16	+17	-5	+10	-11	+1	-16	-1
1000	L	+4	-15	-7	-18	-14	-1	-16	-2	-23	-16	+19	-1
0/100/0	U	+8	+6	+3	0	-6	-8	+5	0	-2	-9	-10	-8
2000	L	0	+9	-7	-8	+8	0	+7	-14	-10	-21	+20	-2
2/20/78	U	+9	-5	-17	-2	-3	+2	-8	-17	-7	-11	+20	0
1000	L	-7	-6	+3	+12	-11	-4	+2	+7	-8	-25	-7	-9
2/20/78	U	+12	+13	+3	+10	---	---	-7	+3	-2	-2	+14	+2
2000	L	-21	+2	+4	-12	-9	0	0	-1	-10	-9	-2	0
15/52/33	U	-16	+12	-24	-34	-9	-19	0	+12	-12	-3	-3	-8
1000	L	+4	0	+4	-23	---	---	+6	-3	-8	-4	-13	-3
15/52/33	U	-19	-14	-10	+6	-14	-20	-18	-12	-26	-9	-4	-2
2000	L	+21	+3	-8	-2	-8	+14	0	-6	-2	-3	+5	-15
15/52/33	U	-14	+29	-2	-6	+10	-2	-4	+3	+7	-6	+16	+6
3000	L	+1	+2	+3	-6	-12	-16	+2	-30	---	---	---	---
30/0/70	U	+15	+5	-22	+4	-7	-6	+16	+14	-6	+10	-15	+2
1000	L	-2	+3	-24	-16	+16	+2	-3	+8	-22	-16	-3	0
30/0/70	U	+8	-12	-25	+1	-18	+2	-8	+1	-5	-12	+5	-8
2000	L	-20	-29	-28	-36	-12	-12	-2	+5	-3	-21	-14	-10
FRA	U	-13	-10	-3	-5	-8	-8	-6	-17	-2	+11	-5	+1
	L	0	-28	-16	-2	-8	-3	-3	-3	-6	+1	-1	-13

*Systolic pressure undetectable in one subject; value given is mean for other four men.

TABLE III. 296

SUMMARY OF STATISTICALLY SIGNIFICANT POSTURAL DECREMENTS OF SYSTOLIC PRESSURE (mm Hg)

Group	Period	Decrement	"t"	P
Flight 1	EXP I	8.85	2.67	<0.02
	REC I	9.42	2.59	<0.02
Flight 2	EXP I	7.75	2.00	<0.05
	EXP II	14.22	3.71	<0.001
Flight 4	EXP I	12.55	2.90	<0.01
	EXP II	15.67	4.40	<0.001
FRA	PRE II	12.63	2.37	<0.05

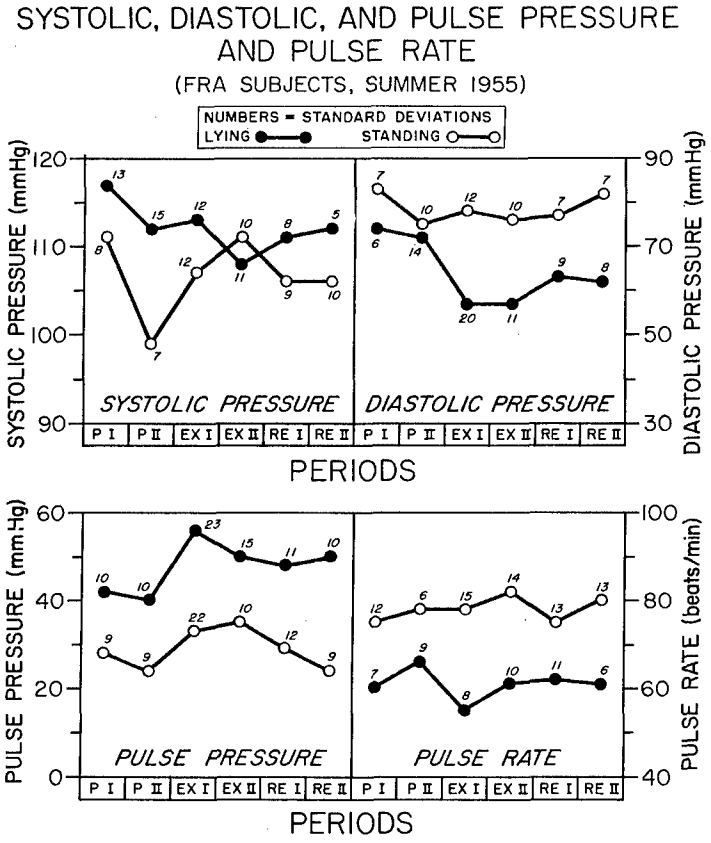


FIGURE III. 110. SYSTOLIC, DIASTOLIC AND PULSE PRESSURE AND PULSE RATE: FRA SUBJECTS.

Diastolic Blood Pressure. The pre-period data are presented in Table III. 297. The mean values for the reclining values are similar for the five groups and for the two periods. The standing values are higher than those measured during reclining, a point we shall discuss in more detail below. Flight 2 and the FRA's show significant decreases from P I to P II in standing pressures.

Reclining diastolic pressure: Inspection of Table III. 298 bring out several significant observations. (1) Beginning in P II subjects began to exhibit very low reclining diastolic pressures. (2) These hypotensive pressures are apparently independent of nutrient mixture and experimental regimen. Low levels of diastolic pressure were observed in P II, EXP I, EXP II, REC I, and REC II. They appeared in men on all diets except 0/100/0 1000 and 15/52/33 1000, 2000, and 3000. Water intake and work load do not appear significantly correlated. (3) The occurrence of hypotension was associated with hot weather. The weather (Figure III. 1) was relatively cool in P I but became hot and remained hot in the remaining periods. Possibly this hypotension reflected a vaso-vagal response to heat stress.

To evaluate this phenomenon further, we must define diastolic hypotension in terms of the present data. Since no low diastolic pressures occurred in P I, we can use the data of this period. According to Table III. 297, the mean diastolic pressure in P I was about 70 mm Hg and the mean standard deviation was about ±10 mm Hg. We therefore define hypotension as 70 minus 3 x 10 equals 40 mm Hg or less. The diastolic pressures of all men exhibiting such a hypotension at least once have been detailed in Table III. 299. Two types of observations have been included: (1) diastolic pressures of 40 mm Hg or less and (2) instances in which an anticubital fossal murmur was detected even with zero pressure in the cuff. Either type of observation may be attributed to marked reduction in peripheral resistance (peripheral vasodilatation).

Study of Tables III. 299 and III. 300 reveals the following facts: (1) Twenty-six subjects developed hypotension at least once during the six-week period; 11 of the cases appeared among men in Flight 2 and 7 in Flight 4. The other 8 cases were distributed rather equally among the remaining groups. (2) In P I the diastolic pressures of these men who subsequently developed hypotension did not differ significantly from the mean diastolic pressures of each of the entire flights. (3) Nine of the 26 men exhibited hypotension twice and one three times. (4) The frequency of hypotension was greatest in REC I.

These observations suggest the following conclusions: (1) Hypotension was brought on in 26% of the subjects by the hot weather. (2) The hypotension was greatest in REC I, at a time when large shifts of water from extracellular spaces into blood normally occurs (WADC TR 53-484, Parts 1 and 2). This phenomenon might explain the high occurrence of hypotension among the men of Flights 2 and 4, especially in REC I and II. These men, it will be recalled, had been on restricted water intake in the experimental periods. The increased frequency of hypotension in REC I and II was in large part due to low pressures among the men of these flights (Table III. 301). (3) Since ten of the men developed hypotension at least twice, it is probable that cardiovascular

adjustment during acclimatization was not occurring among these men. This conclusion is further supported by the greater frequency of hypotension in the recovery periods than in the pre-period and experimental periods.

These trends are also clearly in evidence for the four flights as a whole and for the FRA subjects (Table III. 301 and Figures III. 110 and III. 111). Reclining diastolic pressures declined progressively from P I to REC I and then began to rise in REC II. Exceptions were Flight 4 which reached minimum diastolic values in EXP I and FRA's who reach low diastolic values in EXP II. The evidence strongly suggests that we deal with a nonspecific vascular reaction to the warm weather. When P I values were compared with the lowest values in subsequent periods, four of five comparisons were highly significant (Table III. 301). In the case of Flight 2, the difference was significant at the 10% level. The low P value was due to the high s.d. of REC II. In the light of the general trend, we are inclined to accept this value as having a similar physiological significance.

Standing diastolic pressure: The physiological reaction to standing is an increase in diastolic pressure. Schneider and Truesdell found that, on the average, the diastolic pressure increased 8 mm Hg, Emery, 5 mm Hg (Table III. 286). Our data are very similar (Table III. 302) for the pre-period. The average increase was 5±17.

When we examine the data for standing diastolic pressure (Table III. 303) and change in pressure on standing (Table III. 304), the outstanding observation is that the majority of the subjects adequately maintained their diastolic pressure on standing. Only four men developed diastolic hypotension on standing (pressures of 45 mm Hg or less) (Table III. 305). Three instances of such low diastolic pressures took place in the experimental periods and one each in the pre- and recovery periods. Three of the subjects (26, 56, and 84) with standing diastolic hypotension also had standing systolic hypotension (Table III. 291); one (26) also had reclining diastolic hypotension (Table III. 299).

Since nutrient mixture seemed to have relatively little effect on the diastolic blood pressure, we have called averages for the men in each flight and in each period. The data are presented in Table III. 301 and Figures III. 110 and III. 111. Study of this material brings out several significant facts. (1) There was a tendency for the standing diastolic pressure to increase from period to period. Because the lying pressure tended to fall, the postural increment became progressively greater. (2) During the experimental periods there was a tendency for the standing diastolic pressure to fall (Figure III. 111). The decrease tended to be greater among men on limited water than on unlimited water and was greatest in the case of Flight 2. As a matter of fact there was also a marked decrease in the postural increment of diastolic pressure in this flight. The men were not able to maintain their pressure under the stress of gravity. Here again is strong evidence of potential vascular collapse. We interpret the changes as sub-clinical heat exhaustion accentuated by dehydration. The FRA subjects did not exhibit much variation of the standing diastolic pressure (Figure III. 110). This fact supports the idea that dehydration played a significant role. The lowest diastolic pressure

for the FRA's occurred in P II. At this time the standing increment was smallest. At the same time the standing systolic was low. These observations support the idea that these subjects reacted to the onset of heat by developing signs of heat syncope.

Statistical analysis of the data supports these inferences. The decreases in standing diastolic pressure from P I to the lowest values in subsequent periods were significant at the 1% level for only Flight 2 (P 0.005). The decreases were significant at the 5% level for Flight 3 and FRA. Thus, in the group exposed to the hardest work and the greatest possible dehydration, we find that the inability to maintain diastolic pressures has deteriorated. A negative test of the same phenomenon would be failure to maintain a standing pressure higher than that measured during reclining. During the pre-periods the majority of the flights exhibited standing diastolic pressures which were significantly higher than lying diastolic pressures (Table III. 306). Inspection of Figures III. 111 reveals that during the experimental periods, it was again Flight 2 that exhibited the greatest decrease in postural increment of diastolic pressure. Flight 1 showed a smaller decrease in EXP I and Flight 4 in EXP II. On the average, however, there was never a decrement. The large standard deviations for Flight 2 and 4 on the other hand, indicate a high order of individual variability and some men did, in fact, show a decrease in diastolic pressure on standing. Striking instances are presented in Table III. 305.

TABLE III. 297

PRE-PERIOD DATA ON DIASTOLIC BLOOD PRESSURE
(mm Hg)

Flight	P I				P II			
	N	M	s.d.	C.V.	N	M	s.d.	C.V.
				Reclining				
1	22	68	8	11.8	21	68	13	19.1
2	21	63	10	15.9	21	63	11	17.5
3	21	73	10	13.7	21	68	22	32.4
4	21	70	10	14.3	22	60	13	21.7
FRA	12	74	6	8.1	11	72	14	19.5
				Standing				
1	22	78	8	10.2	21	79	8	10.1
2*	19	80	9	11.2	21	72	8	11.1
3	21	79	10	12.6	21	77	8	10.4
4	21	70	20	28.6	22	71	7	9.9
FRA**	12	83	7	8.4	11	75	10	13.3

*"t" test on P I vs. P II
*P less than 0.005
**P less than 0.05

TABLE III. 298

RECLINING DIASTOLIC BLOOD PRESSURE
(mm Hg)

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC I	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC I	REC II
ST 0	U	68	63	77	50	61	63	76	70	58	68	63	65
	L	62	61	69	66	41	56	72	60	34	58	57	49
0/100/0	U	67	62	71	54	60	76	66	58	63	74	56	63
1000	L	58	60	60	59	31	68	80	71	80	59	59	65
0/100/0	U	64	58	64	58	53	68	78	78	74	71	67	79
2000	L	56	60	74	43	71	70	65	75	64	60	58	66
2/20/78	U	73	75	64	80	64	82	82	86	56	78	52	66
1000	L	75	71	29	53	73	59	63	56	54	74	62	64
2/20/78	U	68	82	61	48	68	--	72	64	59	63	54	62
2000	L	74	61	51	34	48	58	69	58	44	76	70	56
15/52/33	U	73	68	57	70	66	59	72	15	61	63	55	66
1000	L	60	60	70	--	--	--	66	48	56	64	63	69
15/52/33	U	64	70	66	58	60	64	76	92	70	64	65	76
2000	L	62	70	58	62	20	50	63	42	56	55	54	53
15/52/33	U	73	67	59	66	53	75	69	72	61	70	56	67
3000	L	59	61	55	55	43	62	80	78	--	--	--	--
30/0/70	U	64	69	80	62	58	67	74	82	48	62	62	54
1000	L	52	57	61	62	65	68	75	60	57	62	63	67
30/0/70	U	62	72	81	69	55	57	63	69	48	54	56	63
2000	L	68	67	32	63	70	48	59	58	44	78	58	52
FRA		74	72	57	57	63	62	74	72	57	57	63	62

TABLE III. 299

DIASTOLIC BLOOD PRESSURES OF MEN
WITH RECLINING HYPOTENSION

Flight	Subject Code No.	Diastolic Pressure, mm Hg P I	P II	E I	E II	R I	R II
1	4	74	56	84	56*	58	52/0
	22	72	84	46	62	38	72
Mean P I =		73	(Entire Flight = 68±8)				
2	26	55	68	60	60	10	36
	27	50	34	63	40	0	58
	29	50	54	76	18	64	62
	31	55	60	66	--	--	--
	33	60	60	64	60	63	34
	34	76	74	0	66	76	62
	36	86	64	0	46	82	58
	37	74	64	62	68	40	62
	38	74	58	40	0	56	54
	42	66	78	58	62	20	50
	43	58	64	56	54	28	64
Mean P I =		64	(Entire Flight = 63±10)				
3	61	85	30	68	76	56	68
	62	60	0	54	50	54	64
Mean P I =		68	(Entire Flight = 73±10)				

Flight	Subject Code No.	Diastolic Pressure, mm Hg P I	P II	E I	E II	R I	R II
4	67	70	57	0	62	58/0	58
	68	70	65	0	50*	54/0	--
	69	80	58	72	54	56/0	30
	82	--	60	28	--	----	--
	83	74	34	56	60	66	70/0
	85	70	28	74	62	56	48/0
	86	56	50	42	48	52	58/0
Mean P I =		70	(Entire Flight = 70±10)				
FRA	91	72	50	64	60/0	62	58
	92	72	70	64	40/0	52	56
	94	67	64	0	54	58	58
	102	--	--	--	36	44	56
	31	--	--	--	62	70	48/0
	82	--	--	--	--	--	42
Mean P I =		70	(Entire Flight = 74±6)				

*On rehabilitation diets.

TABLE III. 300

FREQUENCY OF RECLINING HYPOTENSION:
DIASTOLIC PRESSURE <40 mm Hg

Flight	P I	P II	E I	E II	R I	R II
1	0	0	0	0	1	1
2	0	1	3	3	5	2
3	0	2	0	0	0	0
4	0	2	3	0	3	4
FRA	0	0	1	3	1	1
Total	0	5	7	6	10	8

TABLE III. 301

DIASTOLIC BLOOD PRESSURE: RECLINING VS. STANDING*
(mm Hg)

	Flight 1		Flight 2		Flight 3		Flight 4		FRA	
Period	Lying	Stand	Lying	Stand	Lying	Stand	Lying	Stand	Lying	Stand
PRE I	68± 8	78± 8	63±10	80± 9	73±10	79±10	70±10	70±20	74± 6	83± 7
PRE II	68±13	79± 8	63±11	72± 8	68±22	77± 8	60±13	71± 7	72±14	75±10
EXP I	68±11	74± 8	56±21	76±17	61±14	72± 9	52±23	65±21	57±20	78±12
EXP II	63± 9	77±13	56±19	60±23	67± 8	75±20	64±10	69± 9	57±11	76±10
REC I	59± 7	78±10	52±23	67±10	59± 7	78± 9	60± 6	77±14	63± 9	77± 7
REC II	66±11	83±10	60±12	76± 9	66±10	79±12	60±10	80± 8	62± 8	82± 7

*Underlined values significantly different by "t" test at 1% level.

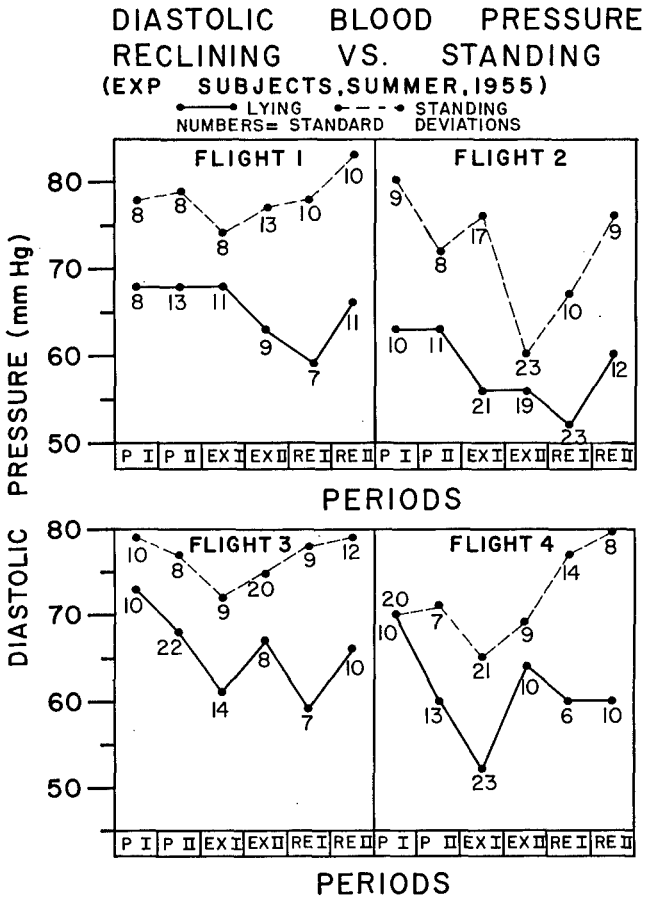


FIGURE III. 111. DIASTOLIC BLOOD PRESSURE: EXP SUBJECTS.

TABLE III. 302

PRE-PERIOD DATA ON POSTURAL CHANGE
OF DIASTOLIC BLOOD PRESSURE
(mm Hg)

A. MEAN POSTURAL CHANGE

Period	Flight 1	2	3	4	FRA
P I	+10	+18	+6	+ 1	+9
P II	+13	+ 9	+9	+11	+3

B. FREQUENCY DISTRIBUTION

Class Interval	No.	%
75-85	1	0.60
65-75	0	0.00
55-65	0	0.00
45-55	1	0.60
35-45	4	2.38
25-35	20	11.90
15-25	36	21.42
(+) 5-15	45	26.78
5- 5	32	19.04
(-) 5-15	22	13.09
15-25	5	2.98
25-35	1	0.60
35-45	0	0.00
45-55	0	0.00
55-65	1	0.60
65-75	0	0.00
Total	168	99.99
Mean	+5±17	

TABLE III. 303

STANDING DIASTOLIC BLOOD PRESSURE
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	76	76	68	100	67	77	82	78	73	70	80	80
	L	85	68	82	68	60	65	74	61	60	64	60	72
0/100/0	U	72	87	81	86	86	90	64	68	74	67	72	70
1000	L	82	71	87	70	60	79	78	73	75	78	96	83
0/100/0	U	78	79	74	70	76	82	90	85	83	85	84	92
2000	L	77	79	80	73	76	85	83	77	---	---	100	94
2/20/78	U	72	90	78	90	85	96	81	74	60	83	88	80
1000	L	80	66	72	72	68	84	67	60	66	64	76	71
2/20/78	U	88	84	85	90	---	---	77	76	73	87	73	79
2000	L	69	70	72	65	64	84	70	75	79	75	68	86
15/52/33	U	82	80	70	64	80	72	89	75	71	84	78	65
1000	L	74	70	58	---	---	---	83	80	54	59	71	85
15/52/33	U	80	77	69	68	76	82	83	80	81	82	76	78
2000	L	90	80	74	58	73	70	43	80	44	68	85	80
15/52/33	U	82	74	78	93	94	94	75	82	63	88	76	75
3000	L	78	78	72	66	75	73	68	73	---	---	---	---
30/0/70	U	78	79	71	65	78	84	70	76	70	64	69	78
1000	L	82	70	72	62	68	80	75	78	68	81	90	82
30/0/70	U	75	69	74	70	68	74	69	67	65	35	68	76
2000	L	82	69	78	67	67	70	64	66	90	68	73	76
FRA		83	75	78	76	79	82	83	75	78	76	79	82

TABLE III. 304

DIASTOLIC BLOOD PRESSURE INCREMENT
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	+8	+13	-9	+27	+6	+17	+6	+10	+9	+6*	+22	+21
	L	+22	+7	+13	+2	+19	+9	+1	+1	+25	+6	+3	+24
0/100/0	U	+6	+25	+10	+32	+26	+14	-2	+10	+11	-7	+16	+7
1000	L	+24	+11	+26	+11	+27	+11	-2	+2	-5	+19	+36	+18
0/100/0	U	+13	+22	+10	+12	+24	+2	+12	+8	+10	+17	+17	+12
2000	L	+21	+19	+6	+14	+5	+15	+18	+4	-14	+13	+42	+28
2/20/78	U	0	+16	+14	+10	+21	+14	-1	-12	+4	+13	+36	+14
1000	L	+5	-5	+31	+17	-5	+25	+4	+4	+12	-10	+14	+6
2/20/78	U	+20	+2	+24	+42	---	---	+4	+12	+14	+24	+19	+16
2000	L	-5	+9	+21	+24	+16	+26	+2	+17	+31	-1	-2	+30
15/52/33	U	+10	+12	+13	+13	+14	+14	+16	+60	+10	+20	+22	-1
1000	L	+16	+10	-12	-2	---	---	+17	+32	-2	-4	+8	+16
15/52/33	U	+16	+7	+3	+10	+16	+18	+7	-12	+11	+18	+11	+3
2000	L	+28	+9	+16	-4	+53	+20	-20	+41	-14	+13	+31	+27
15/52/33	U	+10	+23	+19	+27	+40	+19	+6	+10	+2	+18	+20	+8
3000	L	+16	+16	+18	+11	+32	+11	-12	-4	---	---	---	---
30/0/70	U	+14	+10	-9	+3	+20	+18	-4	-6	+22	+2	-7	+24
1000	L	+30	+13	+12	+8	+3	+12	0	+18	+10	+19	+26	+15
30/0/70	U	+12	-3	-7	+1	+14	+17	+6	-2	+17	-19	+12	+13
2000	L	+14	+5	+46	+8	-2	+22	+4	+8	+46	-10	+15	+24
FRA	U	+17	-3	+19	+23	+17	+19	-4	-11	+23	+24	+5	+18
	L	+10	+10	+28	+17	+15	+27	+12	+17	+18	+12	+18	+10

*Diastolic pressure undetectable in one subject; value given is mean for other four men.

TABLE III. 305

DIASTOLIC BLOOD PRESSURES OF MEN WITH STANDING HYPOTENSION

Flight	Subject Code No.	Diastolic Pressure, mm Hg P I	P II	E I	E II	R I	R II
2	26	72	60	70	64	42	54
3	56	64	68	74	0	72	82
4	84	84	86	30	52	68	85
	86	0	80	0	58	82	76

TABLE III. 306

STATISTICAL ANALYSIS OF PRE-PERIOD DATA ON POSTURAL INCREMENT OF DIASTOLIC BLOOD PRESSURE

A. SUMMARY OF MEANS

Flight	P I Standing	P I Reclining	P II Standing	P II Reclining
1	78 ± 8	68 ± 8	79 ± 8	68 ± 13
2	80 ± 9	63 ± 10	72 ± 8	63 ± 11
3	79 ± 10	73 ± 10	77 ± 8	68 ± 22
4	70 ± 20	70 ± 10	71 ± 7	60 ± 13
FRA	83 ± 7	74 ± 6	75 ± 10	72 ± 14

B. STATISTICAL ANALYSIS

1	4.32	<0.001	3.39	<0.005
2	5.94	<0.001	3.04	<0.005
3	1.72	<0.10	1.64	0.10
4	n.s.	-----	3.48	<0.005
FRA	3.29	<0.005	n.s.	-----

Pulse Pressure. Pre-period data on reclining and standing pulse pressure are presented in Table III. 307. The reclining pulse pressure was remarkably stable from group to group and from period to period. The standing pulse pressure was lower than the reclining pressure because of the decrease in systolic pressure and rise in diastolic pressure. Only one group, Flight 2, showed a significant change from P I to P II. In these men, values for pulse pressure are smaller than observed by Schneider and Truesdell (Table III. 286).

Reclining pulse pressure: The data for the several groups are summarized in Table III. 308. They reflect, in mirror image, the changes previously described for diastolic pressure and thus need not be described in detail. (Compare Figures III. 111 and III. 112).

Standing pulse pressure: On the average, all groups of men exhibited, in the pre-periods, a decrease of pulse pressure on standing; the mean decrease for both periods was 5 mm Hg (Table III. 309). Schneider and Truesdell reported a mean decrease of 6 mm Hg and Emery, 5 mm Hg (Table III. 286).

The data for standing pulse pressure and postural change in pulse pressure are detailed in Tables III. 310 and III. 311. In general, they reflect the alterations already described for systolic and diastolic pressures; viz., a tendency to decrease during experimental periods. A number of men were observed to have had very small pulse pressures on standing (5-10 mm Hg). According to Ladell, Waterlow, and Hudson (1944), a small pulse pressure is characteristic of the vascular alterations seen in heat exhaustion. These trends are presented in Table III. 312 and Figures III. 110 and III. 112. It is significant, we feel, that while the experimental subjects tended to have smaller standing pulse pressures in EXP I and EXP II (Figures III. 112), the FRA control tended to have larger pressures (Figure III. 110).

TABLE III. 307

PRE-PERIOD DATA ON PULSE PRESSURE
(mm Hg)

Flight	N	M	s.d.	C.V.	N	M	s.d.	C.V.
				Reclining				
1	22	41	12	29.3	21	40	14	35.0
2	21	43	11	26.0	21	44	13	29.6
3	21	39	12	30.8	21	39	18	46.1
4	21	39	10	25.6	22	46	44	30.4
FRA	12	42	10	23.8	11	40	11	27.5
				Standing				
1	22	33	9	27.3	21	32	11	34.4
2*	19	23	6	26.1	21	31	10	32.3
3	21	29	8	27.6	21	34	11	29.4
4	21	36	20	55.6	22	32	12	37.5
FRA	12	28	9	32.1	11	24	9	37.5

"t" test on P I vs. P II
*P less than 0.005

TABLE III. 308

RECLINING PULSE PRESSURE
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	40	47	32	50	47	43	44	37	47	30	43	48
	L	45	49	34	42	59	54	42	40	72	55	52	48
0/100/0	U	41	49	28	62	72	42	34	36	31	23	47	35
1000	L	42	54	40	43	75	29	40	40	41	56	35	55
0/100/0	U	30	42	35	51	51	43	32	38	37	45	43	38
2000	L	52	47	31	60	31	36	55	52	56	54	48	62
2/20/78	U	26	41	46	40	44	34	36	27	53	38	46	40
1000	L	31	32	67	49	37	49	36	36	42	30	34	46
2/20/78	U	42	27	54	72	62	--	38	42	58	52	48	52
2000	L	35	46	50	75	60	47	34	40	75	38	32	52
15/52/33	U	55	31	58	55	47	51	34	80	44	37	53	43
1000	L	36	40	40	--	--	--	35	52	34	27	45	39
15/52/33	U	55	38	34	56	44	56	52	20	54	44	52	32
2000	L	36	32	46	50	88	48	45	69	53	48	48	71
15/52/33	U	50	23	38	56	45	32	36	40	46	30	47	37
3000	L	34	32	36	48	57	48	36	56	--	--	--	--
30/0/70	U	36	51	37	60	53	48	28	24	66	36	50	50
1000	L	52	48	60	48	25	26	34	41	66	50	44	41
30/0/70	U	40	43	34	51	54	53	39	39	62	42	50	41
2000	L	58	54	93	54	42	55	36	42	56	26	42	46
FRA		42	40	56	50	48	50	42	40	56	50	48	50

TABLE III. 309

PRE-PERIOD DATA ON POSTURAL CHANGE OF PULSE PRESSURE (mm Hg)

A. MEAN POSTURAL CHANGE

Period	Flight 1	2	3	4	FRA
P I	-8	-18	-7	- 4	-13
P II	-8	-12	-5	-14	-16

B. FREQUENCY DISTRIBUTION

Class Interval	No.	%
75-85	0	0.00
65-75	0	0.00
55-65	1	0.60
45-55	0	0.00
35-45	0	0.00
25-35	2	1.19
15-25	8	4.76
(+) 5-15	20	11.90
5-5	36	21.42
(-) 5-15	40	23.80
15-25	32	19.04
25-35	15	8.92
35-45	9	5.36
45-55	2	1.19
55-65	2	1.19
65-75	1	0.60
Total	168	99.97
Mean	-5±18	

TABLE III. 310

STANDING PULSE PRESSURE
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	37	34	35	5	29	22	37	43	29	20	23	28
	L	18	38	11	21	35	38	28	44	31	21	38	31
0/100/0	U	38	48	29	30	30	45	31	36	9	31	15	27
1000	L	22	28	11	14	32	17	28	36	23	21	18	36
0/100/0	U	31	26	28	39	22	21	25	30	26	19	17	18
2000	L	32	37	19	14	34	21	45	34	32	20	--	--
2/20/78	U	35	21	16	28	20	22	28	23	42	14	30	26
1000	L	20	31	27	28	31	20	34	39	22	15	13	31
2/20/78	U	35	37	33	40	--	--	27	33	42	27	43	34
2000	L	19	39	33	46	35	21	32	23	30	30	32	22
15/52/33	U	30	31	21	27	24	19	18	31	22	14	28	36
1000	L	28	31	56	--	--	--	24	17	28	29	24	20
15/52/33	U	20	17	21	52	14	18	27	21	17	17	37	27
2000	L	28	26	22	52	27	54	66	22	65	27	22	29
15/52/33	U	27	27	17	23	14	11	26	33	51	6	43	35
3000	L	22	17	22	31	14	16	50	31	--	--	--	--
30/0/70	U	43	46	24	61	26	25	48	44	38	44	28	28
1000	L	21	38	25	16	38	16	31	31	33	16	15	26
30/0/70	U	35	34	16	51	23	20	25	42	40	49	43	20
2000	L	25	20	20	15	34	21	30	38	7	15	13	12
FRA		28	24	33	35	29	24	28	24	33	35	29	24

TABLE III. 311

PULSE PRESSURE INCREMENT
(mm Hg)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	-4	-14	+3	-25	-18	-21	-7	+5	-15	-14*	-20	-20
	L	-28	-11	-23	-21	-24	-16	-14	+4	-42	-34	-14	-17
0/100/0	U	+4	-1	+1	-32	-42	+3	-3	0	-22	+8	-32	-8
1000	L	-20	-26	-34	-29	-43	-12	-13	-4	-18	-35	-18	-19
0/100/0	U	0	-16	-7	-12	-24	-22	-7	-7	-12	-25	-26	-20
2000	L	-14	-10	-12	-22	+3	-15	-10	-18	-24	-34	-22	-30
2/20/78	U	+10	-20	-30	-12	-24	-12	-8	-4	-11	-24	-16	-14
1000	L	+10	-1	-40	-5	-6	-29	-2	+3	-20	-15	-21	-16
2/20/78	U	-7	+11	-21	-32	---	---	-10	-14	-16	-26	-5	-18
2000	L	-16	-6	-17	-36	-27	-26	-2	-18	-45	-8	0	-30
15/52/33	U	-25	0	-37	-28	-24	-32	-16	-48	-22	-24	-26	-19
1000	L	-11	-9	+16	-21	---	---	-12	-35	-6	+2	-21	-19
15/52/33	U	-35	-21	-13	-4	-30	-38	-1	+1	-37	-27	-15	-5
2000	L	-8	-6	-24	+2	-61	-8	+21	-48	+11	-16	-26	-42
15/52/33	U	-24	+6	-21	-33	-30	-22	-10	-7	+5	+2	-4	-2
3000	L	-14	-15	-14	-17	-44	-32	+14	-26	---	---	---	---
30/0/70	U	+2	-5	-13	+1	-27	-24	+20	+20	-28	+8	-22	-22
1000	L	-32	-10	-36	-24	+13	-10	-3	-10	-33	-35	-30	-15
30/0/70	U	-4	-9	-18	0	-32	-33	-14	+2	-22	-7	-7	-20
2000	L	-33	-34	-74	-8	-8	-30	-6	-4	-49	-11	-29	-34
FRA	U	-29	-7	-22	-17	-25	-5	+2	-7	-25	-14	-10	-23
	L	-10	-38	-43	-19	-23	-30	-16	-20	-24	-12	-20	-23

*Blood pressure undetectable for one subject; value shown is mean for other four subjects.

TABLE III. 312

PULSE PRESSURE: RECLINING VS. STANDING
(mm Hg)

	Flight 1		Flight 2		Flight 3		Flight 4		FRA	
Period	Lying	Stand	Lying	Stand	Lying	Stand	Lying	Stand	Lying	Stand
PRE I	41±12	33± 9	42±10	23± 6	39±12	29± 8	39±10	36±20	42±10	28± 9
PRE II	40±14	32±11	44±13	31±10	39±18	34±10	46±14	32±12	40±11	24± 9
EXP I	39±12	24± 9	49±27	22±12	48±13	30±16	57±29	31±21	56±23	33±22
EXP II	55± 7	37±16	51±18	25±14	37±11	23±16	43±13	21± 8	50±15	35±10
REC I	51± 9	23± 7	53±20	31±10	47± 7	30±13	44± 9	24±11	48±11	29±12
REC II	45± 8	21± 9	45±20	24±11	42±12	28± 9	50±13	28± 9	50±10	24± 9

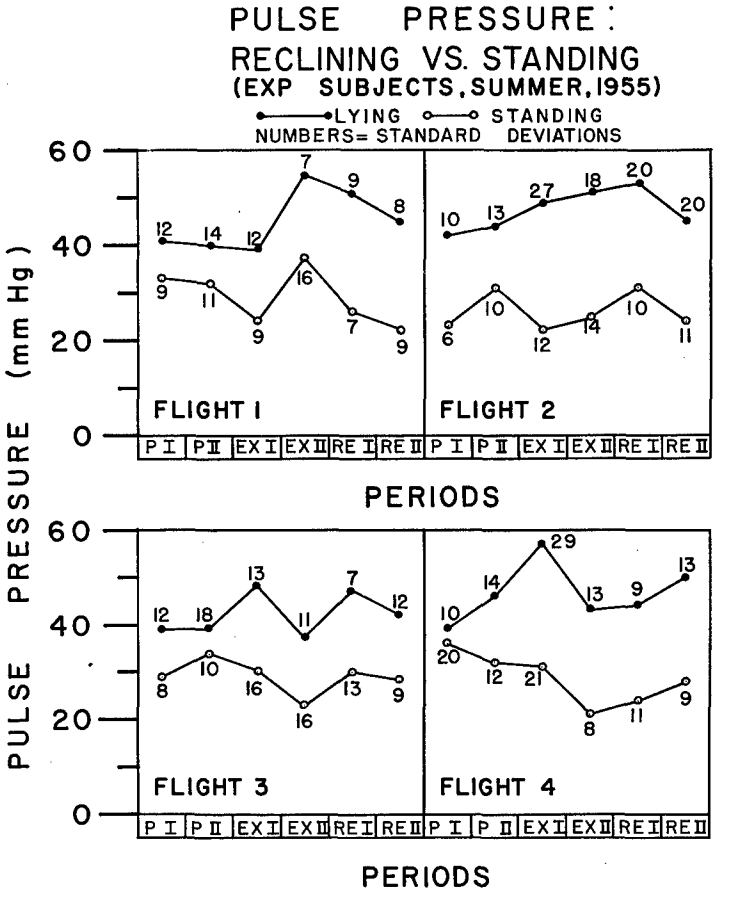


FIGURE III. 112. PULSE PRESSURE: EXP SUBJECTS.

Pulse Rate. Pre-period data on pulse rate are presented in Table III. 313. The pulse rate of the reclining subject was slow by usual standards. For the men on 5-in-1 ration, the mean rate was 59±8 in P I and 62±9 in P II. These values are considerably slower than those reported by Schneider and Truesdell and Emery (Table III. 286). Furthermore they are slower than those observed during the 1954 winter test (Sargent et al., 1955). On standing the pulse rates rose and the interindividual variability increased. The mean standing pulse rate for men on 5-in-1 ration was 76±14 in P I and 79±13 in P II. These values, too, are lower than those of Schneider and Truesdell and Emery (Table III. 286). The postural increment of the pulse rate for the several groups ranged from 12 to 24.

When we analyze the effects of the several experimental regimens on the pulse rate, we are at once faced with certain difficulties. A caloric deficit will cause a bradycardia (Sargent et al., 1954, 1955). The preceding evidence concerning blood pressure suggested that a number of the subjects may have had various degrees of early heat exhaustion. Certainly they exhibited a clear trend toward lowered blood pressure. Such a trend would be expected to cause an elevation of the pulse rate. These opposite tendencies might lead to one of three results: (1) no change in pulse rate, (2) elevated pulse rate, and (3) lowered pulse rate.

The detailed data on pulse rate during the three periods of the summer study are given in Tables III. 314 for reclining pulse, Table III. 315 for standing pulse rate, and Table III. 316 for increment of pulse rate. The influence of caloric intake is summarized in Table III. 317. A study of that table brings out the fact that the lowest reclining pulse rates were among the men on starvation. With increasing caloric intake the pulse rate tended to increase. Men on 3000 Cal/day exhibit no more variability than the FRA controls. No consistent effect of water intake is evident. In contrast were the variations of the standing pulse rate. The most rapid pulse rates were among the men on starvation. The other subjects, on the whole, failed to show any consistent caloric influence. Furthermore, restriction of water did not materially affect the pulse rate.

Since the most striking alterations in blood pressure were noted when the subjects were required to stand, we might anticipate that the systolic hypotension would be associated with a tachycardia. Table III. 318 contains standing pulse rates of the men who were considered to have had standing systolic hypotension. Tachycardia, by definition, is a pulse rate greater than 100 beats/min. Using the pre-period data, we find that such a pulse rate is approximately two standard deviations greater than the mean for P I. It is certain from Table III. 318 that standing systolic hypotension was not the only cause of tachycardia. Moreover, when the subject had a low systolic pressure on standing, he did not necessarily have a rapid pulse. These facts suggest that, under the conditions of our testing, we either missed the expected tachycardia or the subjects had made a rapid reflex adjustment so that an undue increase in the heart rate was not required. Certainly the heart rate increased

on standing but the increase was no greater for the hypotensive men than for those who were able simultaneously to maintain their blood pressure.

The general incidence of tachycardia is also of some interest and strongly suggests an influence of environmental heat accentuated by the experimental regimen (Table III. 319). With the onset of hot weather late in P I, there was a gradual increase in the incidence of tachycardia from six to fourteen cases. Abruptly, in the recovery periods, the incidence fell. This trend supports inferences elsewhere in this report that the men were actively acclimatizing to heat during the experimental periods. It was during this interval that the greatest incidence of hypotensive states took place.

TABLE III. 313

PRE-PERIOD DATA ON RECLINING AND STANDING PULSE RATE AND PULSE INCREMENT (beats/min)

Flight	P I N	P I M	P I s.d.	P I C.V.	P II N	P II M	P II s.d.	P II C.V.
			Reclining Pulse Rate					
1	22	60	8	13.3	21	60	9	15.0
2	21	59	7	11.9	21	64	7	10.9
3	21	60	8	13.3	21	59	10	16.9
4	21	58	6	10.3	22	64	8	12.5
FRA	12	59	7	11.9	11	66	9	13.6
			Standing Pulse Rate					
1	22	84	18	21.4	21	76	12	15.8
2	19	71	11	15.5	21	81	14	17.3
3	21	73	12	16.4	21	74	11	14.9
4	21	73	10	13.5	22	84	12	14.3
FRA	12	75	12	16.0	11	78	6	7.7
			Pulse Increment					
1	22	24	20	83.3	21	16	10	62.5
2	19	12	9	75.0	21	17	11	64.7
3	21	13	11	84.6	21	15	8	53.3
4	21	15	11	73.4	22	20	15	75.0
FRA	12	16	15	93.8	11	13	9	69.2

TABLE III. 314

RECLINING PULSE RATE
(beats/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	64	51	55	48	64	71	59	58	49	51	59	53
	L	58	66	58	56	51	56	54	64	52	51	58	61
0/100/0	U	67	58	62	50	66	58	66	71	57	58	61	70
1000	L	66	74	53	57	47	62	60	69	45	51	59	57
0/100/0	U	64	50	50	69	66	72	56	58	56	67	59	68
2000	L	56	66	48	55	48	56	62	64	56	68	68	62
2/20/78	U	60	62	54	62	72	62	56	68	54	60	52	54
1000	L	60	70	58	54	61	59	56	60	51	50	59	60
2/20/78	U	56	62	46	56	--	--	60	54	48	46	54	54
2000	L	64	62	51	58	53	63	60	61	50	42	58	56
15/52/33	U	60	67	51	55	78	64	56	58	48	44	54	52
1000	L	52	58	50	--	--	--	65	66	61	56	61	72
15/52/33	U	63	73	52	62	74	76	64	50	51	56	57	56
2000	L	56	62	58	72	50	78	60	68	59	60	59	73
15/52/33	U	56	74	56	69	66	61	58	59	54	58	68	64
3000	L	68	66	62	64	58	70	65	70	--	--	--	--
30/0/70	U	52	56	52	67	60	59	56	52	54	60	62	54
1000	L	54	54	52	56	52	60	54	58	54	54	59	64
30/0/70	U	58	58	52	64	74	71	64	59	57	49	58	59
2000	L	56	60	57	58	55	57	52	59	48	48	62	60
FRA		59	66	55	61	62	61	59	66	55	61	62	61

TABLE III. 315

STANDING PULSE RATE
(beats/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	76	70	83	88	72	68	78	80	98	97	85	79
	L	64	91	101	94	78	85	74	75	80	93	80	84
0/100/0	U	72	64	64	78	80	100	86	84	90	68	98	86
1000	L	88	104	92	89	87	89	78	84	72	69	75	88
0/100/0	U	78	66	64	84	76	63	70	74	88	95	92	95
2000	L	70	82	74	88	72	66	84	92	80	70	94	96
2/20/78	U	78	84	72	96	76	78	66	84	66	80	76	64
1000	L	70	64	85	89	83	75	68	74	66	92	74	80
2/20/78	U	78	70	72	92	--	--	74	73	76	76	67	67
2000	L	68	74	80	84	86	71	70	76	75	66	72	64
15/52/33	U	105	100	74	93	82	84	66	65	75	80	68	78
1000	L	68	74	78	--	--	--	66	76	81	88	85	93
15/52/33	U	93	82	78	84	80	80	72	66	67	90	69	83
2000	L	74	66	72	76	70	78	64	90	75	92	91	83
15/52/33	U	117	83	86	105	96	84	66	72	72	94	80	93
3000	L	86	70	101	80	81	106	68	78	--	--	--	--
30/0/70	U	74	72	82	72	76	82	54	52	64	74	76	62
1000	L	60	66	92	98	78	84	86	104	84	85	85	89
30/0/70	U	76	82	88	70	80	77	78	72	90	66	72	78
2000	L	70	90	86	88	77	79	77	96	64	86	72	66
FRA		75	78	78	82	75	80	75	78	78	82	75	80

TABLE III. 316

RECLINING-STANDING PULSE INCREMENT
(beats/min)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	13	19	28	40	8	-3	20	22	48	46	26	26
	L	6	24	42	38	27	29	17	12	28	42	19	23
0/100/0	U	6	6	2	28	14	42	20	13	58	10	37	16
1000	L	22	30	39	32	40	27	18	15	27	18	16	31
0/100/0	U	13	16	14	15	10	-6	14	16	32	29	33	28
2000	L	14	16	26	33	24	10	22	28	24	2	26	34
2/20/78	U	18	22	18	34	4	16	10	16	12	20	24	14
1000	L	10	14	27	35	22	16	12	14	15	42	16	20
2/20/78	U	22	8	26	36	--	--	14	20	28	30	13	13
2000	L	4	12	29	31	33	8	10	15	25	24	14	8
15/52/33	U	45	33	23	38	4	20	10	7	27	36	14	26
1000	L	16	16	28	--	--	--	1	10	20	32	24	21
15/52/33	U	30	9	26	22	6	4	8	16	16	34	12	31
2000	L	18	4	14	4	20	20	4	22	16	32	32	10
15/52/33	U	61	9	30	36	30	23	8	13	13	36	12	29
3000	L	18	4	39	21	23	36	3	8	--	--	--	--
30/0/70	U	22	16	30	5	16	23	-2	0	10	14	14	8
1000	L	6	12	40	42	26	24	32	46	29	31	26	25
30/0/70	U	18	24	36	6	6	6	14	13	33	17	14	19
2000	L	14	30	29	30	22	22	25	37	16	38	10	6
FRA		16	13	32	21	13	20	16	13	32	21	13	20

TABLE III. 317

INFLUENCE OF CALORIC INTAKE AND WATER INTAKE
ON RECLINING AND STANDING PULSE RATE

Experimental Regimen		P I	P II	E I	E II	R I	R II
			Reclining Pulse Rate				
Control		59	66	55	61	62	61
0 Cal	U	61	55	51	51	61	61
	L	56	65	55	54	55	59
1000 Cal	U	59	62	54	57	63	60
	L	58	64	53	54	57	62
2000 Cal	U	61	58	51	58	62	64
	L	58	63	54	58	56	61
3000 Cal	U	57	66	55	64	67	65
	L	66	68	62	64	58	70
			Standing Pulse Rate				
Control		75	78	78	82	75	80
0 Cal	U	78	76	92	96	80	75
	L	69	84	90	94	79	84
1000 Cal	U	77	77	74	80	80	80
	L	74	83	81	86	81	86
2000 Cal	U	78	73	78	80	76	77
	L	72	83	77	85	80	75
3000 Cal	U	92	78	79	100	88	88
	L	73	74	101	80	81	106

TABLE III. 318

STANDING PULSE RATES OF MEN WITH
SYSTOLIC HYPOTENSION ON STANDING*

Flight	Subject Code No.	Pulse Rate P I	P II	E I	E II	R I	R II
1	18	134	116	68	100	96	104
2	26	72	96	92	94	84	76
	27	88	104	92	96	88	96
	29	68	68	72	68	66	64
	32	68	68	80	98	78	84
	34	88	96	108	104	82	94
3	49	108	80	88	68	88	80
	56	64	60	88	80	70	72
4	70	68	68	80	76	84	90
	79	60	68	64	100	72	88
	80	76	80	68	84	76	72
	84	64	80	72	88	78	90

*Underlined values refer to periods of systolic hypotension.

TABLE III. 319

OCCURRENCE AND MAGNITUDE OF STANDING TACHYCARDIA

Period	Number	Subject Code No.
P I	6	18,21,22,49,76,90
P II	8	18,25,27,28,58,74,76,77
E I	11	21,23,25,31,34,44,45,48,54,76,82
E II	14	18,21,22,25,30,34,39,44,45,47,67,74,79,90
R I	6	21,45,50,51,54,101
R II	5	6,18,25,44,101
Period	**Mean**	**Distribution**
P I	114	100,106,108,116,118,134
P II	106	100(2), 104(3),112(2),116
E I	105	100(3),104(3),106,108(2),112(2)
E II	106	100(4),102,104(2),108(4),112(2),116
R I	106	100(2),104,108(2),116
R II	108	100,104(2),110,126

Clinical Reactions to Standing. The general significance of the various changes observed in the blood pressure and pulse rate is greatly enhanced by the fact that some of the subjects developing symptoms during the period of standing. The reactions enumerated in Table III. 320 are generally those which occur under such circumstances. In a number of instances the dizziness was probably more directly due to the preceding venipuncture. The greatest incidence of reactions, however, was in the experimental period and the majority were among men who were on restricted water. These correlations thus strongly support our objective measurements.

After detailed study of this mass of data, we conclude that Subject 34 had heat exhaustion. This man had been subsisting on 30/0/70 2000 L. He experienced orthostatically provoked symptoms, tachycardia, and marked hypotension on standing. Furthermore, he was among those unable to complete the 3.75-mile march because of physical exhaustion. That aspect of his case has been described in Section III. D.9. It also is certain that a number of other men also had symptoms of heat syncope or mild heat exhaustion. Such reactions were generally attributable to dehydration, for they were most common in the flights which were subsisting on limited water.

TABLE III. 320

CLINICAL REACTIONS TO CHANGE OF POSTURE

PRE I	
#52	Mild vertigo during standing 75 minutes after venipuncture.
#56	Fainted upon standing 18 minutes after venipuncture.
PRE II	
	No cardiovascular reactions noted
EXP I	
#4	Clammy and dizzy while standing
#34*	Slight dizziness while standing
#35	Dizzy on standing
#71	Cyanosis noted in arms
#75	Fainted upon standing 37 minutes after venipuncture; cyanosis noted in arms.
#82	Vertigo and vomiting
EXP II	
#34*	Fainted
#45	Unable to detect blood pressure during standing; pulse rate = 133.
#78	Extrasystoles during standing.
REC I	
#52	Difficult to hear standing blood pressure
#83	Extrasystoles during standing
REC II	
#2	Standing blood pressure difficult to obtain
#21	Thready pulse during standing; rate = 84
#63	Extrasystoles during standing
#64	Thready pulse during standing; rate = 82

*Also had standing systolic hypotension.

6. CENTRAL NERVOUS SYSTEM

There are few reliable quantitative tests of function of the central nervous system which can be used under field conditions. In addition to the clinical examination, therefore, we confined our attention to measuring the passage of time and recording the electroencephalogram. The latter records are incomplete because of the epidemic and will not be reported. The clinical observations will be detailed in a subsequent section.

Passage of Time. All subjects judged the passage of time against a stop watch. The intervals (20,45, and 70 seconds) estimated and the conditions of testing were comparable to those employed in previous investigations (Sargent et al., 1954, 1955). In the pre-periods (Table III. 321), the subjects tended to underestimate the intervals of time; the underestimation was generally greater in P I than in P II. A similar trend was noted among the subjects of the 1954 winter study and was ascribed to age. The hypothesis was suggested (Sargent et al., 1955) that the results confirmed the common feeling that the older one becomes the faster time seems to pass.

Twenty seconds: Through the six periods there was a tendency for the estimate to increase; this trend was particularly evident among the men doing hard work and the FRA subjects (Table III. 322). Sixteen of 20 comparisons among the hard work group exhibited the rise from pre-period to experimental period. In most cases the elevated estimate was maintained into the recovery periods. Among the light work groups only ten of 19 comparisons clearly demonstrated a similar trend.

Forty-five seconds: A similar increase in the estimate of the 45-second interval was observed among the men doing hard work and the FRA subjects (Table III. 323). Again the upward tendency became most evident in EXP I and persisted into the recovery periods. Among the hard work group 16 of 20 comparisons exhibited the rise; among the light work groups, nine of 19.

Seventy seconds: The same phenomenon was evident for the 70-second interval (Table III. 324). Among the hard work groups the increase was clearly evident among 11 of 20 comparisons in EXP I. The FRA subjects also showed the rise. The increased estimate did not so clearly persist, however, in EXP II and in REC II. Among the light work the increase was present in EXP I in ten of 19 comparisons.

Comment: The increase in the subject's estimate of the passage of time was independent of nutrient mixture and water intake. It was more uniformly present among men doing hard work than among men doing light work and at the 20- and 45-second intervals than at the 70-second interval. The trend was present in the data for the FRA subjects. The only factor in common was the weather and it is possible that the warm weather may have caused the upward trend. Men exposed to cold weather did not exhibit a downward trend (Sargent et al., 1955). Certainly learning was not involved, for the subjects had no knowledge of how accurate their estimates were. Since we are aware of no comparable data, we can only present this bioclimatic hypothesis as speculation. In contrast, Hoagland (1935) found that with elevated body temperature, time seemed to pass more slowly (i.e., increasing underestimation of clock-time).

TABLE III. 321

PRE-PERIOD DATA ON PASSAGE OF
TIME: 20, 45, AND 70 SECONDS

Flight	P I Mean	P I Range	P II Mean	P II Range
			20 seconds	
1	11.7	3.2-28.0	13.1	3.0-21.9
2	9.8	2.0-16.8	11.1	4.6-26.2
3	14.8	4.0-50.0	18.2	6.0-52.0
4	11.8	3.0-25.0	14.6	7.0-24.0
FRA	10.0	3.2-16.5	15.7	5.5-24.0
			45 seconds	
1	23.8	4.4-60.0	27.9	4.5-52.7
2	20.6	2.2-35.4	24.7	11.0-47.0
3	28.5	6.0-63.0	36.3	6.0-62.0
4	27.1	8.9-75.0	29.2	11.0-41.0
FRA	25.1	10.9-53.0	37.6	16.5-74.0
			70 seconds	
1	44.1	5.8-100.7	49.0	7.4-82.3
2	41.4	3.3-81.0	40.8	14.1-80.4
3	58.8	9.3-110.0	54.3	18.0-95.0
4	54.4	19.7-105.0	48.5	18.0-69.0
FRA	47.0	23.3-95.0	56.9	30.9-102.0

TABLE III. 322

PASSAGE OF TIME: 20 SECONDS

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC II
ST 0	U	15.6	12.0	9.8	12.5	19.0	14.3	24.7	18.4	----	18.2
	L	9.3	14.6	14.0	21.0	12.2	10.6	13.5	15.7	----	17.0
0/100/0	U	12.4	19.4	20.5	23.0	14.0	29.5	13.0	9.5	----	11.0
1000	L	9.2	9.4	12.0	14.0	10.3	5.6	10.0	17.0	----	15.0
0/100/0	U	11.8	15.1	18.5	10.0	25.5	10.2	11.0	11.0	----	11.0
2000	L	10.0	8.0	21.0	22.0	15.4	10.9	16.0	17.0	----	18.0
2/20/78	U	10.4	12.2	12.5	----	13.5	15.2	16.0	19.0	----	14.0
1000	L	16.5	11.5	12.5	16.0	11.0	6.2	9.5	13.0	----	11.5
2/20/78	U	10.7	9.2	19.0	18.0	----	11.0	9.1	14.5	----	13.5
2000	L	8.9	10.1	21.5	7.0	10.0	11.2	16.9	13.5	----	22.0
15/52/33	U	7.2	12.0	18.0	22.0	18.2	7.8	17.5	9.5	----	18.0
1000	L	10.2	9.8	20.0	----	----	17.5	18.0	12.5	----	14.5
15/52/33	U	6.4	7.6	10.5	15.0	19.0	17.5	17.5	14.5	----	14.5
2000	L	8.3	10.6	10.0	----	9.0	9.2	19.5	22.5	----	19.0
15/52/33	U	18.0	15.0	16.0	----	15.1	8.0	11.0	11.0	----	12.5
3000	L	7.6	12.0	11.5	----	20.8	11.5	14.5	----	----	----
30/0/70	U	10.4	16.4	17.5	17.0	12.9	19.0	17.0	15.0	----	18.0
1000	L	8.3	6.0	10.0	----	13.0	24.4	17.5	18.5	----	15.0
30/0/70	U	10.6	13.2	11.0	10.0	10.6	18.8	29.0	23.5	----	23.5
2000	L	9.8	10.6	11.5	8.0	12.5	12.1	12.0	20.0	----	21.0
FRA		10.0	15.7	18.4	18.3	17.7	10.0	15.7	18.4	18.3	17.7

TABLE III. 323

PASSAGE OF TIME: 45 SECONDS

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC II
ST O	U	26.5	28.2	22.7	29.0	22.5	37.6	42.7	36.2	----	43.6
	L	21.4	29.3	26.7	34.3	25.9	32.6	27.0	36.5	----	35.3
0/100/0	U	43.9	43.0	47.0	34.0	27.0	18.9	30.7	19.0	----	28.0
1000	L	25.8	21.2	41.5	25.0	26.2	23.2	25.5	38.5	----	33.0
0/100/0	U	21.1	24.1	38.0	75.0	40.5	17.0	21.8	25.0	----	30.5
2000	L	19.8	33.8	37.0	51.0	32.0	21.1	38.5	36.5	----	44.0
2/20/78	U	23.2	26.4	35.5	----	26.0	29.0	35.5	42.0	----	26.0
1000	L	29.4	26.1	34.0	35.0	26.8	12.0	22.0	23.5	----	31.5
2/20/78	U	12.4	23.2	36.5	39.0	----	21.9	32.2	38.5	----	32.0
2000	L	15.6	27.9	28.0	37.0	51.5	23.9	33.6	31.5	----	23.5
15/52/33	U	15.6	28.3	36.0	42.0	53.0	22.5	24.0	21.5	----	25.0
1000	L	22.6	18.2	31.0	----	----	27.0	27.5	26.5	----	25.5
15/52/33	U	11.9	18.2	21.5	41.0	45.5	27.0	36.5	30.5	----	35.0
2000	L	19.4	21.0	18.0	----	12.0	28.0	37.0	40.0	----	45.0
15/52/33	U	37.0	30.0	39.0	----	25.2	15.5	32.0	24.5	----	31.0
3000	L	18.5	21.5	31.5	----	47.0	24.0	28.5	----	----	----
30/0/70	U	20.3	29.7	48.0	27.0	22.9	38.0	43.0	46.0	----	42.0
1000	L	17.4	16.5	23.0	----	30.0	49.4	35.5	38.5	----	34.0
30/0/70	U	23.4	27.3	25.0	22.0	26.4	43.9	58.0	50.5	----	44.0
2000	L	15.0	27.4	29.0	28.0	32.0	24.4	19.5	45.0	----	34.0
FRA		25.1	37.6	39.0	38.6	41.6	25.1	37.6	39.0	38.6	41.6

TABLE III. 324

PASSAGE OF TIME: 70 SECONDS

Experimental Regimen		Hard Work PRE I	PRE II	EXP I	EXP II	REC II	Light Work PRE I	PRE II	EXP I	EXP II	REC II
ST O	U	55.0	49.0	39.5	50.5	35.0	73.8	58.0	59.4	----	67.6
	L	56.1	51.6	47.0	40.0	29.8	49.4	51.2	56.0	----	51.3
0/100/0	U	64.9	58.6	75.5	34.0	27.0	41.6	44.0	49.5	----	50.0
1000	L	25.8	21.2	41.5	25.0	26.2	67.9	49.5	76.5	----	50.0
0/100/0	U	26.0	37.9	38.0	72.0	58.5	29.1	41.9	53.0	----	51.5
2000	L	46.5	69.5	60.5	78.0	59.0	38.4	64.0	66.5	----	62.0
2/20/78	U	45.7	62.9	57.5	----	26.0	62.0	59.0	77.0	----	49.0
1000	L	49.0	49.2	64.5	56.0	41.8	26.3	25.0	32.5	----	43.0
2/20/78	U	31.4	41.8	55.5	42.0	----	48.1	44.2	57.5	----	50.5
2000	L	30.4	27.5	57.0	74.0	64.5	64.0	52.2	47.0	----	44.0
15/52/33	U	35.1	45.0	54.0	78.0	63.6	46.6	41.5	34.0	----	46.0
1000	L	52.9	27.3	71.0	----	----	55.6	41.5	40.5	----	49.0
15/52/33	U	22.2	28.8	38.0	62.0	54.0	73.5	47.0	41.0	----	63.5
2000	L	31.0	28.7	25.0	----	16.0	65.8	57.0	70.5	----	75.0
15/52/33	U	77.7	56.0	46.5	----	42.3	34.0	54.0	45.5	----	53.0
3000	L	30.2	32.8	62.5	----	84.5	50.0	41.5	----	----	----
30/0/70	U	38.6	56.6	81.5	37.0	39.9	96.0	75.0	78.0	----	76.0
1000	L	40.8	26.4	40.0	----	30.0	74.5	59.5	57.0	----	49.0
30/0/70	U	33.4	53.3	25.0	22.0	26.4	79.7	83.5	79.0	----	75.0
2000	L	26.5	46.0	45.0	52.0	47.0	57.0	41.0	68.0	----	61.0
FRA		47.0	56.9	58.9	66.0	63.4	47.0	56.9	58.9	66.0	63.4

7. Hematology

a. Hematocrit and Erythrocyte Sedimentation Rate

Hematocrit. The means and their variances for the three periods of the summer study are summarized in Table III. 325 A. There was no essential difference between the PRE I and PRE II means in either the experimental or the control (FRA) groups. Since the hematocrit was not consistently affected by work load, water intake, or nutrient mixture (Table III. 326), the observations for all experimental subjects were grouped in EXP I and EXP II for purposes of study. During these periods there was a regular increase in the hematocrit (Table III. 325 A). Among the experimental subjects the increase was statistically significant for both EXP I and EXP II whether or not the subjects had been on restricted water allowances (Table III. 325 B). The increase was less marked among the FRA subjects. In EXP I it was not significant; in EXP II, however, "t" was significant at the 2% level. During REC I all hematocrits returned to approximately pre-period values; in REC II, there was a slight but insignificant rise over REC I values (Table III. 325 A).

These results are in sharp contrast to our previous observations (Sargent et al., 1954, 1955). In the 1953 temperate study and 1954 winter study significant increases in the hematocrit were not observed--even among men on limited intakes of water. We are inclined to ascribe the summer results to dehydration which was accentuated by sweating. The weather became excessively hot late in PRE II and continued hot through EXP I and EXP II. Even the FRA subjects exhibited elevated hematocrits. These results are especially striking when we recall that exposure to heat has been reported by several investigators to cause a shift of water from extracellular spaces into the blood (Bass and Henschel, 1956). Presumably all the subjects had developed some degree of voluntary dehydration (Adolph, 1947).

In the recovery periods we note another difference from our earlier studies. Our previous finding has been that, especially in REC I, there is a marked fall in the hematocrit; the values decrease well below pre-period levels (Sargent et al., 1954, 1955). In the summer, in contrast, such a diminution did not occur. Mean values of hematocrit in PRE and REC are not different. The reasons for the different behavior are not evident. It may be that we deal with a seasonal difference in water metabolism. On the other hand our measurements may not have been so timed as to coincide with the maximum diminution of the hematocrit. They were made later in REC I in the summer test than in the 1954 winter test.

Erythrocyte Sedimentation Rate. Since infection is known to elevate the erythrocyte sedimentation rate (ESR) (Wintrobe, 1946), it was first necessary to make an analysis of our data for such an effect. All the subjects were divided into two groups. The "well" subjects were those who had no known serious infection. The "ill" subjects were those who had known infection or physical findings suggesting latent or subclinical infectious disease. In PRE I and II, EXP II, and REC II, there were no significant differences between the ESR's of the two groups. In EXP I and REC I the mean ESR's were different

with "t" significant at the 1% level. Therefore, in the tables which follow, only "well" subjects were used for computing means in EXP I and REC I whereas all subjects were used for computing means in the other periods.

The next problem was to establish "normal values" for the new method of determining the ESR. As described earlier (Section II: Methods), the ESR was measured at 100°F and the point of maximum sedimentation was taken as the ESR. This technic differed from that used in the 1953 temperate study and the 1954 winter study. Data for all EXP subjects in PRE I and II and REC II were combined (Table III. 328) and a histogram (Figure III. 113) was prepared. The mode was 0.35 and the mean was 0.44±0.30 mm/min.

Pre-period means are given in Table III. 327 A. There were no significant differences between PRE I and PRE II but the FRA subjects had slower sedimentation rates than the EXP subjects. This difference persisted throughout the summer study (Table III. 327 A).

To study whether the experimental period and the water intake had any influence on the ESR, the mean values were compared against comparable PRE I means (Table III. 327 B). The FRA (controls) exhibited no significant alteration in ESR. Likewise the men on restricted water had comparable sedimentation rates in both pre-and experimental periods. In contrast, men on unlimited water did have significantly elevated ESR's in EXP I. In EXP II the ESR returned to pre-period levels.

In the recovery periods, the men on unlimited water and the FRA's had sedimentation rates equal to those in the pre-period. For the men on limited water, the ESR was significantly slowed in REC I but normal in REC II.

In the 1953 temperate study it was found that the nutrient mixture caused marked alterations in the ESR. The pertinent observations for the summer study are given in Table III. 329 and Figures III. 114 and III. 115. The experimental subjects had more variation in the ESR than did the controls. The only regimen which was consistently associated with appreciable elevation of ESR was 2/20/78. In contrast to previous findings with 30/0/70, the patterns for the summer were rather erratic. The men on ST 0 all exhibited low ESR's in REC I, but the values were normal in EXP. Men on 0/100/0 and 15/52/33 exhibited no consistent reactions. Caloric intake and work load were not consistently correlated with alterations of the ESR.

These data must be interpreted with considerable caution. We have attempted to eliminate the influence of the epidemic, but one can still not be certain that we were successful. In EXP I when the epidemic was at its height many of the "well" men had significantly elevated sedimentation rates (Table III. 327 A). It is not possible to conclude either that these data confirm or refute the observations of 1953. Only additional studies on healthy men will permit adequate testing of those results.

TABLE III. 325

HEMATOCRIT
(vol per cent)

A. MEANS AND VARIANCE

Subjects	N	M	s.d.	C.V.	N	M	s.d.	C.V.
		PRE I				PRE II		
All Experimental	84	44.0	2.7	6.1	82	44.1	2.7	6.1
Flights 1 and 3 (unlimited H_2O)	43	44.5	2.4	5.3	41	44.9	3.1	6.7
Flights 2 and 4 (limited H_2O)	41	43.6	2.9	6.6	43	43.6	2.5	5.8
FRA	12	42.2	1.9	4.6	12	43.5	3.5	8.1
		EXP I				EXP II		
All Experimental	79	47.3	2.4	5.2	72	45.9	2.7	5.8
Flights 1 and 3 (unlimited H_2O)	42	47.5	2.2	4.7	37	46.1	2.7	5.8
Flights 2 and 4 (limited H_2O)	37	47.0	2.7	5.8	35	45.8	2.8	6.0
FRA	11	45.1	2.9	6.4	13	45.3	1.5	3.4
		REC I				REC II		
All Experimental	74	43.9	2.2	4.9	71	44.7	2.4	5.4
Flights 1 and 3 (unlimited H_2O)	38	44.0	2.1	4.9	37	44.5	2.4	5.4
Flights 2 and 4 (limited H_2O)	36	43.8	2.2	5.1	34	44.8	2.4	5.4
FRA	12	42.6	2.6	6.0	17	44.5	2.0	4.6

B. STATISTICAL ANALYSIS

Subjects	PRE I Values Tested Against	"t"	"p"
Flights 1 and 3 (unlimited H_2O)	EXP I	5.94	<0.001
Flights 1 and 3 (unlimited H_2O)	EXP II	5.78	<0.001
Flights 2 and 4 (limited H_2O)	EXP I	5.27	<0.001
Flights 2 and 4 (limited H_2O)	EXP II	3.31	<0.001
FRA	EXP I	1.34	>0.1
FRA	EXP II	2.13	<0.05 >0.02

TABLE III. 326

HEMATOCRIT
(vol per cent)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	43.7	46.2	46.7	42.4	42.2	41.9	41.9	41.8	46.5	46.4	41.2	41.6
	L	41.6	41.7	45.8	46.4	41.7	41.1	42.7	43.6	48.4	47.2	41.7	41.9
O/100/O	U	46.4	47.8	47.5	44.5	42.8	43.5	45.8	43.2	47.5	44.6	43.7	43.4
1000	L	45.3	43.4	43.5	46.2	43.8	43.4	43.4	44.6	48.8	46.0	44.4	45.5
O/100/O	U	46.8	50.7	46.8	45.6	45.6	47.8	47.4	47.6	51.2	49.2	47.0	47.0
2000	L	45.8	43.4	46.0	46.0	43.6	44.1	44.4	42.8	45.3	42.0	42.6	45.0
2/20/78	U	45.3	48.2	47.6	46.6	47.5	45.0	46.6	45.0	49.0	50.0	45.4	46.0
1000	L	42.8	43.8	45.2	45.6	44.8	45.8	45.8	45.8	51.8	50.8	45.3	46.5
2/20/78	U	42.9	44.8	44.5	43.6	46.5	----	41.8	39.6	47.3	44.5	43.0	42.6
2000	L	43.4	39.9	43.8	39.5	43.9	44.0	44.4	43.6	45.0	44.6	45.0	48.0
15/52/33	U	43.8	45.5	46.6	43.4	43.2	44.0	46.2	44.0	49.5	49.2	46.2	46.9
1000	L	43.4	43.1	42.5	44.8	45.0	----	44.0	45.0	47.5	44.8	44.2	47.3
15/52/33	U	44.2	43.7	45.6	42.4	42.1	45.0	43.6	41.6	47.3	45.0	43.8	44.0
2000	L	42.0	43.3	44.5	44.0	42.1	44.9	44.2	42.0	45.0	45.0	45.0	46.2
15/52/33	U	44.4	45.4	46.2	45.5	43.4	43.9	45.1	44.0	49.2	48.0	46.3	47.3
3000	L	40.6	44.4	45.6	44.4	43.9	45.0	43.6	44.2	----	----	----	----
30/0/70	U	42.7	42.9	46.8	45.2	43.8	45.8	45.4	44.8	48.8	48.0	43.4	43.5
1000	L	43.2	42.8	48.2	47.0	45.5	42.9	42.6	43.6	46.4	45.6	42.8	43.5
30/0/70	U	45.8	47.0	46.8	45.8	45.0	43.8	43.2	44.0	48.2	47.5	42.8	43.4
2000	L	50.8	46.4	47.8	45.6	46.0	45.2	43.1	42.9	51.5	48.0	43.1	44.4
FRA		42.2	43.2	45.1	45.0	44.3	44.3	42.2	43.2	45.1	45.0	44.3	44.3

TABLE III. 327

ERYTHROCYTE SEDIMENTATION RATE
(mm/min)

A. MEANS AND VARIANCE

Subjects	N	M	s.d.	C.V.	N	M	s.d.	C.V.
		PRE I				PRE II		
All Experimental	84	0.46	0.34	73.9	84	0.44	0.27	61.4
Flights 1 and 3 (unlimited H_2O)	43	0.45	0.38	84.4	41	0.45	0.33	73.3
Flights 2 and 4 (limited H_2O)	41	0.48	0.30	63.8	43	0.38	0.20	52.6
FRA	12	0.29	0.16	53.1	11	0.26	0.14	55.6
		EXP I				EXP II		
All Experimental	79	0.54	0.37	68.5	65	0.36	0.26	72.2
Flights 1 and 3 (unlimited H_2O)	42	0.59	0.36	59.0	33	0.37	0.27	73.0
Flights 2 and 4 (limited H_2O)	37	0.48	0.27	56.2	32	0.35	0.26	74.3
FRA	12	0.30	0.15	50.0	14	0.31	0.25	80.6
		REC I				REC II		
All Experimental	73	0.34	0.29	85.3	71	0.44	0.29	65.2
Flights 1 and 3 (unlimited H_2O)	35	0.35	0.30	85.7	37	0.50	0.36	72.0
Flights 2 and 4 (limited H_2O)	38	0.34	0.27	79.4	34	0.39	0.17	43.6
FRA	13	0.26	0.16	61.5	17	0.33	0.20	60.6

B. STATISTICAL ANALYSIS

Subjects	Comparisons	"t"	"p"
Flights 1 and 3 (unlimited H_2O)	P I: P II	0.000	---
	P I: E I	1.750	> .05, < .10
	P I: E II	0.889	> .40
	P I: R I	1.250	> .30
	P I: R II	0.625	> .50
	E I: E II	2.750	< .01
	E I: R I	3.000	< .005
Flights 2 and 4 (limited H_2O)	P I: P II	1.500	> .10
	P I: E I	0.000	---
	P I: E II	1.625	> .20
	P I: R I	2.333	≅ .02
	P I: R II	1.333	> .10
FRA	P I: R II	0.572	> .50

TABLE III. 328

ERYTHROCYTE SEDIMENTATION RATE: FREQUENCY DISTRIBUTION OF DATA ON EXP SUBJECTS, PRE I, PRE II, AND REC II

Class Interval (mm/min)	N	%
0.00 - 0.09	19	7.95
0.10 - 0.19	34	14.22
0.20 - 0.29	35	14.64
0.30 - 0.39	41	17.15
0.40 - 0.49	31	12.97
0.50 - 0.59	19	7.95
0.60 - 0.69	20	8.37
0.70 - 0.79	13	5.44
0.80 - 0.89	10	4.18
0.90 - 0.99	5	2.09
1.00 - 1.09	1	0.42
1.10 - 1.19	5	2.09
1.20 - 1.29	2	0.84
1.30 - 1.39	1	0.42
1.40 - 1.49	1	0.42
1.50 - 1.59	1	0.42
1.60 - 1.69	0	0.00
1.70 - 1.79	0	0.00
1.80 - 1.89	0	0.00
1.90 - 1.99	1	0.42
Total	239	99.99

TABLE III. 329

ERYTHROCYTE SEDIMENTATION RATE
(mm/min)

Experimental Regimen		Hard Work PRE I*	Hard Work PRE II*	Hard Work EXP I*	Hard Work EXP II**	Hard Work REC I**	Hard Work REC II*	Light Work PRE I*	Light Work PRE II*	Light Work EXP I*	Light Work EXP II**	Light Work REC I**	Light Work REC II*
ST 0	U	0.37	0.51	0.54	0.49	0.12	0.71	0.53	0.61	0.66	0.32	0.16	0.23
	L	0.32	0.22	0.39	0.46	0.22	0.34	0.42	0.54	0.54	0.32	0.10	0.35
0/100/0	U	0.42	0.08	0.48	0.19	0.06	0.12	0.64	0.48	0.52	0.25	0.48	0.50
1000	L	0.61	0.30	0.70	0.55	0.42	0.36	0.72	0.80	0.58	0.22	0.23	0.42
0/100/0	U	0.16	0.42	0.15	0.15	0.37	0.45	0.19	0.14	0.20	0.08	0.30	0.20
2000	L	0.82	0.34	0.25	0.38	0.24	0.42	0.35	0.39	0.20	0.09	0.25	0.35
2/20/78	U	0.41	0.32	0.57	0.84	0.98	0.80	0.45	0.62	1.28	0.50	0.31	0.49
1000	L	0.82	0.49	0.66	0.53	0.44	0.64	1.20	0.33	0.39	0.17	0.17	0.50
2/20/78	U	0.44	0.60	0.52	0.98	----	----	0.11	0.48	0.20	0.40	0.40	0.36
2000	L	0.72	0.56	0.79	0.47	0.74	0.68	0.44	0.18	0.21	0.10	0.20	0.31
15/52/33	U	0.20	0.31	0.36	0.31	0.29	0.73	0.48	0.44	0.80	0.52	0.26	0.58
1000	L	0.38	0.22	----	----	----	----	0.44	0.38	0.52	0.22	0.31	0.47
15/52/33	U	0.38	0.48	0.46	0.22	0.23	1.10	0.89	0.35	0.76	0.46	0.80	0.42
2000	L	0.14	0.21	0.44	0.47	0.17	0.40	0.46	0.30	0.32	0.09	0.18	0.12
15/52/33	U	0.53	0.46	0.64	0.76	0.50	0.64	0.09	0.10	0.20	0.15	0.10	0.14
3000	L	0.10	0.41	0.46	0.43	0.49	0.38	0.16	0.30	----	----	----	0.30
30/0/70	U	0.10	0.17	0.29	0.13	0.11	0.22	0.36	0.24	0.41	0.26	0.26	0.34
1000	L	0.61	0.31	0.82	1.22	0.62	0.34	0.27	0.50	0.40	0.20	0.16	0.27
30/0/70	U	1.01	0.90	0.88	----	0.72	0.86	0.84	0.74	1.17	0.66	0.36	0.78
2000	L	0.32	0.21	0.44	0.40	0.13	0.32	0.57	0.39	0.17	0.16	0.16	0.11
FRA		0.29	0.26	0.30	0.32	0.25	0.32	0.29	0.26	0.30	0.32	0.25	0.32

*"All" subjects in paired means.

**Only "well" subjects in paired means.

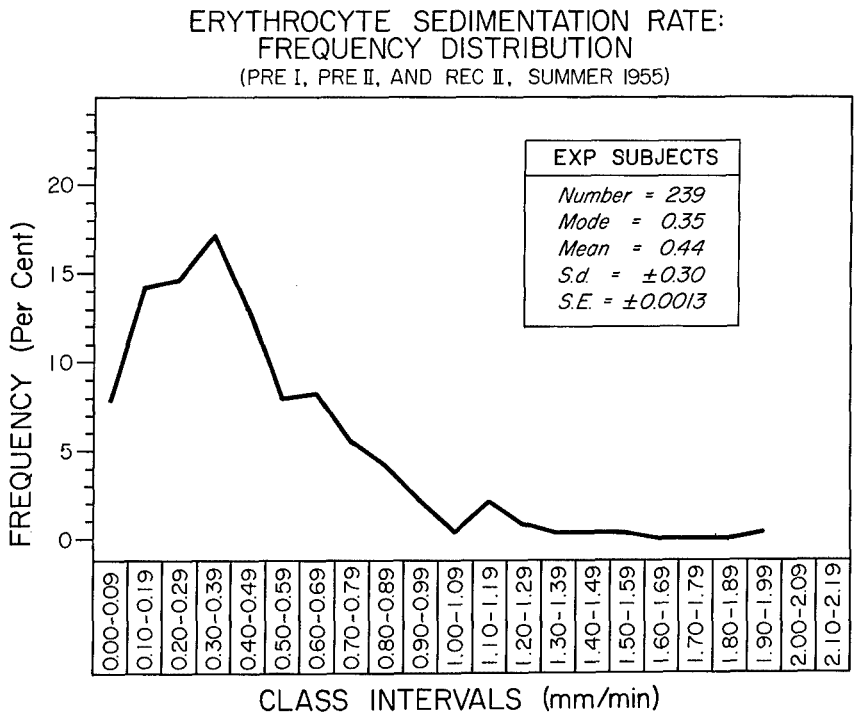


FIGURE III. 113. ERYTHROCYTE SEDIMENTATION RATE; FREQUENCY DISTRIBUTION.

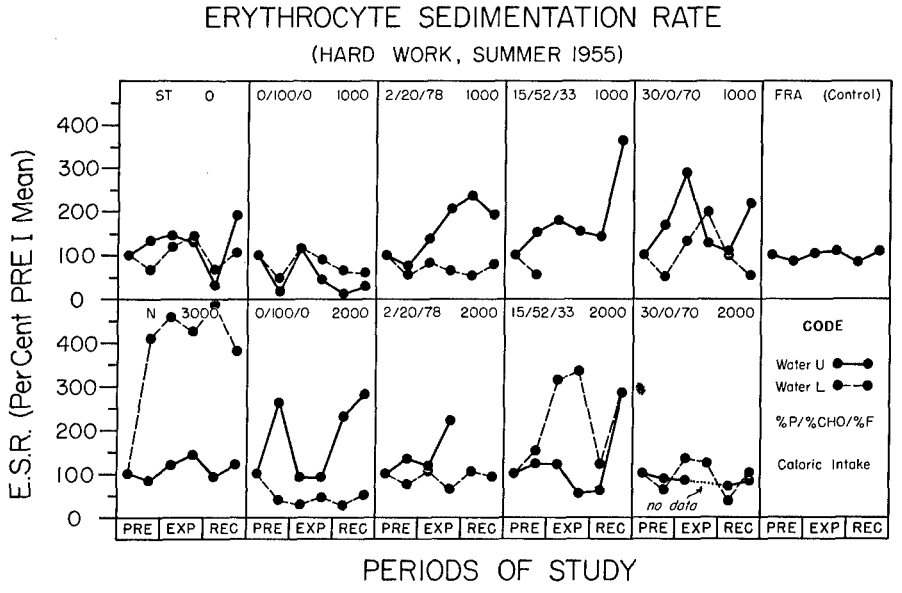


FIGURE III. 114. ERYTHROCYTE SEDIMENTATION RATE: HARD WORK.

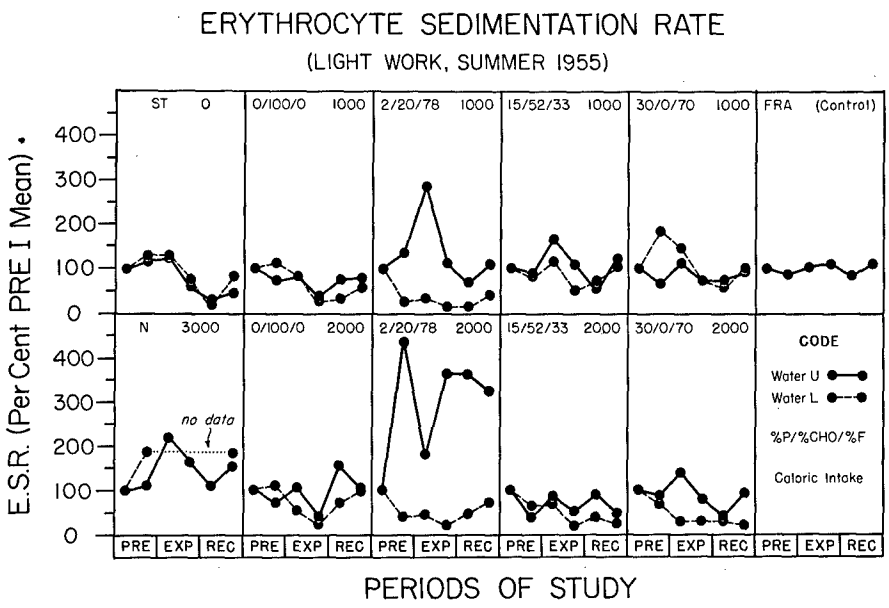


FIGURE III. 115. ERYTHROCYTE SEDIMENTATION RATE: LIGHT WORK.

b. White Cell Count and Differential

The total white cell count was made in a hemocytometer and the differential was determined from a stained smear. From the percentage distribution of the several types of leukocytes, their absolute values were calculated from the total white blood count for the same sample of blood. All data in the following tables are thus expressed in terms of cells per cubic millimeter.

Pre-period Data. The means and ranges for the different leukocytes observed are recorded in Table III. 330. There are no consistent and significant trends between groups or between periods. Furthermore the various means generally agree closely with those calculated for the 1954 winter study. The monocytes, however, did average higher in the summer than in the winter. In the latter study two groups had means of 125 and 138; all others were below 100. In the present series of observations there was only one mean below 200. Since the differentials were read by different technicians in the two years, the differences may be more apparent than real.

Total White Blood Cell Count. Nutrient mixture, water intake, and work load had no appreciable effect on the total white cell count (Table III. 331). Study of the frequency distributions of total white cells revealed that within periods the distributions were similar but between periods there were differences (Table III. 332). There was a significant and general reduction in the

total white cell count in the EXP period. In the recovery period the count returned to levels comparable to that of the pre-periods.

Neutrophil Count. Again we find that the neutrophil count did not discriminate between the three experimental conditions of work, water, and diet (Table III. 333). Like the total white count, however, there was a significant decrease of neutrophils in the experimental periods, and in the recovery periods the levels returned to pre-period values (Table III. 334).

Lymphocyte Count. In contrast to the neutrophils the lymphocytes did not discriminate among work, water, or diet (Table III. 335), and did not exhibit significant changes between periods (Table III. 336).

Eosinophils, Basophils, and Monocytes. These three cells exhibited considerable variability which was chiefly interindividual. There were several subjects who had persistent high eosinophil counts but our clinical data do not allow an explanation. There was no evidence elicited of an allergy among such men. These cells did not discriminate among diet, work, and water (Tables III. 337, III. 338, and III. 339) and there were no consistent differences between periods (Tables III. 340, III. 341, and III. 342).

Comment. The findings regarding the variations of the different white blood cells are in general agreement with the observations made during the 1954 winter test. The alterations in the blood concentration of these cells do not discriminate among diet, work, or water. The general trend of falling total white count and neutrophil count was also recorded during the 1954 winter study. The principal summer findings are illustrated in Figure III. 116. Because of the presence of rather widespread respiratory infection among our subjects, we must again raise the hypothesis that the decrease in total white cells and neutrophils was due to a virus infection rather than a reaction to non-specific stress. The latter characteristically elevates the total white cell count and neutrophils and depresses the lymphocytes. No change in the lymphocyte count was observed in the summer period whereas a distinct fall was found in EXP II of the winter tests. The return of the white cell counts to normal in the recovery periods coincided with subsidence of the epidemic.

In contrast to the 1954 winter study no significant alterations occurred in the basophil count.

TABLE III. 330

PRE-PERIOD DATA ON WHITE BLOOD CELLS
(Cells/mm^3)

Flight	P I Mean	P I Range	P II Mean	P II Range	P I Mean	P I Range	P II Mean	P II Range
		Total White Cell Count*				Eosinophil Count		
1	9.86	6.65-15.50	9.42	6.80-17.20	270	0-676	183	0-720
2	8.88	5.40-13.55	8.33	5.45-11.80	198	0-480	201	0-585
3	9.70	6.30-13.40	8.62	5.40-13.40	393	0-2,470	314	0-2,010
4	9.67	6.60-13.45	8.91	6.25-12.30	205	0-766	191	0-518
FRA	9.39	4.85-19.70	7.90	4.40-14.15	740	0-2,470	524	0-1,960
		Neutrophiles*				Basophil Count		
1	5.43	2.66-8.78	5.14	2.00-12.73	33	0-155	49	0-328
2	4.31	1.55-6.48	4.61	2.18- 8.50	33	0-240	18	0- 82
3	4.75	1.96-8.01	4.58	2.48- 7.92	10	0-134	36	0-140
4	4.97	2.11-9.15	4.52	2.18- 8.11	5	0-105	9	0-201
FRA	4.89	1.36-13.99	3.60	1.16-10.33	59	0-394	15	0- 98
		Lymphocytes*				Monocyte Count		
1	3.66	2.09-6.51	3.59	1.89-6.12	378	0-1080	361	0-2,400
2	3.59	2.30-6.59	3.28	2.43-5.00	452	0-1099	227	0-546
3	3.97	1.89-8.58	3.19	2.09-4.88	223	0- 840	358	0-1,780
4	3.93	2.15-6.19	3.87	2.66-5.16	333	0- 874	295	0-658
FRA	3.17	1.86-5.30	3.73	1.74-4.52	245	0- 660	191	0-752

*Thousands/mm^3

TABLE III. 331

TOTAL WHITE BLOOD CELL COUNT
(Thousands/mm^3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	9.80	9.30	7.88	8.25	6.97	8.57	11.14	9.65	7.95	7.02	7.16	8.63
	L	7.82	8.42	5.92	7.12	6.01	5.83	10.03	9.16	6.51	6.80	6.62	8.16
0/100/0	U	10.05	9.18	7.78	6.50	6.20	5.45	8.48	8.32	5.45	7.15	6.45	7.50
1000	L	8.77	7.45	7.22	8.52	6.38	7.87	9.20	8.68	5.65	7.15	8.42	10.25
0/100/0	U	10.12	9.12	7.60	8.45	8.85	10.08	7.08	5.92	6.02	6.07	4.40	7.58
2000	L	10.02	8.72	10.10	9.87	8.02	10.82	10.28	8.25	9.60	8.10	7.70	9.20
2/20/78	U	7.50	7.65	7.12	6.45	7.15	6.50	8.30	7.82	8.20	7.80	7.75	8.80
1000	L	9.40	10.18	11.08	11.30	10.62	10.90	9.88	7.88	5.90	4.98	6.68	8.15
2/20/78	U	8.70	6.88	5.28	5.30	6.60	----	9.50	8.38	6.28	6.08	8.60	8.28
2000	L	10.22	9.30	12.08	9.72	9.05	8.57	8.14	6.82	5.32	3.90	5.60	6.10
15/52/33	U	8.65	9.51	8.90	9.62	8.65	8.15	8.75	8.82	6.92	5.80	6.52	7.18
1000	L	9.02	8.24	6.15	6.50	----	----	8.82	9.55	6.80	6.32	7.22	9.60
15/52/33	U	12.12	8.55	7.32	11.70	12.00	13.45	11.28	8.90	7.68	7.02	8.20	9.05
2000	L	7.18	7.85	8.45	8.10	4.90	6.50	12.42	9.55	7.20	6.35	8.30	8.12
15/52/33	U	9.92	9.02	8.52	10.85	9.10	9.60	9.00	8.45	6.58	6.68	7.58	8.88
3000	L	8.45	6.35	10.25	9.40	8.52	9.25	9.95	9.55	----	----	----	----
30/0/70	U	8.30	8.32	6.95	10.02	7.42	6.60	7.50	8.00	5.40	6.00	7.55	6.15
1000	L	10.80	9.18	10.80	13.90	7.20	9.95	8.40	10.32	4.65	5.70	7.68	8.25
30/0/70	U	13.50	16.82	15.28	16.60	12.70	10.32	12.68	10.05	8.75	9.05	7.70	8.98
2000	L	8.15	7.48	6.00	9.62	8.18	9.15	8.78	9.10	6.85	4.20	6.60	6.10
FRA		9.39	7.90	8.45	8.93	8.27	8.48	9.39	7.90	8.45	8.93	8.27	8.48

TABLE III. 332

TOTAL WHITE BLOOD CELL COUNT: STATISTICAL ANALYSIS

A. FREQUENCY DISTRIBUTION*

Class Intervals (thousands/mm^3)	Frequency Distribution, % PRE	EXP	REC
3.0 - 3.9	0.00	2.80	0.00
4.0 - 4.9	1.04	7.27	3.93
5.0 - 5.0	4.17	11.18	9.55
6.0 - 6.9	10.42	21.80	15.17
7.0 - 7.9	19.80	17.33	20.79
8.0 - 8.9	17.19	11.74	20.79
9.0 - 9.9	17.71	9.50	13.49
10.0 - 10.9	10.94	7.27	6.74
11.0 - 11.9	7.29	2.80	4.50
12.0 - 12.9	5.21	1.68	2.25
13.0 - 13.9	3.65	4.47	1.69
14.0 - 14.9	0.52	0.56	0.56
15.0 - 15.9	0.52	0.00	0.56
16.0 - 16.9	0.52	0.00	0.00
17.0 - 17.9	0.52	1.12	0.00
18.0 - 18.9	0.00	0.00	0.00
19.0 - 19.9	0.52	0.56	0.00
Total	100.02	100.08	100.02

*Includes both EXP and FRA subjects.

B. CHI-SQUARE TESTS

Test	d.f.	X^2	P
P I vs. P II	16	18.63	<0.30
E I vs. E II	16	7.76	<0.975
R I vs. R II	11	15.35	<0.20
PRE vs. EXP	16	45.11	<0.0005
PRE vs. REC	15	19.61	<0.20

TABLE III. 333

NEUTROPHIL COUNT
(Thousands/mm^3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	5.90	5.26	4.28	----	2.87	4.07	5.60	5.20	3.79	3.48	3.57	4.16
	L	3.36	4.10	2.86	3.06	2.73	2.06	5.86	4.54	3.13	3.32	3.10	4.10
0/100/0	U	5.78	5.80	3.06	3.18	3.16	3.00	3.94	4.45	2.72	3.92	3.86	4.35
1000	L	4.90	3.68	4.08	3.54	3.42	4.42	3.42	3.86	2.22	3.10	3.60	4.80
0/100/0	U	6.01	5.13	3.49	4.60	4.41	4.55	2.71	2.95	2.33	2.09	1.50	3.23
2000	L	4.78	5.07	4.80	4.66	3.68	5.37	5.72	5.38	3.49	3.51	3.46	6.26
2/20/78	U	3.50	3.82	2.82	2.77	2.65	2.28	4.80	4.82	5.08	4.45	4.50	5.02
1000	L	4.52	6.90	6.97	4.57	5.96	5.70	3.08	3.38	2.20	1.50	2.58	3.42
2/20/78	U	4.22	3.24	1.71	1.27	2.24	----	4.33	4.24	2.98	2.74	4.88	4.56
2000	L	5.05	5.62	6.50	4.18	5.24	4.18	4.14	3.14	2.12	1.60	2.18	3.05
15/52/33	U	4.32	5.16	4.10	4.10	4.90	4.41	5.35	3.96	3.62	2.01	2.98	2.62
1000	L	3.28	4.82	3.38	3.51	----	----	5.00	4.98	2.84	3.25	3.72	5.61
15/52/33	U	6.30	3.95	3.54	5.50	5.40	7.13	3.38	4.89	4.40	3.59	2.92	4.62
2000	L	3.35	4.08	3.38	1.94	1.91	3.06	8.05	5.07	3.17	2.90	4.89	4.41
15/52/33	U	5.43	2.62	4.66	3.56	4.34	4.88	4.84	4.86	3.40	3.26	4.00	4.95
3000	L	4.18	2.82	5.05	3.92	4.08	2.88	5.58	4.84	----	----	----	----
30/0/70	U	4.04	4.50	3.53	5.84	3.48	3.36	3.82	2.48	2.92	2.94	4.23	6.33
1000	L	6.07	5.55	6.36	8.76	2.59	5.07	4.34	6.36	2.34	2.54	3.95	4.77
30/0/70	U	8.37	12.04	8.38	10.88	8.86	5.76	7.00	5.95	4.58	4.89	3.91	5.56
2000	L	4.52	3.99	2.82	4.14	3.82	4.64	3.63	4.70	3.49	2.31	4.03	3.48
FRA		4.89	3.60	4.02	4.02	4.25	4.22	4.89	3.60	4.02	4.04	4.25	4.22

TABLE III. 334

NEUTROPHIL COUNT: STATISTICAL ANALYSIS

A. FREQUENCY DISTRIBUTION*

Class Intervals (thousands/mm^3)	Frequency Distribution, % PRE	EXP	REC
0.0- 0.9	0.00	2.24	0.56
1.0- 1.9	3.13	13.42	8.43
2.0- 2.9	11.98	21.80	19.11
3.0- 3.9	21.36	26.27	19.11
4.0- 4.9	26.05	16.21	27.54
5.0- 5.9	17.19	11.18	14.61
6.0- 6.9	10.42	3.35	7.31
7.0- 7.9	4.69	1.68	2.25
8.0- 8.9	2.60	2.24	0.56
9.0- 9.9	0.52	1.12	0.00
10.0-10.9	0.52	0.00	0.00
11.0-11.9	0.52	0.00	0.56
12.0-12.9	0.52	0.00	0.00
13.0-13.9	0.52	0.56	0.00
Total	100.02	100.07	100.04

*Includes both EXP and FRA subjects.

B. CHI-SQUARE TEST

Test	d.f.	X^2	P
P I vs. P II	12	9.83	<0.70
E I vs. E II	12	11.77	<0.60
R I vs. R II	11	7.20	<0.80
PRE vs. EXP	13	41.64	<0.0005
PRE vs. REC	13	18.04	<0.20

TABLE III. 335

LYMPHOCYTE COUNT
(Thousands/mm^3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	3.01	3.39	3.34	----	3.91	3.59	4.16	3.46	3.31	2.51	3.01	3.41
	L	3.75	3.94	2.77	3.76	3.20	3.09	3.59	3.95	2.85	3.38	3.06	3.43
0/100/0 1000	U	3.46	3.16	4.28	3.25	2.85	1.96	4.01	3.56	2.20	3.02	2.28	2.55
	L	2.52	3.59	2.66	4.60	2.60	2.89	4.99	4.04	2.99	3.36	3.65	4.34
0/100/0 2000	U	3.23	3.67	3.47	3.43	4.18	5.16	4.06	2.56	2.68	3.16	2.42	3.58
	L	4.25	3.23	4.75	4.26	3.52	3.97	4.08	3.71	3.48	3.48	3.39	2.67
2/20/78 1000	U	3.39	2.90	3.93	3.10	3.29	3.12	2.54	2.50	2.54	2.50	2.87	3.26
	L	3.84	2.82	3.14	5.64	3.99	4.35	4.38	4.13	3.47	3.00	3.58	4.36
2/20/78 2000	U	4.12	3.48	3.35	3.82	3.96	----	3.86	3.64	2.80	3.09	3.33	3.24
	L	4.50	3.10	4.38	4.85	2.76	3.63	3.52	3.02	2.46	2.11	3.14	2.99
15/52/33 1000	U	3.86	3.52	4.36	5.10	3.38	2.72	2.24	3.84	2.94	3.28	3.34	4.09
	L	5.13	2.86	2.46	2.21	----	----	2.96	4.28	3.58	2.86	3.08	3.54
15/52/33 2000	U	4.92	3.98	3.31	5.38	5.76	5.51	7.17	3.41	2.35	2.78	4.14	3.77
	L	2.57	3.38	4.22	5.75	2.79	3.25	4.18	4.21	3.67	3.20	3.21	3.56
15/52/33 3000	U	4.11	4.88	3.35	6.36	4.18	4.17	3.77	2.82	2.39	2.98	2.57	3.54
	L	2.95	3.14	4.48	4.64	3.59	5.22	3.66	4.16	----	----	----	----
30/0/70 1000	U	4.00	2.84	3.15	3.59	3.44	2.36	2.62	4.88	2.11	2.58	2.57	2.21
	L	3.73	3.40	3.77	4.45	4.18	4.28	3.72	3.45	2.16	2.84	3.42	3.18
30/0/70 2000	U	3.72	4.62	4.93	5.12	3.50	3.64	4.22	3.16	3.26	3.57	2.95	2.91
	L	2.86	2.66	2.76	4.18	3.66	3.55	4.10	3.68	3.01	1.72	2.24	2.32
FRA		3.17	3.73	3.54	4.09	3.26	2.97	3.17	3.73	3.54	4.09	3.26	2.97

TABLE III. 336

LYMPHOCYTE COUNT: STATISTICAL ANALYSIS

A. FREQUENCY DISTRIBUTION*

Class Intervals (thousands/mm^3)	Frequency Distribution, % PRE	EXP	REC
1.00-1.49	0.00	1.12	0.56
1.50-1.99	2.08	3.35	1.68
2.00-2.49	10.94	16.77	11.24
2.50-2.99	16.15	16.77	19.67
3.00-3.49	20.84	12.30	20.79
3.50-3.59	19.80	16.21	24.17
4.00-4.49	13.02	15.09	14.05
4.50-4.99	8.34	8.38	3.37
5.00-5.49	3.65	4.47	1.68
5.50-5.99	2.08	3.35	1.12
6.00-6.49	1.56	1.12	0.56
6.50-6.99	1.04	1.12	1.12
7.00-7.49	0.00	0.00	0.00
7.50-7.99	0.00	0.00	0.00
8.00-8.49	0.00	0.00	0.00
8.50-8.99	0.52	0.00	0.00
Total	100.02	100.05	100.19

*Includes both EXP and FRA subjects.

B. CHI-SQUARE TESTS

Test	d.f.	X^2	P
P I vs. P II	14	10.64	<0.80
E I vs. E II	11	13.54	<0.30
R I vs. R II	11	17.06	<0.20
PRE vs. EXP	15	11.77	<0.70
PRE vs. REC	15	10.10	<0.90

TABLE III. 337

EOSINOPHIL COUNT
(Cells/mm^3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	220	231	177	---	95	286	759	694	353	681	371	738
	L	99	104	74	56	189	180	82	146	298	63	256	307
0/100/0	U	262	128	177	0	124	164	84	94	194	68	103	114
1000	L	156	75	132	170	267	240	460	187	154	217	700	822
0/100/0	U	368	195	262	128	130	106	118	144	276	386	270	447
2000	L	155	208	407	406	402	930	52	165	0	145	154	184
2/20/78	U	316	396	154	580	1,144	910	210	273	82	78	155	352
1000	L	285	187	332	92	445	425	202	277	118	277	333	236
2/20/78	U	416	68	160	106	396	---	522	198	176	124	347	209
2000	L	274	169	225	222	670	134	102	290	618	0	112	61
15/52/33	U	440	284	267	0	136	490	488	44	138	116	86	251
1000	L	96	222	246	65	---	---	274	71	131	118	103	343
15/52/33	U	330	166	388	585	240	538	271	54	278	162	362	474
2000	L	274	156	422	243	147	130	0	96	72	76	34	45
15/52/33	U	142	120	207	312	488	288	195	258	154	170	539	266
3000	L	217	292	460	503	600	925	472	344	---	---	---	---
30/0/70	U	34	126	102	272	420	475	225	320	54	180	388	123
1000	L	156	181	285	0	72	100	196	165	73	123	119	134
30/0/70	U	338	82	65	206	204	206	420	304	338	104	435	134
2000	L	364	410	224	924	564	685	325	217	68	0	264	122
FRA		740	524	515	511	498	500	740	524	515	511	498	500

TABLE III. 338

BASOPHIL COUNT
(Cells/mm^3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST 0	U	0	64	22	---	0	0	0	82	56	21	0	0
	L	27	14	62	16	0	89	0	0	20	0	65	33
0/100/0	U	0	0	28	0	0	0	0	0	0	0	38	0
1000	L	0	0	0	0	0	64	0	100	35	72	0	0
0/100/0	U	55	0	76	0	0	0	0	0	0	0	0	42
2000	L	16	0	0	102	110	0	52	0	0	0	0	0
2/20/78	U	0	36	31	0	0	0	0	0	0	0	0	0
1000	L	46	0	39	0	0	60	0	0	0	0	0	30
2/20/78	U	48	0	0	0	0	---	5	68	0	0	0	44
2000	L	0	38	172	63	0	0	2	0	32	0	0	0
15/52/33	U	40	120	0	140	0	0	0	0	0	0	0	0
1000	L	0	50	0	0	---	---	0	0	0	0	31	0
15/52/33	U	122	36	0	0	120	0	0	54	0	0	0	40
2000	L	39	40	0	0	0	0	0	0	0	0	49	0
15/52/33	U	0	60	72	0	0	0	38	84	0	0	0	0
3000	L	0	0	53	0	0	48	0	0	---	---	---	---
30/0/70	U	34	164	32	58	0	66	0	0	0	0	0	0
1000	L	168	0	0	0	72	0	0	0	0	0	42	0
30/0/70	U	68	0	88	0	0	103	67	98	0	0	0	0
2000	L	42	39	68	0	0	47	0	0	0	0	0	0
FRA		59	15	36	0	10	11	59	15	36	0	10	11

TABLE III. 339

MONOCYTE COUNT
(Cells/mm^3)

Experimental Regimen		Hard Work PRE I	Hard Work PRE II	Hard Work EXP I	Hard Work EXP II	Hard Work REC I	Hard Work REC II	Light Work PRE I	Light Work PRE II	Light Work EXP I	Light Work EXP II	Light Work REC I	Light Work REC II
ST O	U	564	351	69	---	89	173	450	240	440	332	164	238
	L	368	276	153	233	203	411	503	534	221	32	136	335
0/100/0	U	540	92	233	65	62	327	254	224	348	140	168	488
1000	L	399	104	344	210	90	254	327	251	204	406	480	288
0/100/0	U	460	128	301	168	132	254	186	268	546	263	216	270
2000	L	672	222	152	442	314	552	361	0	779	113	693	92
2/20/78	U	291	219	194	0	72	195	223	234	492	156	232	176
1000	L	612	262	404	657	232	376	319	92	216	196	178	118
2/20/78	U	387	103	52	106	0	---	158	220	303	124	44	214
2000	L	409	372	792	411	380	631	266	378	96	195	168	0
15/52/33	U	132	372	178	289	224	530	126	978	226	306	167	213
1000	L	512	276	62	195	---	---	582	216	246	90	299	110
15/52/33	U	461	428	86	234	480	269	46	302	384	204	884	141
2000	L	744	192	422	162	49	65	192	176	288	178	117	118
15/52/33	U	241	1351	243	285	91	259	0	422	525	109	316	118
3000	L	434	96	121	324	259	180	244	208	---	---	---	---
30/0/70	U	181	492	134	258	82	338	450	320	324	300	378	184
1000	L	192	45	393	695	288	498	140	354	68	192	154	165
30/0/70	U	338	86	852	400	127	621	120	536	574	492	401	360
2000	L	366	380	120	389	116	230	225	504	274	168	66	183
FRA		245	191	329	351	256	238	245	191	329	351	256	328

TABLE III. 340

EOSINOPHIL COUNT: STATISTICAL ANALYSIS*

Class Intervals (cells/mm^3)	Frequency Distribution, % PRE	EXP	REC
0 - 99	26.57	32.98	20.23
100 - 199	26.05	25.71	19.11
200 - 299	15.63	13.98	22.48
300 - 399	12.50	6.71	7.31
400 - 499	7.29	7.27	7.31
500 - 599	2.60	5.59	5.62
600 - 699	1.56	1.68	1.69
700 - 799	1.04	2.24	4.50
800 - 899	1.04	0.00	1.69
900 - 999	0.52	0.56	2.81
1000 -1099	0.00	0.56	1.12
1100 -1199	0.00	0.56	0.56
1200 -1299	0.52	0.56	2.25
1300	4.69	1.68	3.37
Total	100.01	100.08	100.05

*No significant differences within or between periods.

TABLE III. 341

BASOPHIL COUNT: STATISTICAL ANALYSIS*

Class Intervals (cells/mm^3)	Frequency Distribution, % PRE	EXP	REC
0 - 49	79.71	81.06	84.30
50 - 99	10.94	10.06	10.68
100 - 149	5.21	5.59	2.81
150 - 199	2.08	1.68	0.00
200 - 249	1.04	1.12	1.69
250 - 299	0.00	0.00	0.00
300 - 349	0.52	0.00	0.56
350 - 399	0.52	0.00	0.00
400 - 449	0.00	0.00	0.00
450 - 499	0.00	0.00	0.00
Total	100.02	100.07	100.04

*No significant differences within or between periods.

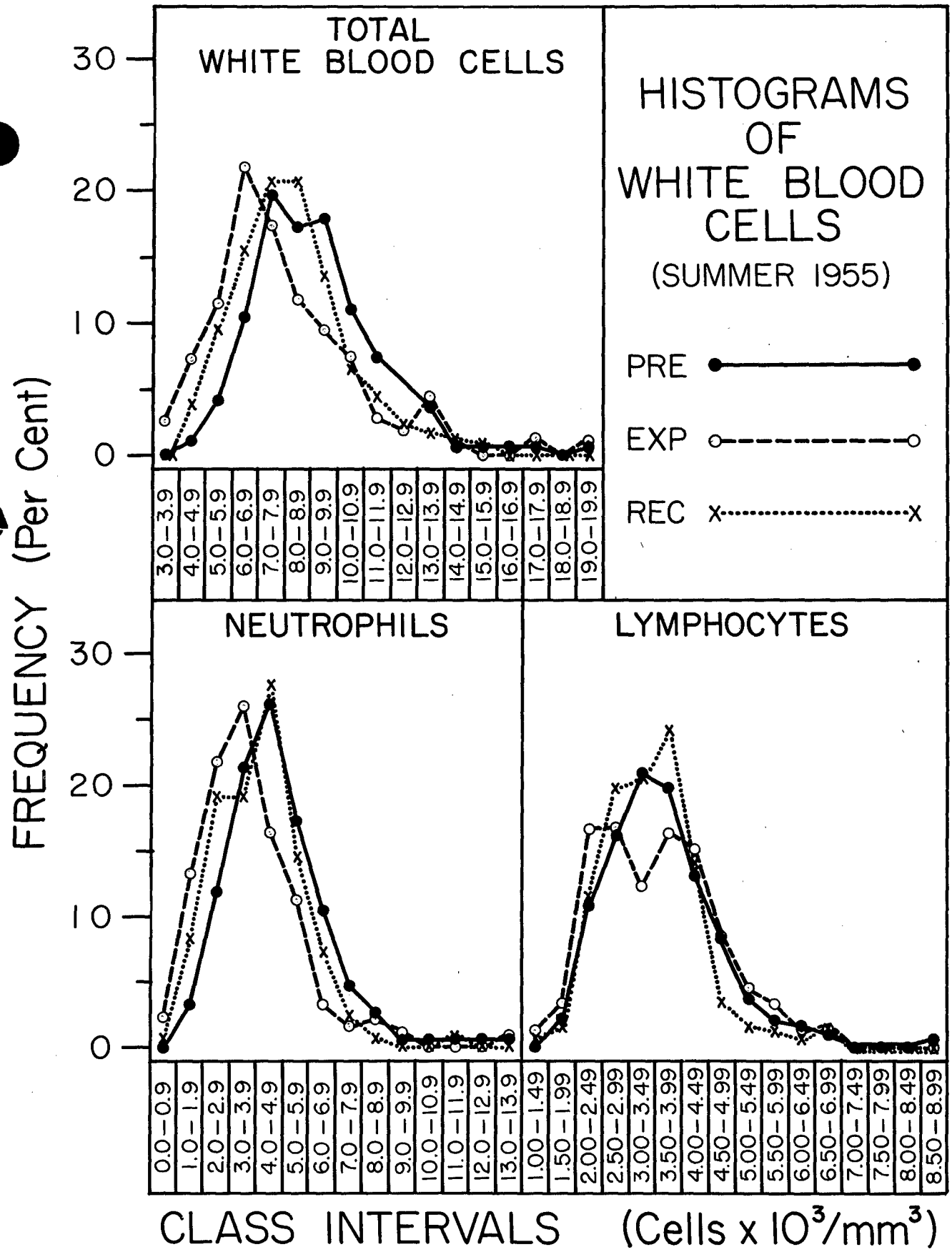
TABLE III. 342

MONOCYTE COUNT: STATISTICAL ANALYSIS*

Class Intervals (cells/mm^3)	Frequency Distribution, % PRE	EXP	REC
0 - 99	22.92	16.77	23.04
100 - 199	15.63	24.60	29.22
200 - 299	17.71	21.24	17.42
300 - 399	16.67	12.30	13.49
400 - 499	8.86	10.62	7.31
500 - 599	5.73	6.15	5.06
600 - 699	5.21	3.91	0.56
700 - 799	2.08	2.24	0.56
800 - 899	2.60	0.56	0.00
900 - 999	0.52	0.00	1.69
1000 - 1099	1.56	0.00	1.12
1100	1.04	1.68	0.56
Total	100.53	100.07	100.03

*No significant differences within or between periods.

FIGURE III. 116. HISTOGRAM OF WHITE BLOOD CELLS.


TOTAL
WHITE BLOOD CELLS
HISTOGRAMS
OF
WHITE BLOOD
CELLS
(SUMMER 1955)
PRE
EXP
REC
NEUTROPHILS
LYMPHOCYTES
FREQUENCY (Per Cent)
30
20
10
0
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9
8.0–8.9
9.0–9.9
10.0–10.9
11.0–11.9
12.0–12.9
13.0–13.9
14.0–14.9
15.0–15.9
16.0–16.9
17.0–17.9
18.0–18.9
19.0–19.9
0.0–0.9
1.0–1.9
2.0–2.9
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9
8.0–8.9
9.0–9.9
10.0–10.9
11.0–11.9
12.0–12.9
13.0–13.9
1.00–1.49
1.50–1.99
2.00–2.49
2.50–2.99
3.00–3.49
3.50–3.99
4.00–4.49
4.50–4.99
5.00–5.49
5.50–5.99
6.00–6.49
6.50–6.99
7.00–7.49
7.50–7.99
8.00–8.49
8.50–8.99
CLASS INTERVALS (Cells x 10³/mm³)

H. CLINICAL EVALUATIONS OF NUTRIENT COMBINATIONS
(Prepared in collaboration with R. Kosmala)

The object of these studies is the whole castaway, not a part of him. The measure of the whole man is the clinical record, and functional tests only have meaning in the light of the performance of the whole man. Statistically significant abberations in biochemical or physiological measures may have great academic interest; but, for practical purposes, a nutrient regimen recommended for the survival of a castaway stands or falls depending on the clinical reactions provoked by that regimen. If they are deleterious, no matter how minute the functional changes may have been, the regimen is harmful. The clinical record is the central concern of these investigations.

In this section we shall present the clinical observations made during the 36-day period of the 1955 summer test. The material that will be dealt with concerns (1) the epidemic and its implications, (2) clinical reactions to nutrient mixtures, (3) detailed considerations of noteworthy case histories, and (4) additional clinical and functional data on the period of rehabilitation. The fact that an epidemic of respiratory disease took place during these field tests has greatly complicated the problem of interpretation. We have made every effort to separate the symptoms of the infectious disease from the symptoms more likely attributable to the experimental nutrient regimens. The separation has been simplified by drawing on our previous experience with these regimens. We, nevertheless, caution the reader to make his own judgments with care.

1. Infectious Diseases and the Epidemic

The general course of the epidemic of respiratory infection has been presented in Section II. O. There we reported that 18% of the 100 volunteer subjects and 12% of the 174 total personnel at Camp Atterbury became so severely ill that they had to be hospitalized and, in some cases even air-evacuated to a USAF General Hospital, for treatment. Table III. 343 presents the clinical details concerning this experience. In the pre-period (22 June--5 July) there were seven cases of respiratory infection, five of which had bronchial or pulmonary signs and symptoms. In the experimental period (6 July--14 July) there were 15 cases of infectious disease, in 11 of which the clinical findings and complaints indicated serious respiratory disease. One subject died from Waterhouse-Friederichsen's syndrome and one man had acute mastoiditis. In the recovery period (15 July--27 July) there were seven additional cases, four of which were diagnosed as having respiratory infection. A second case of mastoiditis developed.

While these observations indicate the serious nature of the epidemic, the total impact of the infectious process is further brought out in Table III. 344 in which minor signs and symptoms are listed according to date of onset. The predominant findings were referable to an infection of the respiratory system--tonsillitis, pharyngitis, rhinitis, cough, and enlargement of lymph nodes draining phargngeal tissues. A few men had ear infections and some had oral infections such as abscess of gum and gingivitis. In all there were 43 men in the pre-period with complaints of this nature; 29 in the experimental period; and 12 in the recovery period.

These data demonstrate that the infectious process was widespread in the subject-population. In some the reaction was minor—sore throat, cough, enlarged lymph nodes--and in others the reaction was severe--pneumonia, bronchitis, mastoiditis, and fatal septicemia. What effect the agent responsible had on those men whose resistance was great enough to prevent development of any clinical signs and symptoms is difficult to state.

The course of the epidemic was typical of those reported by other investigators. The outbreak started with minor complaints and few serious cases. The frequency of minor complaints progression increased and reached a maximum on 4 July. Eight to ten days later the maximum of severe cases appeared. In the "recovery period" the incidence of both major and minor cases gradually abated.

TABLE III. 343

EPIDEMIC INFECTIOUS DISEASE

A. VOLUNTEER SUBJECTS

Subject Code No.	Date of Onset	Clinical Diagnosis	Disposition
42	22 June	Tonsillitis	Sick Bay
59	24 June	Lobar pneumonia	Fort Harrison*
46	26 June	Tonsillitis	Sick Bay
17	30 June	Bronchopneumonia	Sick Bay
40	1 July	Bronchitis	Sick Bay
58	3 July	Bronchopneumonia	Sick Bay
41*	7 July	Otitis media; mastoiditis	Bartholomew County Hospital
77	7 July	Waterhouse-Friederichsen's Syndrome	Bartholomew County Hospital; expired 8 July; autopsy
88	8 July	Bronchopneumonia	Air Evacuation 14 July
87	8 July	? Infectious mononucleosis	Air Evacuation 14 July*
73	9 July	Chronic otitis media	Sick Bay
2	9 July	? Infectious mononucleosis	Air Evacuation 14 July*
39	12 July	Pharyngitis	Air Evacuation 18 July
16	12 July	Bronchitis	Air Evacuation 14 July
82	12 July	Pharyngitis	Air Evacuation 14 July*
20	12 July	Bronchopneumonia	Air Evacuation 14 July
13	13 July	Bronchopneumonia	Air Evacuation 14 July
52	13 July	Bronchitis; asthma	Sick Bay
5	14 July	Pharyngitis; fever	Air Evacuation 14 July*
73	15 July	Bronchitis	Air Evacuation 18 July
101	15 July	Bronchitis	Sick Bay
15	17 July	Seminal vésiculitis	Air Evacuation 20 July
62	21 July	Pharyngitis	Sick Bay
19	21 July	Otitis media; mastoiditis	Bartholomew County Hospital
68	22 July	Bronchopneumonia	Air Evacuation 23 July
98	26 July	Otitis media	Outpatient

*Subsequently returned to Camp Atterbury

B. SUPPORT PERSONNEL

Name	Date of Onset	Clinical Diagnosis	Disposition
McGee	5 July	Lobar pneumonia	Sick Bay
Kelley	7 July	Bronchopneumonia	Sick Bay
Bridge	14 July	? Bronchopneumonia	Air Evacuation 14 July*

*Subsequently returned to Camp Atterbury

TABLE III. 344

OCCURRENCE OF UPPER RESPIRATORY AND OTHER INFECTIONS

A. PRE-PERIODS

Date of Onset	Subject Code No.	Description of Condition
6/22	2	Mild tonsillitis
	14	Enlarged tonsils
	21	Abscess of tooth
	27	Tonsillitis
	37	Sore throat and cough
6/23	60	Pharyngitis
	78	Pharyngitis
6/24	36	Cold
	39	Mild pharyngitis
	44	Cold
	47	Cough and enlarged cervical nodes
	71	Cold and cough
	76	Pharyngitis and injected ear drum
	86	Cold and enlarged tonsils
	94	Cough and sore throat
6/25	43	Sore throat and cough
	45	Cold
	48	Mild pharyngitis
	67	Pharyngitis
	68	Pharyngitis
	77	Pharyngitis and tonsillitis
	95	Toothache
6/26	38	Pharyngitis and cough
6/28	56	Mild pharyngitis
7/3	21	Mild pharyngitis
7/4	1	Mild pharyngitis
	4	Mild pharyngitis with chest pain
	11	Enlarged tonsils
	29	Injected tonsillar pillars
	30	Pharyngitis
	32	Enlarged cervical nodes
	34	Enlarged cervical nodes
	54	Mild pharyngitis
	55	Enlarged cervical nodes
	57	Pharyngitis and cough
	64	Enlarged cervical nodes
	65	Pharyngitis
	70	Enlarged tonsils
	75	Toothache
	79	Pharyngitis
	85	Pharyngitis and tonsillitis
	91	Enlarged tonsils and infected ear drum
	96	Enlarged cervical nodes

TABLE III. 344 (Continued)

OCCURRENCE OF UPPER RESPIRATORY AND OTHER INFECTIONS

B. EXPERIMENTAL PERIODS

Date of Onset	Subject Code No.	Description of Condition
7/6	59	Cold and cough
7/7	10	Cough
	84	Gingivitis
7/8	97	Mild bronchitis
7/9	28	Chest cold and pharyngitis
7/11	38	Earache
7/12	11	Vincent's angina
	22	Cough with rales and wheezes
	72	Chills, sore throat, and inflammed eardrum
7/13	51	Cough and enlarged tonsils
	56	Chest pain
	86	Pharyngitis, bronchitis, and hemoptysis
7/15	3	Tonsillitis and pharyngitis
	11	Pharyngitis
	12	Sore gums, cough, and furuncle
	17	Abscess of molar
	31	Pharyngitis
	36	Gingivitis
	44	Mild Pharyngitis
	62	Mild Pharyngitis
	69	Pharyngitis
	71	Injected right eardrum
7/15	74	Mild pharyngitis
	83	Mild pharyngitis
	84	Mild pharyngitis
	90	Pharyngitis
	92	Pharyngitis
	96	Pharyngitis
	100	Mild pharyngitis

C. RECOVERY PERIODS

Date of Onset	Subject Code No.	Description of Condition
7/18	33	Sore throat and earache
7/24	44	Earache and cold
7/26	4	Mild pharyngitis
	69	Mild pharyngitis
	79	Mild pharyngitis
	80	Pharyngitis
	83	Mild pharyngitis
	84	Injected eardrum
	85	Enlarged tonsils
	91	Mild pharyngitis
	96	Enlarged cervical nodes
7/27	36	Infected tonsils

Clinicopathological Reports on Two Cases. At this point we present the detailed records of two men who became seriously ill during the epidemic. One man developed acute mastoiditis requiring hospitalization and surgery; the second died.

Subject 41: This 17-year old, white male complained of a right earache on the third and fourth days of the pre-period. From the eighth to the thirteenth days he complained of sore throat, cough, chest pain, and tender tonsillar nodes. On 4 July a physical examination revealed bilaterally injected tonsillar pillars, harsh breath sounds at both lung bases, and bilateral inguinal nodes. The following day his earache recurred and became progressively worse during the first two days of the experimental period. He was placed in Sick Bay on July 7. At this time he had an oral temperature of 99.7°F and pulse rate of 72. The hematocrit was 39.4% and the erythrocyte sedimentation rate 0.21 mm/min.

From the third day of the experimental period (5-7 July) he was given drops in the right ear, nose drops, and a daily intra-muscular injection of penicillin. On 8 July he was hospitalized at Bartholomew County Hospital under the care of Dr. D. D. Yoder.

Past history revealed measles, mumps, chicken pox and whooping cough, from each of which recovery was complete. In July 1954 he was hospitalized five days for cerebral concussion. There had been no previous attacks of otitis media.

Physical Findings: Ears - Right external auditory canal is swollen, and filled with purulent exudate, the drum is markedly inflammed. There is marked tenderness on motion of the auricle and moderate tenderness over the right mastoid bone. Hearing is decreased. Left - external auditory canal is swollen and tender. The left drum is normal in appearance. Nose - Air passage is adequate, no polyps are present. Throat - teeth well repaired, tongue normal. Tonsils - atrophic, vocal cords are normal in color and motility. Neck - thyroid normal in size. Chest - lungs, normal expansion, no pathological rales heard, no areas of abnormal dullness. Heart - normal in size, no pathological murmurs heard. Reflexes - knee and elbow normal.

Progress Notes:

7-8-55 Acutely ill, complaining of pain back of right ear.

7-9-55 Is not feeling any better. Myringotomy of right ear drum was performed with Pyribenzamine as a topical anesthesia.

7-10-55 Temperature normal but now complaining of pain in left ear.

7-11-55 Feels better.

7-12-55 Feels better.

7-13-55 May go home.

Final Diagnosis: Acute mastoiditis, right ear. External otitis, bilateral.

Subject 77: This 17-year old Negro male complained of nasal congestion on the third day of the pre-period. On the fourth day a sore throat developed and the tonsils and pharynx were injected and the right cervical nodes were enlarged and tender. On the eleventh day the sore throat and physical findings were unchanged. On 4 July (thirteenth day) examination revealed injection of right tonsil, enlargement of left tonsil, large bilateral cervical nodes, slight enlargement of thyroid, and absent left cremasteric reflex.

On 7 July (second day of experimental period) he complained of anorexia of several hours' duration. He was able to eat only half of the evening meal but then vomited it. He returned to his camp. He complained of severe thirst, bitemporal headache, and stiffness in the right leg. He was weak and lethargic and had difficulty answering questions. Since his condition failed to improve, he was returned to the Sick Bay. Examination there revealed that the skin was warm and dry except for minimal sweating on the face and in the axillae. The right ear drum was slightly injected, the right mastoid tender, and the tonsils injected. The tendon reflexes were hypoactive. He was restless. At 2130 the temperature per os was 104.6°F; pulse, 126; and respiratory rate, 27. The erythrocyte sedimentation rate was 0.62 mm/min; hematocrit, 42.9%; and white blood cell count, 8,500. The urine showed 4+ acetonuria but no protein or urobilinogen. At 2150 hours his rectal temperature was 105.8°F; he was given 1250 ml of water orally as part of the water diuresis test. This test was abandoned because of the subject's condition (Table III. 345). From 2150 to 2400 hours he was sponged with alcohol, draped in chilled sheets, and drafted with fans. Between 2210 and 2330 hours the rectal temperature stabilized at 104.9-105.1°F.

At 2230 hours he was given 350 ml of water orally and at 2320 hours, 107 gm of sucrose in 200 ml of water. From 2335 to 2400 hours the rectal temperature rose steadily to 105.5°F at which time he was placed in a "walk-in" refrigerator. At 0015 hours (8 July) the rectal temperature was 105.1°F; pulse, 150; respiratory rate, 42; and blood pressure, 80/60. At 0050 hours intravenous 5% dextrose in saline was started; the blood pressure was 90/60. The subject had continuous shaking chills while in the refrigerator.

At 0145 hours the rectal temperature was 104.0°F. At 0200 hours he was removed from the refrigerator. He was given 300 ml of water orally and 600,000 units of penicillin intramuscularly. At 0215 hours the rectal temperature was 103.0°F; pulse, 94; respiration, 38; and blood pressure, 80/65. At 0335 hours the rectal temperature was 102.8°F; pulse, 148; respiration, 54; and blood pressure, 80/45. A generalized petechial rash appeared at 0340 hours. At 0435 hours the rectal temperature was 104.5°F; pulse, 140; respiration, 56; and blood pressure, 70/45; 300 ml of water were given orally. At 0520 hours the rectal temperature was 102.0°F; pulse, 156; respiration, 48; and blood pressure, 75/45. A specimen of urine was passed at 0530 hours. The examination revealed: 0 ketonuria; 2+ albuminuria; numerous finely and coarsely granular casts; numerous white blood cells; 1-2 red blood cells per high-power field; occasional epithelial cells; and amorphous phosphates, cylindroids, and bacteria.

TABLE III. 345

CLINICAL OBSERVATIONS ON SUBJECT 77

Time	Rectal Temp. F	Pulse Rate	Respir-ation	Blood Pressure	Remarks
July 7					
Initial	(104.6)*	126	25	115/46	*Temperature, p.o.
2150	105.8	144	-	-	1250 ml water orally
2155	105.7	-	-	-	Sponged with
2200	105.8	-	-	-	alcohol; draped
2205	105.3	146	-	-	in chilled sheets;
2210	105.0	144	-	-	drafted with fan
2215	105.0	-	-	-	from 2150 to
2220	105.0	144	-	-	2400.
2225	105.1	-	-	-	
2230	104.9	-	-	-	350 ml water p.o. at 2230
2240	105.0	-	-	-	
2245	105.1	-	-	-	
2250	105.1	142	-	-	
2255	105.1	-	-	-	
2300	105.1	-	40	-	
2305	105.0	-	-	-	
2310	105.0	150	46	-	
2315	105.1	146	-	-	2320; 107 gm sucrose in
2330	104.9	150	-	-	200 ml. H_2O.
2335	105.3	-	-	-	
2340	105.5	-	-	-	
2345	105.5	-	-	-	
2350	105.5	-	-	70/40	
2355	105.5	-	42	80/60	Moved to refrigerator at 2400
July 8					
0015	105.1	150	42	80/60	
0045	104.9	-	-	-	150 ml water p.o. at 0130
0050	-	-	39	90/60	I.V. fluids started
0110	-	140	-	90/60	Continuous shaking
0120	104.8	-	-	-	chills while in
0145	104.0	-	-	-	refrigerator
0215	103.0	94	38	80/65	Moved to #486 at 0210; 300
0230	103.5	-	-	-	ml water p.o., 600,000 units
0240	103.2	144	-	-	of penicillin I.M.
0250	103.2	-	-	-	
0305	102.7	-	42	-	
0335	102.8	148	54	80/45	0325: I.V. fluids stopped
0345	103.5	-	-	-	1 L 5% glucose in saline.
0400	103.9	160	52	90/50	Generalized petechial rash
0435	104.5	140	56	70/45	at 0340
0520	102.0	156	48	75/45	300 ml water p.o. at 0435
0532	-	-	-	-	Voided into pint can.

Between 0630 and 0830 hours the patient developed shock. There was no blood pressure or pulse, the skin was cold, and the rectal temperature was 104.0°F. The muscles were tender and there was generalized areflexia, belly tenderness, and ileus. A blood specimen at 0800 hours had a white blood cell count of 25,900. The differential revealed 90% polymorphonuclear leukocytes (42% stab cells) and 10% lymphocytes. The subject was given 5% dextrose in water (with 40 mEq KCl added) by the intravenous route. The KCl was added since an EKG suggested moderate hypokalemia. The shock state did not respond to 1 ml of 1:2600 adrenaline subcutaneously. At 0915 and 0920 he was given 50 mg of ephedrine intravenously but still failed to respond. He was transferred by ambulance to Bartholomew County Hospital where he expired shortly after arrival. The clinical diagnosis was Waterhouse-Friederichsen Syndrome, presumably due to meningococcemia.

An autopsy was performed by Dr. D. L. Adler, pathologist for the Bartholomew County Hospital, and 1/Lt. K. Lauer, who was a medical officer on the summer tests. The autopsy report contained the following information:

General Description

The body is that of a young, adult, colored male measuring approximately 70 inches in length and estimated to weigh approximately 160 pounds. Scalp hair is dark brown. Irides are brown. Pupils measure 4 mm in diameter each. The sclera show no evidence of jaundice. Nose contains a yellowish somewhat frothy material which is dried. Mouth and ears are essentially normal. No gross changes are seen on external examination of the neck, chest, abdomen, external genitalia, or extremities. Innumerable petechial, and confluent hemorrhages are seen within the skin. These hemorrhages are scattered throughout.

Internal Examination

Body Cavities. The pericardial sac contains a normal amount of straw-colored fluid. The heart lies free in the sac. The pleural cavities contain no free fluid. The lungs are moderately well aerated. Subparietal pleural hemorrhages are seen. These are petechial in nature. The abdominal cavity contains no free fluid. Organs maintain normal relations. The diaphragm arches normally. The liver extends 1 cm above the right costal margin. The spleen is small and does not extend above the left costal margin. The mesenteric lymph nodes are enlarged. The intestines are somewhat distended. Small petechial hemorrhages are seen beneath the serosa in portions of the bowel. The cranial cavity is not explored.

Thoracic Organs. Heart: The heart weighs approximately 350 gm. It is normal in size and shape. The petechial hemorrhages are seen beneath the epicardium of the right and left ventricle. Some of these petechial hemorrhages are confluent. The heart contains a few chicken fat clots. The endocardium is smooth and greyish. The circumferential valve measurements are within normal limits. The valves show no anatomic pathologic changes. No vegetations seen. The papillary muscles and chordae tendineae are grossly

normal. The right ventricle averages 6 to 10 mm in thickness and the left ventricle 12-18 mm. There is no sign of infraction, recent or old. Coronary arteries are essentially normal. Small petechial hemorrhages are seen with the adventitia of the coronary arteries. Lungs: The lungs each weigh approximately 650 gm. Small petechial hemorrhages are seen beneath the pleura of both lungs. The lungs are moderately well aerated. There is no evidence of edema, consolidation, tuberculosis, or tumor. Hilar structures are essentially normal. The bronchi show mucosal congestion.

Abdominal Organs. Gastro-intestinal system: No pathologic changes are seen in the gastro-intestinal system except for subserosal hemorrhages in the lower bowel previously described. Liver: The liver is normal in size and shape and weight. Multiple sections show no gross pathologic changes. The gall bladder is essentially normal. Pancreas: No gross changes seen. Spleen: No gross changes seen. Genito-Urinary System: Both kidneys are essentially similar and may be described as one. They each weigh approximately 225 gm. Capsules strip easily revealing smooth, brown, cortical surfaces. Cortex averages 8-10 mm in thickness and the medulla, 12-18 mm in thickness. There is some congestion of the vessels in the medulla. Calices, pelves, ureters and urinary bladder are essentially normal. Both adrenal glands are approximately twice the normal size. They are quite firm and dark bluish in color. They are obviously the site of massive hemorrhage.

Microscopic Description

Heart: Subepicardial hemorrhages are seen. Endocardium and myocardium are essentially normal. Mitral valve shows no pathologic changes. Coronary arteries are essentially normal.

Lungs: There is intense capillo-venous congestion with some red cell extravasation into alveoli. Bronchi are essentially normal except for mild mucosal congestion. There is no evidence of malignancy, tuberculosis, or pneumonia.

Liver, Spleen, Kidneys: Normal except for congestion.

Pancreas: Normal.

Adrenals: No normal tissue remains. The gland is completely hemorrhagic, obliterating both cortex and medulla.

Summary

This man died with Waterhouse-Friederichsen disease, presumably meningococcic in etiology. He had all the classical signs and symptoms and apparently died in shock.

Pathologic Diagnoses

1. Hemorrhage, massive, adrenal glands.

2. Hemorrhages, petechial subepicardial, subpleural, subserosal, stomach and intestines.
3. Hemorrhages, petechial and confluent, skin.
4. Lymphadenitis, hyperplastic, mesenteric.

Since no blood cultures were obtained, an etiologic diagnosis could not be made.

Epidemiological Investigation. Review of the clinical experiences at Camp Atterbury suggested that the agent (or agents) causing the infectious process was probably a member of the group responsible for respiratory disease. Although a few men had non-respiratory infections such as gingivitis, Vincent's angina, and seminal vesiculitis, the majority developed signs and symptoms in the respiratory system or its adnexa--the lymphatic tissues of neck, and the ear. It is a difficult procedure to make an etiological diagnosis in retrospect but we are collecting the information necessary to establish at least the most probable cause or causes. We have been assisted in this epidemiological investigation by Dr. John H. Dingle, Chairman of the Army Epidemiology Board; Dr. Harry F. Dowling, Chairman of the Committee on Respiratory Disease; Dr. Alexander D. Langmuir, Chief, Epidemiology Branch, U. S. Public Health Communicable Disease Center; Dr. Morris Schaeffer, Medical Director, Laboratory Branch (Virus and Rickettsia Section), Communicable Disease Center; Dr. Keith E. Jensen, In Charge of Respiratory Virus Disease Unit, Laboratory Branch (Virus and Rickettsia Section), Communicable Disease Center; and Dr. Lester M. Dyke, Director of Health Service, University of Illinois. The proposed plan of attack has been based on a differential clinical diagnosis involving (1) histoplasmosis, (2) Q-fever, (3) psittacosis, (4) ARD virus infection, (5) infectious mononucleosis, (6) influenza, and (7) infection from meningococcus.

Histoplasmosis: To discover whether or not histoplasmosis was one of the of the causes, 15 persons from the University who had participated in the 1955 summer trials were given a skin test with histoplasmin. The tests were performed by Dr. R. M. Chappel of the University Health Service. X-rays of the chest were also taken. The results of the skin testing are summarized in Table III. 346. Five or 33% of the tests were positive for previous exposure to histoplasmosis. The X-rays of the chest were "essentially negative and show no evidence of active pathology." The incidence of positive reactions was no greater than that expected in the general population. Histoplasmosis is thus ruled out as a significant element in the epidemic of Camp Atterbury.

Infectious Mononucleosis: On clinical grounds four subjects (2, 39, 73, 87) were suspected of having infectious mononucleosis. Sera were tested for heterophil agglutination with the following results:

Subject No.	Titer
2	1:7
39	1:14
73	0
87	1:14

TABLE III. 346

HISTOPLASMIN SKIN TESTS ON
15 UNIVERSITY PERSONNEL

Name	48-Hour Reaction
M.R.H.	0 reaction
S.F.M.	0 redness, no reaction
S.M.	0 redness, no reaction
N.M.	2-cm redness
W.G.	0 reaction
C.M.	0.5-cm wheal, no redness
B.H.	0 reaction
V.W.S.	2-cm wheal, 5-cm redness
F.S.	1-cm wheal, 3-cm redness
N.S.	0 reaction
S.C.	1-cm redness
D.C.	0 reaction
E.M.	1-cm wheal, 3-cm redness
R.A.	0 reaction
R.E.J.	0 reaction

These titers are all low and indicate that the subjects did not have infectious mononucleosis. Presumably none of the other men, who were not diagnosed clinically as having infectious mononucleosis, would have shown significant titers.

Other Viruses: After some discussion with Drs. Schaeffer and Jensen, samples of serum from 11 subjects who had been seriously ill were sent to Montgomery, Alabama, for laboratory testing. The subjects selected were Nos. 2, 5, 15, 17, 40, 41, 42, 46, 52, 58, 82, and 87. In addition, samples of sera from Subject No. 77 were sent. As controls, the other groups of sera were included. Four men were selected who had been outpatients or who had only physical findings suggestive of respiratory infection. One man was selected from each flight: Nos. 4, 30, 54, and 85. Four other men were selected who at no time revealed clinical or physical evidence of respiratory infection. Again one man in each flight was chosen: Nos. 18, 26, 63, and 99. The serial samples of sera sent for study are indicated in Table III. 347.

The basic principle of the tests being conducted is that a rise in serum antibodies to a particular virus after the patient has been ill with a disease of unknown etiology implicates that particular virus as the probable cause of illness. Although the serological work is not yet complete, a letter from Dr. Jensen dated 17 January 1957 indicates that influenza virus and ARD virus were not among the responsible agents.

"We have carried out complement fixation tests using strains from four types of influenza (A,B,C, and D) and with adenovirus type IV. To date no diagnostic rises in antibody concentrations have been observed. These

results suggest that the infections experienced during the epidemic were not due to influenza agents or adenoviruses currently recognized. I hasten to add, however, that this does not exhaust the possibility that the epidemic may have been of viral etiology. Other agents from the respiratory tract are known and we intend to examine the sera with these additional antigens.

"I was very surprised that we did not find rises in titer with the adenovirus antigen. As you may know, this family of viruses has been associated with epidemics of respiratory disease in military groups. They have also been called the RI, ARD, or APC agents and have been studied intensively by M. Hilleman at Walter Reed Army Institute of Research and R. Huebner at N. I. H. We now have 14 antigenically different types in the lab. The reported experience has been that serologic diagnosis of infection with any of the family could be made using a representative strain in complement fixation tests because of shared antigens."

A letter from Dr. Jensen dated 3 April 1957 deepens the mystery: "Complement fixation tests with psittacosis and Q-fever antigens have failed to establish diagnosis. No significant increases in titer were demonstrated in CF tests carried out by our Diagnostic Unit using CF antigens of influenza A and B (soluble and viral), psittacosis, Q, and adenovirus."

These tests rule out the common agents of epidemic disease among military personnel and make identification of the cause increasingly important for military public health practice. We may have been faced with an infectious disease of etiology yet undescribed by epidemiologists.

TABLE III. 347

SERIAL SERA SELECTED FOR VIROLOGICAL ANALYSIS

Date	Specimen Number
June	
26	2, 4, 5, 15, 17, 18, 30, 40, 41, 42
27	46, 54, 58, 63, 77, 85, 87, 99
July	
2	2, 4, 5, 15, 18, 26, 30, 41, 42
3	46, 52, 54, 58, 63, 77, 82, 85, 87, 99
10	2 (July 9), 4, 5, 15, 17, 18, 26, 30, 41, 42
11	46, 52, 54, 63, 77, (July 7), 82, 85, 87
14	4, 15, 17, 18, 26, 30, 40, 42
15	46, 52, 54, 58, 63, 85, 99
19	4, 15, 17, 18, 26, 30, 40, 42
20	46, 52, 54, 58, 63, 85, 99
24	2, 4, 5, 17, 18, 26, 30, 40, 41, 42
25	46, 52, 54, 58, 63, 82, 85, 87, 99

2. Systemic Complaints

Twice daily the medical officers made a check on each subject. All complaints were recorded and tabulated according to body systems concerned. Table III. 348 lists the complaints according to system. Details concerning individual case histories may be found in Appendix IV. Here we shall confine our attention to the number and frequency of complaints in the experimental period. As mentioned earlier an attempt was made to separate complaints attributable to respiratory infection from those due to regimen. The reader is again cautioned to bear this fact in mind as he studies the present text.

In Table III. 349 are summarized the number of different complaints recorded for two men. In Table III. 350 are summarized the frequency of complaining by the same groups of two men. In all the tabulations on systemic complaints Subjects 87 and 88 have been eliminated since they participated in but two days of the experimental period on 15/52/33 3000 L, Light Work.

General Observations. Among the gastro-intestinal complaints, hunger, anorexia, nausea, gagging, heartburn, and abdominal cramps were most common in all groups. Weakness, lethargy, light headedness, blackout spells, headache, fatigability, nervousness, and depression were more frequently encountered with regard to the central nervous system. Numbness, muscle cramps, and joint pain were the predominating neuromuscular complaints.

Nutrient Combination. Study of Tables III. 349 and 350 indicates that the systemic complaints varied with nutrient combination. There was a tendency for characteristic symptom complexes to be associated with the different nutrient mixtures.

On the 0/100/0 regimen the complaints were mild abdominal cramps, hunger, weakness, and dizziness. The weakness was more pronounced at 1000 Cal/day than at 2000 Cal/day. The complaints of abdominal cramps and hunger would be expected because this regimen provided no bulk to fill the stomach, rapidly emptied out of stomach, and was assimilated faster than other nutrient mixtures. The generalized weakness was due to lack of calories, protein, and fat in the diet. These deficiencies caused generalized deterioration with protein and fat catabolism and a consequent weakness. The dizziness occurred in Subject No. 8 who had an episode of hyperventilation tetany at the time.

The subjects on 2/20/78 had many complaints of abdominal cramps, nausea and vomiting. The complaints of weakness were not too marked but headaches were quite frequent. The abdominal cramps, nausea, and vomiting can be traced to the high fat diet. The weakness was due to lack of protein with a consequent breakdown of body protein. The headaches may well have been due to either gastro-intestinal upsets or the effects of heat.

The subjects on 30/0/70 had severe abdominal pains, nausea, vomiting, and gas. The complaints of headache and weakness were more pronounced than in the 2/20/78 diet. The gastro-intestinal complaints can again be traced to the high fat concentration and the headaches to gastro-intestinal upset. The

weakness here, however, may be attributed to a lack of carbohydrate and the consequent ketosis. Carbohydrate is necessary for normal metabolic processes to take place and when absent, the body must derive its energy from other sources (protein and fat) at great expense to the body.

The severity of the abdominal complaints is attested in the history of Subject No. 31 who was so incapacitated by them that he had to be removed from the meat bar diet after five days.

The STO diet was the worst from the standpoint of number and frequency of complaints. The complaints were hunger, severe abdominal pain and stomach cramps, burning stomach, marked weakness, fatigue, dizziness, headache, depression, sore muscles and joints, and in one case, intermittent amblyopia with restricted visual fields. There was a steady and progressive deterioration of the body with marked defects in efficiency and coordination. Subjects 3, 4, 68, and 70 were unable to complete the experimental period because of the severe exhaustion and debility provoked by starvation. In fact, the only other subject who was unable to complete the experimental periods for reasons of regimen was No. 31 mentioned above.

In sharp contrast to the clinical deterioration noted among men on starvation, 0/100/0, 2/20/78, and 30/0/70 was the relative absence of severe complaints from subjects on 15/52/33. These men fared the best. The worst complaints were those of mild abdominal cramps and some weakness, particularly at the low calorie levels. One subject, however, had sufficiently severe abdominal cramps one night to suggest an attack of acute appendicitis. He was No. 85. His cramps ameliorated with rest and he was able to complete the experimental period.

Caloric Intake. As the caloric deficit increased the complaints among the subjects increased (Table III. 351). With starvation, the frequency of complaints was maximal, especially in the category "central nervous system."

The subjects on STO were in worse shape than all the other subjects. Oral and gastro-intestinal complaints were hunger, abdominal pain and cramps, nausea, vomiting, thirst, sore mouth, and sore tongue. The nausea and vomiting occurred in Subject No. 2 who had simultaneous severe abdominal pains. He was diagnosed clinically as having infectious mononucleosis and air-evacuated to Chanute AFB. The complaints of thirst and abdominal pains and cramps were highest during the first five days, after which there were only three such complaints. The complaints of sore mouth and tongue occurred during the last four days. Hunger persisted for the first four days.

Complaints referable to the central nervous system were light-headedness, weakness, dizziness, blindness, headache, nervousness, irritability, fatigue, and depression. All of STO subjects were extremely weak, lethargic and easily fatigued. They showed mental dullness, lack of coordination, and marked deterioration. The subjects in Flight 1 did not show as much deterioration or complain as much as those in Flight 3. However, they did not last as long. Only one man completed the nine-day experimental period. Subject No. 1 was

taken off his diet that morning because of blindness. All the starving subjects of Flight 3 completed the experimental period, which for them ended on the tenth day.

All subjects became nervous and irritable during the first four days of the experimental period. This was followed by lethargy and depression as the subjects became weaker and more easily fatigued. The complaints of weakness, light-headedness, dizziness and fatigue accounted for 63% of the "central nervous system" complaints; nervousness, irritability, lethargy, and depression, for 31%.

The large number and severity of "central nervous system" symptoms only serves to illustrate the marked deteriorating effects of starvation. All body functions are markedly depressed but the "central nervous system" is hit the hardest. At times of "stress" the body functions are altered to preserve the most vital organs and processes. In the 1000- and 2000-Calorie regimens there was sufficient nutrition to preserve the more vital processes and functions during the experimental period. This was accomplished at the expense of body fat and lean body mass. On the starvation regimen body fat and lean body mass must supply all the energy necessary to maintain the body. After the first few days of starvation this process cannot keep pace with the energy output. Consequently all body systems deteriorate and signs and symptoms of nervous system days function rapidly appear and increase.

The neuromuscular complaints were leg cramps, and tingling and numbness of the legs. All these complaints were elicited from subjects of Flight 3. They began to appear on the 3rd of the period and persisted for variable lengths of time (up to five days) in each subject. There was only one case of joint pain which persisted for only one day. Since these complaints developed before the subjects in Flight 1 were taken off starvation, there can be no evident relationship to length of time on starvation because no subject in Flight 1 developed these complaints.

The oral and gastro-intestinal complaints on the 1000-Calorie regimens were abdominal pain, thirst, nausea, hunger, gagging, anorexia, burning stomach, and loose stools followed by constipation. These complaints were more frequent here than among the 2000-Calorie regimens. Abdominal pains were severe and, in several instances, subjects required medication to relieve the pain. The nausea, vomiting and gagging persisted among subjects on the high fat regimens and frequency of these complaints increased. One subject (No. 54) ate less of his meat bar each day, developed an increasing anorexia, and, by the sixth day, refused to eat any more. Loose stools followed by constipation also appeared among subjects on the high fat diets.

The complaints of the "central nervous system" were light-headedness, weakness, fatigue, irritability, lethargy, and dizziness. These complaints were more pronounced among the men on the 1000-Calorie regimens than among the men on the 2000-Calorie regimens. The complaints became more frequent as the experimental period went along and a peak was reached during the 5th to 9th days. These men appeared to be weaker, to be less efficient and to have undergone more mental and physical deterioration than did those on the 2000-Calorie

regimens.

Only one subject (No. 6) developed any neuromuscular complaints. He reported "leg cramps" on two successive days.

The subjects on the 2000-Calorie regimens had more complaints of different nature than did the subjects on the 3000-Calorie diet. The oral and gastro-intestinal complaints were abdominal cramps and pain, nausea, vomiting, gagging, sore mouth, hunger and anorexia. The nausea, vomiting, gagging, and anorexia were confined entirely to men on the high fat regimens and were the only complaints present more than once in any subject.

The "central nervous system" complaints were those of weakness, headache, dizziness and light-headedness. These complaints were distributed throughout the experimental period with a peak at the 4th to 6th days. Only one subject (No. 55) had a subjective complaint lasting more than one day. He complained of weakness on four successive days.

The neuromuscular complaints were hyperventilation tetany with tingling extremities, sore feet, sore knee and leg cramps. This case of tetany (No. 8) was due to an anxiety reaction and will be discussed in the following section. Two subjects complained of sore feet one time. The sore knee complaint was due to one subject (No. 12) who hurt himself while playing basketball. Subject No. 59 complained of intermittent leg cramps on four successive days.

At both the 1000- and 2000-Calorie levels the subjects on 15/52/33 had the least complaints. The most frequent symptom was hunger. One subject had no complaints, three complained of slight abdominal cramps, one was dizzy, one had a headache, and one had leg cramps. All of the complaints were mild and none caused any undue strain or impairment of function. These findings point out the importance of a balanced intake of protein, carbohydrate and fat.

The subjects on the 3000-Calorie regimen had the least complaints. The complaint of hunger was the only oral or gastro-intestinal complaint. One subject (No. 65) was hungry throughout the experimental period. One subject (No. 44) developed an anxiety reaction with dizziness and hyperventilation tetany due to family difficulties.

Work and Water. In evaluating our clinical material, we have found it difficult to separate the effects of water restriction from those of work. Table III. 352 presents a grouping of the data which brings out again the influence of nutrient mixture and caloric intake but also illustrates the complex inter-relations which existed between water and work.

Only between Flights 1 and 2 (Hard Work) was there a clear accentuation of symptoms by limitation of water. It would be expected that Flights 1 and 2 would have more complaints than Flights 3 and 4 (Light Work). Flight 2 did have more complaints than Flight 4, suggesting an effect of work load, but Flight 3 had more complaints than Flight 1 which is contrary to the expected results.

Flight 2 had almost two times the number and three times the frequency of complaints as did Flight 4. A check of the complaints with reference to regimens reveals that in only two of the nine possible comparisons (0/100/0 2000 and 15/52/33 2000) did subjects in Flight 4 have more complaints. Among the other regimens the subjects in Flight 2 had the most complaints both as to number and frequency.

On the 0/100/0 2000 and the 30/0/70 1000 diets the subjects in Flight 1 had more complaints as to frequency and number than the paired controls in Flight 3. The subjects in Flight 1 had a greater number of complaints on the 15/52/33 3000 diet, while the subjects in Flight 3 had a greater frequency of complaints on the same diet. In the other seven regimens the subjects in Flight 3 had the greatest number and frequency of complaints.

It might be assumed that Flight 3 would have had the lowest number and frequency of complaints. However, the overall evaluation showed that Flight 3 had the second highest number of complaints and the highest frequency of complaints. Two factors, the epidemic of infectious disease and the work output of the subjects probably both influenced these results.

The subjects who became ill were chiefly men of Flights 1 and 4. Because of the nature and severity of the epidemic, the subjects would tend to be more concerned with respiratory symptoms and would minimize or not mention other complaints. Since subjects suffering from the epidemic were placed in "Sick Bay" or air-evacuated to Chanute AFB, it is possible that the subjects would focus their attention on respiratory complaints with hopes of getting out of the field trial. The work output of the subjects probably also had a marked influence on the data. The subjects in Flights 1 and 2 had very little time to themselves. When not undergoing testing, they were marching to and from their camps or recuperating from the marches.

The subjects in Flight 2 had a frequency of complaints which was less than twice the number of different complaints. Clinically, however, they were all on the verge of exhaustion. The medical officer and medical non-commissioned officer of the flight marched and ate with the subjects throughout the experimental period. They contributed greatly to the morale of the subjects, which was unexpectedly high considering their physical condition. It is felt that this flight did not complain as much as their physical condition would warrant.

The subjects in Flights 3 and 4 spent much less time each day in marching that did the men of Flights 1 and 2. Consequently, they had long periods of time each day during which they could lie around in their tents or elsewhere in the field. This allowed them ample time in which to think about their symptoms and discuss them with fellow subjects, and consequently, magnify and increase each others symptomology.

In summary, then, our observations suggest that the epidemic and hard work tended to decrease the frequency of complaints referable to regimen, while light work tended to increase the frequency. It is felt that the total complaints among Flights 1 and 2 were lower than expected. The complaints in Flight 3 were much higher than expected and this was due to poor morale and

excessive time for introspection. The complaints from Flight 4 were just about the number expected. These men had a very high morale as a whole which it is felt would tend to neutralize all other factors.

Limiting the amount of water had a definite effect. Table III. 352 shows that all members of Flight 2 had a greater number and frequency of complaints than did the subjects of Flight 1. When subjects in all the flights are considered, this relationship holds for number of complaints (except for 2/20/78 2000) but only holds for four of the diets with respect to frequency. These discrepancies are due to Flight 3. The relationship in Flights 1 and 2 is excellent. These results would be expected, for water is the medium of metabolic transfer in the body. Dehydration due to restricted water would mean less efficient transfer of metabolites, and consequently a greater deterioration of the physiologic processes would take place resulting in a greater number of complaints. The type of complaints, however, remained the same. The frequency increased and complaints of thirst and sore mouth were more common among men on limited water than among men on unlimited water.

Comment. The regimens were ranked on the basis of the number of complaints. The ranking was done, first for men in Flights 1 and 2 (Table III. 353A) and then for all men (Table III. 353B). We feel that the former ranking is more representative of the clinical impact of the several regimens. By either standard, STO was the worst and 15/52/33 the best. In Table III. 353A 30/0/70 ranks next to starvation, and there is little difference between the 2/20/78 and 0/100/0 diets. When all subjects are considered, there was little difference with respect to the 2/20/78, 0/100/0, and 30/0/70 regimens.

TABLE III. 348

CLASSIFICATION OF COMPLAINTS BY SYSTEMS

Gastrointestinal System

1. Anorexia
2. Hunger
3. Nausea
4. Vomiting
5. Gagging
6. Heartburn
7. Gas
8. Abdominal cramps
9. Loose stools
10. Frequent stools
11. Constipation
12. No bowel movements
13. Burning anus
14. Hemorrhoids
15. Dry heaves
16. Abdominal pain
17. Flatus
18. Burning stomach

Central Nervous System

1. Weakness
2. Lethargy
3. Light headedness
4. Fainting
5. Blackout spells
6. Insomnia
7. Sleepiness
8. Headache
9. Chilliness
10. Anxiety
11. Euphoria
12. Hysterical reactions
13. Nightmares
14. Fatigability
15. Extremities (falling asleep)
16. Jittery
17. Nervous
18. Irritable
19. Amblyopia
20. Depressed
21. Blurring vision
22. Dimming vision
23. Reduced visual fields

Oral Complaints

1. Dry mouth
2. Sore mouth
3. Sore tongue
4. Cracked lips
5. Thirst
6. Change in taste
7. Gritty sensation in mouth
8. Severe thirst (hoarseness and sore tongue)
9. Decreased thirst
10. Coated tongue
11. Sore gums

Neuromuscular System

1. Muscle cramps, e.g., legs
2. Joint pain
3. Sore feet
4. Burning feet
5. Numbness
6. Tingling
7. Parethesia
8. Hyperventilation tetany
9. Hyperesthesia

Miscellaneous

1. Sore throat
2. Toothache
3. Cough
4. Chest pain
5. Adenopathy
6. Heat rash
7. Dysuria
8. Backache
9. Bleeding gums
10. Hiccoughs
11. Dry skin
12. Acetone breath
13. Sweating profusely

TABLE III. 349

ANALYSIS OF SYSTEM COMPLAINTS BY NUMBER OF DIFFERENT COMPLAINTS
(per two men)

	15/52/33 3000		30/0/70 2000		15/52/33 2000		2/20/78 2000		0/100/0 2000		30/0/70 1000		15/52/33 1000		2/20/78 1000		0/100/0 1000		ST 0	
	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L
Gastrointestinal System																				
Hard Work	1	4	1	9	3	0	2	2	1	2	2	4	1	1	4	3	2	3	4	4
Light Work	1	x	3	0	3	6	5	0	1	5	1	3	3	2	8	2	3	1	7	5
Central Nervous System																				
Hard Work	2	4	0	8	1	4	1	4	6	5	3	6	0	2	4	6	1	3	4	10
Light Work	0	x	2	2	2	2	1	1	1	3	1	2	1	0	0	6	6	1	10	8
Oral																				
Hard Work	0	4	1	4	0	0	0	2	0	2	0	4	0	1	0	1	0	3	1	5
Light Work	0	x	0	0	2	0	1	0	0	1	0	1	0	1	0	2	1	0	1	1
Neuromuscular																				
Hard Work	0	1	2	2	1	2	0	1	1	0	0	0	0	0	0	2	1	1	0	1
Light Work	0	x	0	0	0	0	1	1	0	1	0	0	0	1	0	2	0	0	4	1
Miscellaneous																				
Hard Work	1	1	2	3	1	2	2	0	1	1	3	2	0	1	1	1	1	2	1	4
Light Work	0	x	1	2	0	1	2	1	1	2	0	0	1	0	2	0	0	4	2	2
Total	X		42		30		27		34		32		15		44		33		75	

TABLE III. 350

ANALYSIS OF SYSTEM COMPLAINTS BY FREQUENCY OF COMPLAINTS
(per two men)

	15/52/33		3000		30/0/70		2000		15/52/33		2000		2/20/78		2000		0/100/0		2000		30/0/70		1000		15/52/33		1000		2/20/78		1000		0/100/0		1000		ST 0	
	U		L		U		L		U		L		U		L		U		L		U		L		U		L		U		L		U		L		U		L	
Gastrointestinal System																																						
Hard Work	1		6		1		17		3		0		3		5		1		3		3		18		2		1		4		5		5		6		11		9	
Light Work	10		x		8		0		7		12		5		0		1		5		6		3		9		2		44		2		8		2		27		12	
Central Nervous System																																						
Hard Work	2		6		0		23		1		4		2		6		6		8		4		10		0		4		5		15		1		3		6		30	
Light Work	0		x		5		2		2		2		1		1		1		6		2		2		2		0		0		6		30		1		44		11	
Oral																																						
Hard Work	0		5		1		5		0		0		0		2		0		2		0		6		0		1		0		2		0		3		1		8	
Light Work	0		x		0		0		3		0		4		0		0		1		0		1		0		1		0		2		2		0		2		1	
Neuromuscular																																						
Hard Work	0		1		5		2		1		4		0		3		1		0		0		0		0		0		0		2		2		1		0		1	
Light Work	0		x		0		0		0		0		4		1		0		1		0		0		0		1		0		2		0		0		20		1	
Miscellaneous																																						
Hard Work	1		1		2		4		1		2		2		0		1		2		3		2		0		3		1		1		1		6		1		6	
Light Work	0		x		1		2		0		1		5		1		2		3		0		0		1		0		4		0		0		6		6		3	
Total	x				78				43				45				44				60				27				95				77				200			

TABLE III. 351

SYSTEM COMPLAINTS VS. CALORIC INTAKE FOR SUBJECTS ON UNRESTRICTED WATER
(Frequency/Two Subjects)

System Complaints	Caloric Intake, Cal/day			
	3000	2000	1000	0
Oral and Gastrointestinal	2.8	2.3	5.2	10.2
Central Nervous	1.0	2.2	5.5	25.0
Neuromuscular	0.0	1.4	0.2	10.0

TABLE III. 352

COMPLAINTS VS. WORK, WATER, AND NUTRIENT MIXTURE
(On basis of two subjects)

Experimental Regimen		Hard Work		Light Work		Total	
		Number	Frequency	Number	Frequency	Number	Frequency
ST 0	U	10	19	24	99	34	118
	L	24	54	17	28	41	82
0/100/0	U	5	9	10	40	15	49
1000	L	12	19	6	9	18	28
0/100/0	U	9	9	3	4	12	13
2000	L	10	15	12	16	22	31
2/20/78	U	9	10	10	48	19	58
1000	L	13	25	12	12	25	37
2/20/78	U	5	7	10	19	15	26
2000	L	9	16	3	3	12	19
15/52/33	U	1	2	5	12	6	14
1000	L	5	9	4	4	9	13
15/52/33	U	6	6	7	12	13	18
2000	L	8	10	9	15	17	25
15/52/33	U	4	4	1	10	5	14
3000	L	14	19	-	-	-	-
30/0/70	U	8	10	2	8	10	18
1000	L	16	26	6	6	22	42
30/0/70	U	6	9	6	14	12	23
2000	L	26	51	4	4	30	55

TABLE III. 353

COMPLAINTS VS. NUTRIENT REGIMEN
(On basis of two subjects)

A. FLIGHTS 1 AND 2

Regimen	Number	Frequency
ST 0	17.0	36.5
30/0/70	14.0	24.0
2/20/78	9.0	14.5
0/100/0	9.0	13.0
15/52/33	6.0	8.3

B. ALL SUBJECTS

ST 0	37.5	100
2/20/78	17.8	32.5
0/100/0	16.8	30.2
30/0/70	16.0	34.5
15/52/33	8.0	16.8

3. Special Case Reports

Several of the subjects developed interesting clinical syndromes during the course of the 1955 summer tests. In previous sections we have given detailed accounts of several heat syndromes, such as anhidrosis, hypohidrosis, and heat exhaustion. Here we shall discuss two cases of hyperventilation tetany, a case of "dyskinesia" of Stenson's duct, and a case of transient amblyopia.

Hyperventilation Tetany. During the early course of the experimental period, three of the subjects developed tetany. Subject No. 33 exhibited the signs of tetany during and after the heat acclimatization test. His record has been detailed under the section (Section III. D. 9) dealing with incapacitation during the 3.75 mile march. Subjects Nos. 8 and 44 developed signs of tetany as a result of anxiety and hyperventilation.

Subject No. 8 was a young white male subsisting on the 0/100/0 2000 diet with an unrestricted water intake. On 8 July, the third day of the experimental period, he developed severe hysterical hyperventilation and sobbing after returning to the campsite of Flight 1 following the evening meal. Physical examination revealed carpopedal spasm and bilateral median nerve palsy. With reassurance and bag-breathing, the signs and symptoms ameliorated and there were no further episodes of a similar nature for the remainder of the field trial.

Subject No. 44 was a young white male subsisting on the 15/52/33 3000 diet with a restricted water intake. On 9 July, the fourth day of the experimental period, he experienced the sudden onset of tingling sensations in the

arms and severe abdominal cramps, after returning to the campsite of Flight 2 following the afternoon meal. He was immediately returned to Sick Bay. Observation revealed a very anxious appearing, well-developed, well-nourished, young male who was sobbing with pain and hyperventilating. Physical examination revealed carpopedal spasm and a positive Chvostek's sign. Paresthesia was accentuated by inflating the blood pressure cuff above the level of the diastolic blood pressure. Palpation of the abdomen disclosed general tenderness and spasm. The subject cried out from occasional spasms of pain. Rest and bag-breathing led to rapid amelioration of the pain. Two hours later the young man had no complaints, and there were no further episodes of a similar nature for the remainder of the field trial.

Comment: Both of these subjects were very anxious; however, Subject No. 8 was worse. He had numerous complaints about domestic problems and it was felt at the time that he was trying to be taken off the project. His signs and symptoms were those of a typical anxiety reaction in a neurotic person. Sargent (1940), Cecil and Loeb (1953), and Noyes (1954) have pointed out that dyspnea with tetany is very common in anxiety states. Noyes notes that feelings of impending doom and fear of unpleasant future circumstances can be changed by the neurotic individual into verbal complaints more acceptable to reality (those with whom he is in contact) and to himself. A similar mechanism is used in conversion hysteria. Unlike the conversion hysteria, however, there is no psychogenically induced incapacitating physical defect, but rather a marked anxiety which can cause hyperventilation. Under proper care the patient may later realize what the source of his problem was. The length of time for recovery varies with each patient and the precipitating circumstances.

This picture would certainly fit Subject No. 8. His symptoms appeared shortly after he learned that Subject No. 77 had expired. His complaints of domestic problems (fear that his wife was unfaithful) only represented a conversion of his fear of death or injury into these other complaints, which were used as an excuse to leave the project. These complaints and his symptoms disappeared when it was pointed out that the trial would soon be over and should anything happen to him, he would be given prompt medical attention and air-evacuated to Chanute Field.

Subject No. 44 did not present any verbal complaints similar to those of Subject No. 8. It is possible that the death of Subject No. 77 made him more concerned for himself. When he developed his abdominal cramps he only became more anxious. The pain became worse and the subject began to hyperventilate. Tetany was the sequela. It is very possible that the abdominal pain was the sole precipitating factor. McCance (1932) showed that pain can be used to induce hyperventilation tetany and that, in this manner, it could be produced more easily than by other means. He further stated that this did not hold for all persons, but only occurred in those individuals more than normally susceptible to pain.

The hyperventilation tetany in Subject No. 33 was due to work in the heat. Bazett and Haldane (1921), Landis, et al., (1926), Fowweather, et al., (1940), and Wingfield (1941) have all reported cases of hyperventilation tetany due to

heat itself as well as working in heat. As the body begins to accumulate heat, the depth of respiration is increased. This is soon followed by a further increase in depth and a rise in the rate of respiration unless the body can lose heat by other routes. These conditions then cause an uncompensated CO_2 deficit and an increase in the alkalinity of the blood which leads to tetany. Powweather stated that the appearance of tetany was dependent on the state of acid-base equilibrium at the onset of hyperventilation as well as the susceptibility of the individual to alkalosis and, therefore, would account for the fact that some individuals develop tetany and others do not under the same conditions. That tetany should develop in a man on a ketogenic and acidotic diet, then, is remarkable indeed, and demonstrates how debilitating heat can be for an anhidrotic castaway living on meat bar.

As can be seen from the record of Subject 33, at the end of 24 minutes of marching his rectal temperature was 2°F higher than it was at the beginning of the march. His respiratory rate was 43; he complained of tingling in hands, arms, chest, and mouth; and a positive Chvostek's sign was elicited. He was placed on a shaded bed and 46 minutes after the march all tingling had disappeared and respiration was normal. Although his rectal temperature was 101.4°F at the time the tingling disappeared, heat loss was greater than heat production and hyperventilation was not necessary as a means of heat dissipation. This recovery was accomplished by two means. He was resting in bed and not producing heat as he was while marching. Therefore, less body heat had to be dissipated. The bed was located in the shade next to an open window and, therefore, minimal sweating in this cool location was able to dissipate accumulated body heat and stabilize and finally lower body temperature. This can be seen in the subject's record. Nineteen minutes after the march the rectal temperature was 101.4°F where it remained for the next 27 minutes. Thereafter, it began to slowly drop and within 25 minutes more was down to 100.8°F at which time the observations were discontinued.

Dyskinesia of Stenson's Duct. Subject No. 32 was a well-developed, well-nourished, 18-year old, white male. His past history was non-contributory except for mumps, tracheotomy performed at age 5 for diphtheria, and a possible allergy to egg. Physical examination on 20 June did not reveal anything of significant nature.

During the pre-period days on the 2nd and 3rd he complained of a heat rash. On the 5th day, during the course of a venipuncture, he had a fainting spell which lasted about five minutes. During this spell he exhibited several clonic movements of the upper extremities and did not react to painful stimuli. Physical examination on 4 July was within normal limits.

In the experimental period he subsisted on the 30/0/70 1000 diet with limited water intake. On the first day he complained of slight thirst, headache, occasional stomach cramps, mild fatigue, and being "short-winded". He had stomach cramps and was dizzy on the 2nd day. On the 3rd and 4th days he complained of moderate thirst, postprandial burning stomach, sore tongue, and occasional stomach cramps. He had a gritty sensation in the mouth on the 5th day and a slight burning stomach on the 7th day. Physical examination on 15

July was not remarkable.

Rehabilitation began on 15 July. For the first three days the food allowed was restricted and then gradually increased. On 18 July he began to eat ad libitum. During evening medical rounds on 18 July, he complained of shooting pain bilaterally in the region of the mandibular joint. This pain had begun on 15 July, had gradually decreased in the past three days, had only occurred at meal times, and was most intense at the beginning of the meal. He was given a slice of lemon to suck and experienced immediate bilateral pain localized over the regions of both parotid glands. The pain was shooting in nature and did not radiate. Oral mucosa did not show any evidence of injection or hyperplasia. The ostia of Stenson's ducts appeared normal; there was no detectable flow of saliva. No evidence of stone or gravel was found in the duct. The pain disappeared within one minute after removing the lemon from the mouth. In the area over the parotid glands, the tissues felt swollen and there was some tenderness on palpation. A repeat test with a lemon slice elicited the same signs and symptoms. These signs and symptoms gradually regressed and disappeared completely in the next few days. The remainder of the recovery period was uneventful and free of complaints. Physical examination on 26 July was within normal limits.

Comment: A review of the literature failed to uncover any similar cases. The only reports available on functional dyskinesia of duct systems are those relating to the biliary tract. Ivy and Sandblom (1934), Ivy (1936), Barband (1942), and Best and Taylor (1950) all reported on "autonomic imbalance" causing spasm of the bile duct. Choledochal denervation by Lagerlof (1947) was followed by prompt relief of symptoms and decrease of pressure in the common duct to normal levels. Farmer (1954) stated that reflex action resulting from a distended colon could cause biliary spasm while Alexander (1934), Carter et al., (1939), and Lockwood (1948) have all reported on the psychosomatic aspects of biliary spasm. In all of the above articles the causes of biliary spasm, in the absence of pathology, were interpreted as being due to autonomic imbalance of unknown etiology, to psychogenic causes due to anxiety and tension, or to obscure reflex action from other parts of the body.

In light of the facts and findings in our case, a possible explanation may be arrived at by an analogy with the biliary system.

There was no evidence of inflammation of the gland, pathology of the ostia, stones or gravel in the duct, or spasm of the buccinator muscles. These findings would then rule out mechanical or inflammatory causes.

The parotid gland and duct, like the biliary system, has both a parasympathetic and sympathetic innervation. There is normal balance of stimulation between the two systems which can be influenced by chemical stimuli as well as by psychic factors.

Since an autonomic imbalance can cause biliary tract spasm, it is also possible that our case could be due to the same cause. It is doubtful that the change of diet was the precipitating mechanism because the subject had his

symptoms from the first day of rehabilitation and metabolic changes do not occur instantaneously.

In this case, water balance may have some meaning. The subject was in negative water balance during the experimental period which would indicate that he was dehydrated. He was allowed to drink water ad libitum during the rehabilitation period. In dehydration there is a shifting of body water and changes of body metabolites. The absorption and redistribution of body water in a dehydrated person is rapid and there is a simultaneous shifting of metabolites. In our case, the dehydration and rapid rehydration with simultaneous shifting of metabolites may possibly account for an autonomic imbalance with a consequent spasm of Stenson's duct.

Best and Taylor (1950) have pointed out that reflex action due to mechanical, chemical, or nervous stimuli from other parts of the body can cause marked changes in salivary gland activity. It may, therefore, be possible that an unknown reflex mechanism was the precipitating factor.

The psychogenic factor cannot be overlooked in this case. On 26 June the subject fainted during the course of a venipuncture and during the fainting spell he did exhibit several clonic movements of the upper extremities and did not react to painful stimuli. This suggests that the subject may have had some anxiety and fears. It is, therefore, possible that the precipitating mechanism was psychogenic in origin or due to an epileptiform type of disturbance.

Transient Amblyopia. Subject No. 1 was a healthy, young, white male who completed the pre-period without any complaints. Physical examination on 4 July was negative except for a mild pharyngitis.

During the experimental period, he was on starvation and was only allowed vitamins and unlimited water. On the 3rd day of the period he complained of light-headedness and abdominal pain. He again complained of abdominal cramps on the 5th day following the heat acclimatization test. On the 6th day he complained of weakness and he became dizzy on standing. From the 7th to 10th days he was still weak and dizzy, and he experienced blurring and dimming of vision for several minutes on standing. There was some narrowing of visual fields. On the 9th day he was taken off the starvation regimen and given intravenously 2000 ml of 5% dextrose in saline plus 1000 ml of 5% dextrose in water. On the 10th day he was given 300,000 units of penicillin intramuscularly. Physical examination on 15 July revealed narrowed visual fields and hypoactive knee and ankle reflexes.

During the first three days of the recovery period there was a residual restriction of the visual fields. He received 300,000 units of penicillin per day for the first two days. From the 4th to the 6th days he experienced abdominal cramps and pain which were intensified by exercise. He was given 4.5 gm of NaCl on the 6th day. The rest of the recovery period was uneventful. Physical examination on 26 July revealed hypoactive patellar reflexes.

The subject did not show classical signs and symptoms of heat exhaustion.

Subjectively he experienced weakness and dizziness on standing which would indicate inadequate peripheral vasomotor control and a consequent postural hypotension which persisted for several minutes. Objectively he showed signs of lack of coordinated effort and was in negative water balance. These findings suggest that the subject was a borderline or very early case of heat exhaustion.

Visual disturbances are well documented findings in heat exhaustion. The etiology is presumably due to cardiovascular disturbances. The loss or decreases of peripheral vasomotor control causes an inadequate circulation to the brain and the eye. This commonly produces blurring and dimming of vision particularly on exertion and when arising from the recumbent position. Rogers (1943) stated that visual disturbances are among the early warning signs of heat exhaustion. Wallace (1943) pointed out that visual disturbances in heat exhaustion can also include temporary blindness. The exact etiology of the blindness is unknown but probably due to a combination of dehydration and cardiovascular inadequacy.

4. Rehabilitation

Clinical Remarks. Considering the subjects as a group, there were very few significant complaints attributable to regimen during the rehabilitation period. Nausea, vomiting, and bowel complaints were singularly absent. Two conditions contributed to this result. First, previous experience had taught us that restriction of food intake for a few days made it much easier for the organs and systems to begin returning to normal. Second, due to the heat, when free feeding was resumed, appetites were depressed and the tremendous intakes of food observed in the winter study did not occur. The more moderate eating did not provoke the few episodes of projectile vomiting we observed in the winter and there were many fewer instances of complaints of feeling bloated or distended.

Recovery Diuresis. Among the intriguing phenomena observed during the rehabilitation period of the 1954 winter test was a marked diuresis when the subjects changed from 5-in-1 ration to Field Ration A (Sargent et al., 1955). To investigate this phenomenon further we extended the recovery period two days (July 26 and 27) at Camp Atterbury and fed the experimental subjects Field Ration A. Records were maintained of fluid intake and 24-hour urinary specimens were collected and the volume was measured.

From the data available only those of Flights 1 and 2 could be used. Flights 3 and 4 were given the Heat Acclimatization Test on the day before (July 25) the dietary change was made and, because of the extra sweating that was provoked, we do not think that their urinary volumes can be compared to those collected on days when the men were doing only moderate work all day.

Interpretation of the results is further complicated by the fact that the weather at the time of the dietary change was extremely hot. The maximum temperatures were 99°, 103°, and 104°F on the day before, the day of, and the day after the dietary change. Since it is difficult to allow for sweat loss, we cannot merely examine the urinary volumes for evidence of diuresis.

We must take into account the water intake. We have expressed the 24-hour urinary volume as a percentage of the 24-hour fluid intake.

In Table III. 354 we have summarized the results of our analysis. Data for Flight 1 and 2 from the 1954 winter test have been recalculated for comparative purposes. (Changes exhibited by Flights 3 and 4 were comparable.) It is at once apparent that a diuresis did not occur in the summer. The urinary volumes of the day before the dietary change (July 26) increased only slightly in relation to concurrent fluid intake. In the winter the urinary volumes exceeded the fluid intakes by as much as 58%. These data do not support the hypothesis that the diuresis of the winter test was the result of dietary change. Since, however, hot weather is antidiuretic, these data cannot be construed as refuting such an hypothesis.

TABLE III. 354

RECOVERY DIURESIS

	Summer 1955				Winter 1954	
Flight	Date	Mean Fluid Intake	Mean Urine Vol.	%	Date	%
	July	ml	ml		March	
1	25	4455	1362	30.6	28	84.9
	26	3492	1518	43.5	29	157.6
	27	3200	799	25.0	30	137.1
2	25	4037	1315	32.6	28	85.3
	26	3406	1214	36.4	29	138.4
	27	4094	686	16.8	30	134.0

SECTION IV: DISCUSSION

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A. INTRODUCTION

The purpose of this discussion is to attempt to judge the relative merits of 20 combinations of protein, carbohydrate, fat, calories, and water, used both in hard work and light work. Attention will be centered on the single practical question: Is it possible to settle on a single optimal combination as a potential all-purpose survival ration?

We shall also discuss how the experiences and observations of 1955 confirm and extend the five major generalizations that arose from the temperate study of 1953 and the cold weather study of 1954. In addition we shall present four major theoretical generalizations which have arisen from the hot weather study of 1955. These are:

a) Heat acclimatization phenomena
b) Anhidrosis as a criterion of water requirement
c) Concept of osmotic balance
d) Chemical composition of sweat

B. THE OPTIMAL NUTRIENT COMBINATION FOR SURVIVAL IN MOIST HEAT

In order to make adequate judgments, logical criteria must be established. Among the many measurements which were made in this study, 27 proved to be discriminatory among the several nutrient combinations, could be quantitatively expressed, and could be logically related to maintenance or deterioration of the survival potential of the castaway. Other quantitative measurements could not be so used, either because they were not discriminatory among nutrient combinations, or because they were autocorrelated with other discriminatory measures, or because they have not been proved to be predictive of potential damage.

In previous reports we have emphasized the central position which clinical observations occupy in any study on problems of survival. Deterioration in the body as a whole may give rise to detectable signs and symptoms before there are measurable physiological and biochemical deviations from normal. Only one truly serious defect in an otherwise perfect ration could lead to fatal deterioration in a survivor. This concept of "the weakest link" in an otherwise superior survival ration must be emphasized constantly in any consideration of various possible survival rations.

The crucial importance of clinical observation was dramatically demonstrated in the hot weather study. Several cases of total anhidrosis appeared, a syndrome of the gravest import. However, biochemical and other quantitative measurements were not significantly different between the anhidrotic subjects and others on the same regimen who were still sweating. Therefore, biochemical and physiological measurements would not have detected the dangerous deterioration in these men. Clinical observation did.

1. Biochemical and Physical Ratings

Biochemical and physiological measurements have been summarized to permit rank-order treatment (Table IV. 1 for Hard Work and Table IV. 2 for Light Work). In the final compilation 27 measurements were used, all logically related to survival potential. Defense of these selections is as follows:

Body Composition. Minimal decreases in body weight and body water, as measured by D_2O space and water diuresis test, are advantageous. The interpretation of water diuresis data was that the least change from PRE II was best.

Kidney Function. Normal kidney function is critical in survival. The osmotic parameters have been discussed fully in Section III. E. For present purposes mean urine volume was interpreted on the basis that the least volume during limitation of water is the best. The least calculated U/S ratio was considered the best. Among clinical investigators creatinine clearance and serum non-protein nitrogen are currently in favor as diagnostic of renal function. We take the least change in creatinine clearance as best and the lowest serum non-protein as best. It must be considered that when formed elements are present in the urine, actual or potential tissue damage exists. We have used cylinduria and hematuria in work (EXP I) for rating with the interpretation that the "least number" is best in both cases.

Endocrine Function. A diminution in 17-ketosteroid excretion is generally considered to mean an alteration in adrenocortical function, and we have considered the least change to be the best. Serum chloride is probably related to adrenal-cortical function as well as dietary intake of water, nitrogen, and salt. We have considered the least change as best.

Liver Function. Because of its importance to all metabolic processes, liver function is very important in survival studies. Clinical investigators consider that a decrease in serum cholinesterase is diagnostic of diminished liver function, and we have taken the lowest value in EXP II or REC I as worst.

Circulatory System. Orthostatic hypotension must be considered potentially dangerous, and we have ranked the standing systolic blood pressure with the interpretation that the lowest is the worst.

Respiratory Function. Voluntary ventilation capacity was discriminatory among regimens and is generally considered to be of diagnostic significance in the sense that substantial diminution means trouble somewhere in the complex series of anatomical and physiological events that are necessary for normal respiration. We have taken the greatest decrease in EXP I as worst. Resting oxygen consumption has been discussed in detail in Section III. G. 4. It is related to diet, thyroid function, and environmental temperature. We have taken the least change between PRE II and EXP I as best.

Nutrient Balance. Negative balances of calories, water, nitrogen, chloride, sodium, potassium, and phosphorus will lead sooner or later to deterioration. We have interpreted, for all these, greatest negativity as worst. Until proved otherwise, ketonuria must be considered deleterious. For ranking purposes we have listed as worst the highest percentage of specimens in EXP I which showed a strongly positive acetone reaction (+2, +3, or +4). As discussed in Section III. B. 12, osmotic balance is important to the castaway particularly during limitation of water. If too low, it will not permit retention of ingested water; if too high, it provokes increased obligatory renal water loss. We have considered the least deviation from 470 μosm/min as best.

Heat Tolerance. Under standard conditions of work, the least rise in rectal temperature (EXP I) is best. Sweat rate is correlated closely with effectiveness of acclimatization. We have used sweat rate corrected for body weight and ambient environmental temperature as defined in Section III. D. 2. From the point of view of heat tolerance, we consider the largest rate of sweating as the best.

In setting up the tables, mean values for all nutrient combinations were assigned rank-order numbers, the number one representing best. In the hard work groups all 21 possible regimens were rated. In the light work groups only 20 regimens could be rated because both subjects on 15/52/33 3000 L were removed from the experiment early in EXP I. A mean composite score was then calculated for each regimen. In order to permit manipulation on the basis that all regimens had 27 ranked criteria it was necessary to add a mean score where blanks existed in Tables IV. 1 and IV. 2. Twenty-four hour urinary volume

and osmotic excretion could only be ranked in the subjects on limited water for hard and light work groups alike. Chloride and sodium balances were impossible to calculate for FRA's. In the hard work groups data were missing for body water in 15/52/33 2000 L, and U/S ratio, standing systolic pressure, and sedimentation rate in 15/52/33 1000 L. With these interpolations, the data summarized in Tables IV. 3 and IV. 4 and Figures IV. 1 and IV. 2 were prepared. Each nutrient combination had rank-order scores which fell into four quartiles, the best being the first quartile (1 - 5) and the worst being the fourth quartile (16 - 21).

Before discussing the results of rank-ordering, it is necessary to mention quantitative measurements not pertinent for the present purpose for one or another of four main reasons: (a) Changes were so small that attempting to rank-order the regimens would be statistically absurd. (b) The measurement had no demonstrable relation to survival potential, i.e., ability to withstand the stresses of survival for not more than 10-14 days. (c) The data were incomplete or technically unreliable. (d) An additional group of measurements was omitted so as not to bias by auto-correlation the average rank-order. Among the measurements omitted by one or more of these criteria were:

Body Composition. Body fat, photographs of subjects, and other anthropometric data.

Renal Function. Minute urinary volume, albuminuria in rest, hematuria in rest, minute urinary urea, urea clearance, urinary osmotic excretion, osmotic clearance, minute urinary creatinine, serum creatinine, epithelial cells, white blood cells, and urinary glucose.

Endocrines. Serum sodium, potassium, calcium, and inorganic phosphate; minute urinary creatine.

Liver Function. Serum total cholesterol and urinary urobilinogen.

Circulation. Resting pulse rate, resting blood pressure, standing pulse and diastolic blood pressure, and electrocardiogram.

Respiration. Carbon dioxide production, pulmonary ventilation, respiratory rate, tidal volume, and respiratory quotient.

Hematology. Hematocrit, total leukocyte count, and differential white cell count.

Nutrient Balances. Calcium balance, urinary acidity, titrable acidity, fat intake, and carbohydrate intake.

Gastrointestinal Function. Serum amylase, fecal wet weight, fecal fat, fecal muscle fibers, and benzidine reaction.

Central Nervous System. Passage of time and electroencephalogram.

Heat Tolerance Test. Pulse rate, skin temperature, all sweat chemistry, both qualitative and quantitative; and quantitative and qualitative data on urine during and after march.

Four major conclusions are supported by the data relative to the hard work group. First, with unlimited water, no nutrient combination ranked as high as the ideal controls (FRA) or as low as starvation. However, 15/52/33 3000 and 2000 were close to the ideal controls. Second, with limited water, the two best scores were achieved by 15/52/33 3000 and 2/20/78 2000; and no nutrient combination was as bad as starvation. Third, regardless of water intake, with a single exception (15/52/33 L), no nutrient combination at 1000 Cal/day ranked as high as the same nutrient combination at 2000 Cal/day. Fourth, water restriction worsened the score of every nutrient combination with the single exception of 0/100/0 1000, the score of which approximated that of starvation in any case.

Turning to the light work groups, four major conclusions may be drawn similar to those for hard work. First, with unlimited water, no regimen was close to the ideal controls (FRA) and none was as bad as starvation. Second, with limited water, the best regimen was 15/52/33 2000, and none was as bad as starvation. Third, regardless of water intake, with the single exception of 30/0/70, nutrient regimens at 2000 Cal/day scored better than they did at 1000 Cal/day. Fourth, with limitation of water, scores were decreased in all regimens except 15/52/33 2000 L.

Clearly, the conclusions are the same for hard and light work (Table IV. 3 and IV. 4; Figures IV. 1 and IV. 2). Increasing the calorie intake improves the score of any nutrient combination; restriction of water makes the score worse. Of the 2000-Calorie regimens, 15/52/33 and 2/20/78 were the best when water was unrestricted; with limited water 2/20/78 was the best, followed by 15/52/33. Of the 1000 Calorie regimens 15/52/33 was the best regardless of water intake, followed by 2/20/78.

It is noteworthy that neither meat bar nor pure carbohydrate came close to 15/52/33 or 2/20/78 in this study. Admittedly, both proved to be better than starvation. However, our data do not support the claims of Gamble and others in behalf of pure carbohydrate for hot weather, nor that of Steffanson in behalf of pemmican for hot weather.

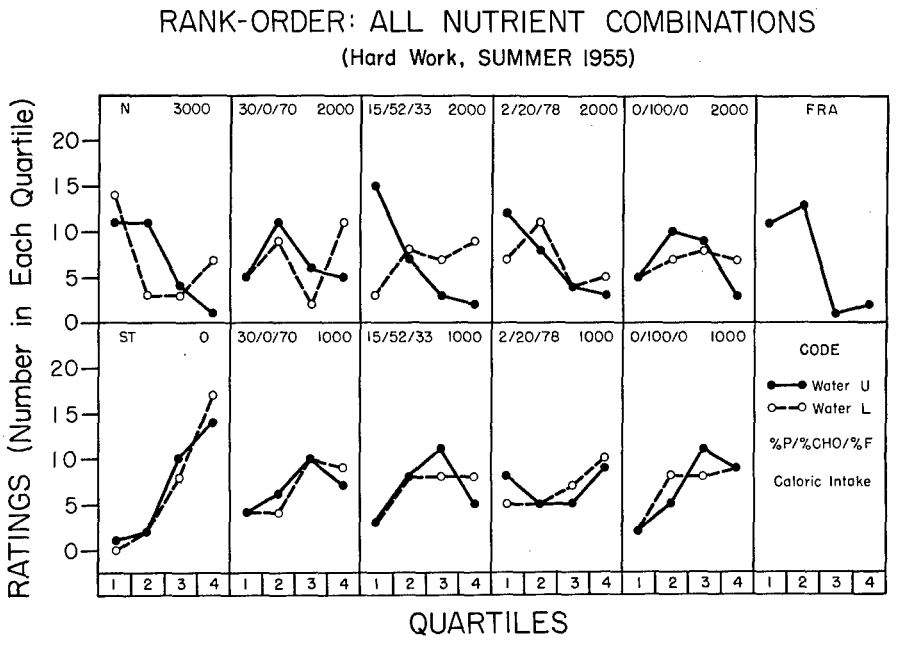


FIGURE IV. 1. RANK-ORDER: ALL NUTRIENT COMBINATIONS--HARD WORK.

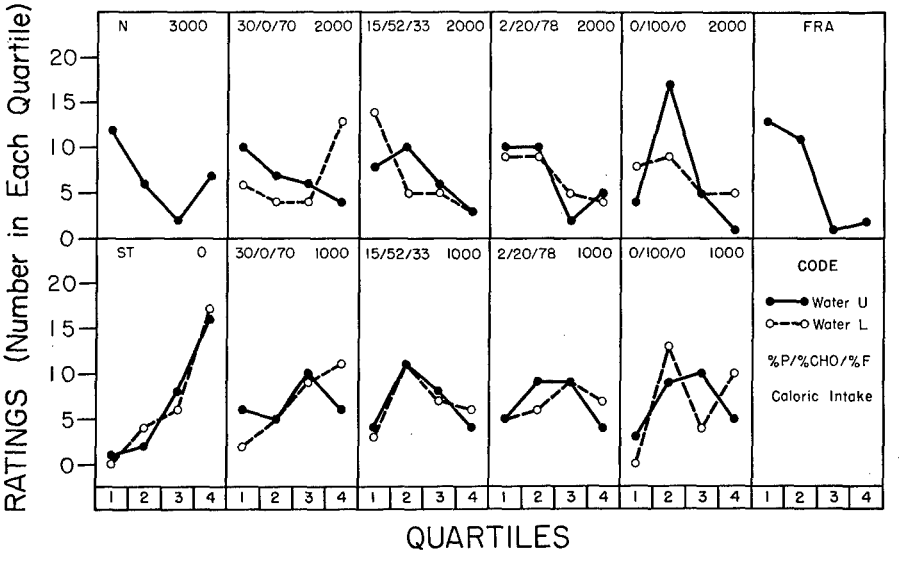


FIGURE IV. 2. RANK-ORDER: ALL NUTRIENT COMBINATIONS--LIGHT WORK.

TABLE IV. 1
RANK-ORDER OF NUTRIENT COMBINATIONS: HARD WORK

Measurement (Second week of experimental period unless otherwise specified in text)	Nutrient Combinations										
	FRA	N 3000		30/0/70 2000		15/52/33 2000		2/20/78 2000		0/100/0 2000	
	U	U	L	U	L	U	L	U	L	U	L
Body Composition											
1. Body Weight	1	2	4	7	14	3	6	5	8	9	12
2. Body Water	2	8	15	12	20	1	-	4	6	16	10
3. Water Diuresis	2	9	21	1	19	5	18	3	16	8	6
Kidney Function											
1. Osmotic Parameters											
a. 24-hr vol	-	-	18	-	21	-	12	-	5	-	2
b. U/S ratio	6	3	18	12	19	11	16	2	17	5	7
2. Creat Clearance	3	8	2	6	7	10	20	21	17	13	16
3. Serum NPN	10	11	18	19	20	14	15	1	4	2	5
Endocrines											
1. 17-Ketosteroid	6	4	5	13	3	2	1	7	12	14	15
2. Serum Chloride	8	8	2	6	2	4	14	12	18	12	14
Liver Function											
1. Serum ACh-ase	2	3	7	9	9	20	6	6	14	9	12
Circulation											
1. Std Sys Press	8	6	14	3	19	4	10	1	8	11	17
Respiration											
1. Vol Vent Cap	10	4	11	6	19	1	17	14	2	20	5
2. O_2 Consump	2	17	3	20	6	15	6	21	4	8	13
Hematology											
1. Sed Rate	6	11	20	3	10	9	19	17	6	4	1
Balances											
1. Calorie	3	2	1	10	5	4	7	11	6	8	9
2. Water	1	14	10	5	16	4	11	7	2	12	8
3. Nitrogen	1	2	3	5	6	4	8	7	8	15	14
4. Chloride	-	12	4	20	18	7	16	1	2	6	17
5. Sodium	-	6	2	8	3	1	14	4	10	12	18
6. Potassium	16	8	1	9	6	2	21	5	7	14	13
7. Phosphorus	2	3	1	6	8	7	9	4	6	18	16
8. Ketonuria	4	4	4	14	15	4	4	13	12	4	10
9. Osmotic	-	-	21	-	17	-	4	-	6	-	15
Heat Tolerance											
1. Rectal temp Δ	6	8	20	12	18	1	19	4	21	4	10
2. Sweat rate	6	1	3	17	8	5	21	4	11	12	16
Kidney in Work											
1. Cylindruria	13	6	6	16	6	6	6	6	6	6	16
2. Hematuria	20	4	4	15	4	16	13	10	4	10	4
Mean	6.0	6.6	8.8	10.2	11.8	6.4	12.0	7.6	8.8	10.1	11.1

TABLE IV. 1 (Continued)

RANK-ORDER OF NUTRIENT COMBINATIONS: HARD WORK

Nutrient Combinations											
30/0/70 1000		15/52/33 1000		2/20/78 1000		0/100/0 1000		ST 0		FRA
U	L	U	L	U	L	U	L	U	L	
17	19	12	18	12	12	14	16	20	21	1
11	14	6	13	3	17	9	7	18	19	2
14	20	11	7	4	17	15	13	10	12	2
-	14	-	-	-	9	-	7	-	16	-
13	16	8	-	2	4	9	10	20	14	6
1	11	10	12	4	19	15	5	18	14	3
16	21	10	7	3	8	12	6	13	17	10
10	17	10	8	21	20	20	9	18	16	6
12	8	8	6	4	18	20	14	14	19	8
11	4	1	16	18	12	21	18	18	15	2
2	20	15	-	5	13	6	18	12	16	8
8	21	6	18	9	16	4	12	13	15	10
18	10	16	9	10	2	14	19	8	12	2
18	15	14	-	16	2	7	8	13	12	6
18	13	19	15	16	14	17	12	21	20	3
18	3	16	17	9	6	20	13	21	19	1
10	11	13	12	16	20	19	17	21	18	1
13	8	15	19	14	3	11	9	5	10	-
9	5	7	17	20	11	18	15	13	16	-
11	3	11	20	18	4	15	17	11	18	16
15	14	12	10	21	10	17	19	13	20	2
20	19	11	4	16	16	4	4	21	18	4
-	13	-	2	-	10	-	19	-	8	-
4	12	4	16	12	16	8	8	14	14	6
9	19	2	7	10	15	14	13	18	20	6
6	6	19	6	6	18	14	14	20	21	13
4	11	21	4	4	12	17	19	14	18	20
11.5	12.8	11.1	11.4	10.9	12.0	13.2	12.6	15.5	16.2	6.0

TABLE IV. 2

RANK-ORDER OF NUTRIENT COMBINATIONS: LIGHT WORK

Measurement (Second week of experimental period unless otherwise specified in text)	Nutrient Combinations										
	FRA	N 3000		30/0/70 2000		15/52/33 2000		2/20/78 2000		0/100/0 2000	
	U	U	L	U	L	U	L	U	L	U	L
Body Composition											
1. Body Weight	1	2		8	15	7	5	3	5	10	5
2. Body Water	2	5		16	16	4	6	3	11	7	10
3. Water Diuresis	9	8		4	20	3	16	5	18	7	11
Kidney Function											
1. Osmotic Parameters											
a. 24-hr vol	-	-		-	12	-	2	-	5	-	7
b. U/S Ratio	8	18		15	20	4	19	9	6	3	1
2. Creat Clearance	2	16		1	16	11	2	6	10	12	9
3. Serum NPN	14	17		18	20	8	13	1	4	5	2
Endocrines											
1. 17-Ketosteroid	8	2		8	12	2	4	7	16	12	5
2. Serum Chloride	6	10		2	1	6	6	10	2	16	16
Liver Function											
1. Serum ACh-ase	4	4		8	2	3	12	1	17	10	18
Circulation											
1. Std Sys Press	2	13		18	19	6	12	1	5	4	14
Respiration											
1. Vol Vent Cap	10	4		11	16	6	12	17	5	8	2
2. O_2 Consump	2	8		4	19	15	16	18	11	12	7
Hematology											
1. Sed Rate	10	18		15	1	8	5	20	3	9	4
Balances											
1. Calorie	1	2		4	7	10	5	9	6	8	3
2. Water	2	12		11	5	12	3	14	1	10	17
3. Nitrogen	1	4		2	7	5	3	8	10	12	14
4. Chloride	-	16		19	16	18	4	2	1	8	5
5. Sodium	-	4		14	2	13	1	17	8	10	6
6. Potassium	10	17		1	11	16	4	20	6	7	6
7. Phosphorus	1	2		5	17	4	3	6	7	10	8
8. Ketonuria	2	2		13	17	2	2	12	12	2	7
9. Osmotic	-	-		-	16	-	7	-	13	-	20
Rectal temp Δ	4	18		2	20	16	6	2	9	14	14
Sweat Rate	3	4		1	10	14	5	2	20	6	14
Cylindruria	18	9		9	9	9	9	9	9	9	9
Hematuria	20	4		10	4	15	11	4	13	8	19
Mean	6.1	8.8		8.8	12.2	8.7	7.1	8.2	8.6	8.8	9.4

TABLE IV. 2 (Continued)

RANK-ORDER OF NUTRIENT COMBINATIONS: LIGHT WORK

Nutrient Combinations										
30/0/70 1000		15/52/33 1000		2/20/78 1000		0/100/0 1000		ST 0		FRA
U	L	U	L	U	L	U	L	U	L	
12	16	17	12	14	10	18	14	20	19	1
14	14	12	8	9	17	1	20	18	19	2
2	19	1	17	10	15	6	13	12	14	9
-	14	-	9	-	18	-	16	-	21	-
17	14	13	16	10	5	2	7	12	11	8
14	7	12	15	4	8	19	19	19	6	2
16	19	12	10	3	9	11	7	15	6	14
1	17	10	10	6	15	14	18	19	20	8
16	6	10	6	14	14	19	18	20	12	6
12	16	8	16	8	12	14	6	19	20	4
3	11	10	16	10	20	8	8	15	18	2
13	19	6	14	20	15	2	9	3	18	10
20	10	2	5	14	4	14	6	17	8	2
11	16	17	12	19	2	6	6	13	14	10
13	11	17	14	18	12	15	16	20	19	1
4	9	8	6	15	7	20	16	18	18	2
6	14	11	9	18	16	15	17	19	20	1
13	12	14	7	2	10	6	10	9	17	-
7	3	12	5	11	19	8	15	16	18	-
3	15	18	12	2	13	8	10	14	19	10
9	16	11	14	12	18	14	15	20	19	1
16	19	7	10	14	18	10	7	15	20	2
-	2	-	4	-	4	-	18	-	11	-
9	20	2	9	9	14	6	16	9	14	4
17	16	7	18	9	13	11	8	12	19	3
9	9	9	9	9	9	9	9	20	19	18
4	14	4	17	4	4	16	9	18	12	20
10.7	13.2	10.0	11.1	10.6	11.9	10.9	12.3	15.7	16.0	6.1

TABLE IV. 3

RANK-ORDER QUARTILES: ALL REGIMENS

Experimental Regimen		Hard Work Quartiles 1	2	3	4	Light Work Quartiles 1	2	3	4
ST 0	U	1	2	10	14	1	2	8	16
	L	0	2	8	17	0	4	6	17
0/100/0	U	2	5	11	9	3	9	10	5
1000	L	2	8	8	9	0	13	4	10
0/100/0	U	5	10	9	3	4	17	5	1
2000	L	5	7	8	7	8	9	5	5
2/20/78	U	8	5	5	9	5	9	9	4
1000	L	5	5	7	10	5	6	9	7
2/20/78	U	12	8	4	3	10	10	2	5
2000	L	7	11	4	5	9	9	5	4
15/52/33	U	3	8	11	5	4	11	8	4
1000	L	3	8	8	8	3	11	7	6
15/52/33	U	15	7	3	2	8	10	6	3
2000	L	3	8	7	9	14	5	5	3
15/52/33	U	11	11	4	1	12	6	2	7
3000	L	14	3	3	7	-	-	-	-
30/0/70	U	4	6	10	7	6	5	10	6
1000	L	4	4	10	9	2	5	9	11
30/0/70	U	5	11	6	5	10	7	6	4
2000	L	5	9	2	11	6	4	4	13
FRA		11	13	1	2	13	11	1	2

TABLE IV. 4

RANK-ORDER OF REGIMENS: SUMMARY OF BIOCHEMICAL AND PHYSIOLOGICAL RATINGS

Experimental Regimen		Hard Work	Light Work	Mean
ST 0	U	20	19	19.5
	L	21	20	20.5
0/100/0	U	19	13	16.0
1000	L	17	17	17.0
0/100/0	U	7	7	7.0
2000	L	11	9	10.0
2/20/78	U	9	11	10.0
1000	L	15	15	15.0
2/20/78	U	4	3	3.5
2000	L	6	4	5.0
15/52/33	U	10	10	10.0
1000	L	12	14	13.0
15/52/33	U	2	5	3.5
2000	L	16	2	9.0
15/52/33	U	3	7	5.0
3000	L	5	-	(5.0)
30/0/70	U	13	12	12.5
1000	L	18	18	18.0
30/0/70	U	8	7	7.5
2000	L	14	16	15.0
FRA		1	1	1.0

2. Clinical Interpretations

Final decisions among these nutrient combinations must rest on clinical grounds, because all had defects which might be in the category of "weakest link." We shall discuss the clinical findings in relation to symptomatology and also actual incidence of cases requiring prompt attention by a medical officer (hyperpathy). The detailed discussion of clinical findings will be found in Sections III. D. 9 and III. H. 2 and 3.

A quantitative summary of symptomatology will be found in Table IV. 5, from which five major conclusions can be drawn. First, with unlimited water no experimental regimen produced as much symptomatology as starvation nor as little as 15/52/33 3000. Second, with limited intake of water the most symptoms were produced by starvation, the least by 15/52/33 1000. Third, if one compares all the 1000- and 2000-Calorie regimens with starvation and N-3000, an increase of calories diminished symptoms when water was unlimited. Fourth, when water was limited addition of calories in the high osmotic regimens, especially 30/0/70, increased symptomatology; with the regimens of lowest osmotic intake and restricted water, increase of calories diminished symptomatology. Fifth, incidence of symptoms among light work groups was not

always similar for a given regimen as was the incidence for hard work groups on the same regimen. Among the hard work groups, limitation of water invariably increased symptoms for any regimen.

More striking than symptomatology was the incidence of cases requiring medical attention in order to avoid serious events in the patient. These hyperpathies are summarized in Table IV. 6, from which three major conclusions may be drawn. First, water intake is overwhelmingly important in moist heat. There were eleven cases of incipent heat disease. All of these were associated with limitation of water. Second, the protein/carbohydrate/fat ratio in the regimen was important. No cases were encountered in 15/52/33, but cases were encountered for all other nutrient combinations. Third, cases were strikingly prevalent in the ST 0 and 30/0/70 subjects. In the whole study there were 17 subjects on starvation; five of these appear in Table IV. 6. There was a total of 15 subjects on 30/0/70 1000 and 2000; six of these required special medical attention. These two regimens accounted for 11 of the 15 cases reported.

Considering the clinical studies as a whole, the incidence of system complaints, and the incidence of hyperpathy, the best regimens were 15/52/33 1000 and 2000, whereas starvation and 30/0/70 were by far the worst.

TABLE IV. 5

COMPLAINTS VS. WORK, WATER, AND NUTRIENT MIXTURE
(On basis of two subjects)

Experimental Regimen		Hard Work		Light Work		Total	
		Number	Frequency	Number	Frequency	Number	Frequency
ST 0	U	10	19	24	99	34	118
	L	24	54	17	28	41	82
0/100/0	U	5	9	10	40	15	49
1000	L	12	19	6	9	18	28
0/100/0	U	9	9	3	4	12	13
2000	L	10	15	12	16	22	31
2/20/78	U	9	10	10	48	19	58
1000	L	13	25	12	12	25	37
2/20/78	U	5	7	10	19	15	26
2000	L	9	16	3	3	12	19
15/52/33	U	1	2	5	12	6	14
1000	L	5	9	4	4	9	13
15/52/33	U	6	6	7	12	13	18
2000	L	8	10	9	15	17	25
15/52/33	U	4	4	1	10	5	14
3000	L	14	19	-	-	-	-
30/0/70	U	8	10	2	8	10	18
1000	L	16	26	6	6	22	42
30/0/70	U	6	9	6	14	12	23
2000	L	26	51	4	4	30	55

TABLE IV. 6

HYPERPATHY DURING EXPERIMENTAL PERIOD

Subject Code No.	Nutrient Regimen	Water	Clinical Diagnosis
33	30/0/70 2000	L	Anhidrosis, collapsed in heat test, hyperventilation tetany
74	0/100/0 2000	L	Anhidrosis
76	30/0/70 1000	L	Anhidrosis
26	ST 0	L	Hypohydrosis
68	ST 0	L	Hypohydrosis
70	ST 0	L	Hypohydrosis
73	0/100/0 2000	L	Hypohydrosis
75	30/0/70 1000	L	Hypohydrosis
78	30/0/70 2000	L	Hypohydrosis
79	2/20/78 1000	L	Hypohydrosis
82	2/20/78 2000	L	Hypohydrosis
4	ST 0	U	Collapsed in heat test
31	30/0/70 1000	L	Collapsed in heat test
34	30/0/70 2000	L	Collapsed in heat test, heat exhaustion
1	ST 0	U	Transient amblyopia

3. General Considerations

Our general conclusions are applicable to young healthy men who are classified at the Induction Center for general duty in the U. S. Air Force. These conclusions are also applicable to comparable age groups of civilian populations. However, the problem of survival feeding is important in two other major areas: the whole civilian population in time of disaster and castaways who are injured or ill. It is not known what the nutritional requirements for survival are among civilian groups such as children, women, and the aged.

Our considered opinion is that the nutritional requirements for the injured or ill castaway must not be neglected. Shortage of man power and the substantial investment of time and money in training make mandatory the rescue and rehabilitation of all castaways. It is well-known that the nutritional requirements of the ill and injured are different from the healthy, but exact knowledge is lacking on the survival requirements of the injured or ill castaway.

C. THEORETICAL IMPLICATIONS OF PRESENT STUDY

1. Previous Concepts Confirmed and Extended

a. The Balanced Diet. The present study confirms fully the conclusions reached in the temperature study of 1953 and the cold weather study of 1954. A regimen of 15% of calories from protein, 52% from carbohydrate, and 33% from fat is less deleterious to organ and system function than any other regimen. Wide deviations from this "normal mixture" lead to some kinds of deterioration of function, sometimes severe. Examples are diminished heat tolerance with meat bar and deranged kidney function with pure carbohydrate.

b. Minimum Nutritional Requirements. The present investigation has confirmed once more that some food is always better than starvation. It has also confirmed the fact that no low calorie regimen will prevent deterioration entirely. An important contribution is an unequivocal estimate of the water requirements in moist heat based on the fact that cessation of sweating, a phenomenon of grave portent, will occur in light work subjects in a few days when only one canteen of water per day (910 ml/day) is provided. Two canteens per day (1820 ml) will prevent this dangerous condition in light work subjects and three canteens per day (2730 ml) in hard working subjects.

In a previous report (Sargent et al., 1955. Vol. I, Table IV. 9) an estimate has been presented for minimal requirements for nutrient balance under various conditions of environment and work. Using the same criteria we now add data for hard and light work in moist heat (Table IV. 7). A slight previous systematic error in calculating carbohydrate and fat has been corrected.

Moist heat increased the estimated minimal requirements for water, potassium, and chloride. Presumably nutrient losses in sweat accounted for these increases. Estimates for nitrogen, sodium, calcium, phosphorus, carbohydrate, and fat were not materially different between moist heat and moderate cold.

Reservations in considering these data include the facts that a catabolic reaction was demonstrably present in all hot weather groups and that the source of nitrogen in our regimens was probably not of as high a quality as those recommended by the N.R.C. Calculations of "index of nitrogen utilization" support this statement as discussed in Appendix II.

As emphasized in previous reports, all these estimates are certainly goals which should be approximated as nearly as possible because sooner or later negative balances are deleterious to efficiency.

TABLE IV. 7

MINIMAL REQUIREMENTS FOR NUTRIENT BALANCE UNDER MOIST HEAT, TEMPERATE CONDITIONS, MODERATE COLD, AND EXTREME COLD

Nutrient	Moist Heat 1		Temperate 2	Moderate Cold 3		Extreme Cold 4	NRC 5
	Hard Work	Light Work	Light Work	Hard Work	Light Work	Sedentary	Men, Physically Active
Water, liters (including preformed and metabolic)	4.5	3.2	2.4	3.0	2.5	2.5	3.0
Calories, Cal	3000	3000	2700	3500	3000	3000	3200
Nitrogen, gm	19	18	15	20	16	8	11
Potassium, mEq	76	66	45	60	60	20	--
Sodium, mEq	146	65	100	140	75	100	86
Calcium, gm	0.6	0.5	0.6	0.5	0.4	1.1	0.8
Chloride, mEq	144	141	14	110	110	90	86
Phosphorus, gm	1.0	1.1	1.3	1.4	1.2	1.0	1.5
Carbohydrate, gm	390	390	320	440	400	400	495
Fat, gm	110	110	90	130	110	135	85
Vitamins				No clear evidence			

1 Present report
2 Sargent et al., 1954
3 Sargent et al., 1955
4 Medical Nutrition Laboratory, 1948
5 National Research Council, 1953

c. Catabolic Reactions in the Castaway. In the hot weather as in the cold weather study, a catabolic reaction was measurable independently of regimen, and in the same nutrients: calories, water, nitrogen, potassium, chloride, and phosphorous. During the rehabilitation phase there was a strong anabolic reaction.

d. Limits of Homeostasis. In a previous report (Sargent et al., 1955) there was a discussion of the normal ranges as a measure of homeostasis. The hot weather study provided data on physiological reactions to heat and the regulation of sweat as well as a large new series of data on the same constituents of serum as measured previously. The generalizations previously made are strengthened.

e. Statistical Necessity for True Controls. One of the striking features of the hot weather study was the conclusive and invaluable contribution made by the "ideal" controls to the interpretation of the data. These men were under the same observational and metabolic conditions as the experimental subjects but they lived at all times in a regimen of high quality fresh and frozen foods and unlimited fluids. They represented the healthy young man with an optimal regimen. In general their biochemical, physiological and clinical appraisals enabled the observers to distinguish among the experimental subjects reactions which were due environment as contrasted with effects due to restricted regimens in a manner that was unequivocal. No packaged ration would permit such unequivocal judgments because even in P I and P II the 5-in-1 ration produced effects which must be considered inferior by our standards. This statement can be documented by reference to tables on the various observations made in P I and P II, in particular those on nutrient balance.

The "ideal" controls were used also as standards against which to compare experimental subjects. Calculations of deuterium oxide space, respiratory metabolism, water balance, and the decisions on the environmental parameters of the heat acclimatization test were all based on the reactions of the "ideal" controls.

In our opinion all investigations on military nutrition should be based on such "ideal" controls and not on a group of subjects subsisting on any packaged ration which may contain as yet unrecognized defects which render them unsuitable for purposes of true control. Specific examples are some factors in the 5-in-1 ration which leads to a high incidence of positive benzidine reactions and an abnormally large percentage of undigested meat fibers (Section III. G. 2). Clearly 5-in-1 ration should not be used as the control in any study of gastrointestinal function.

2. New Concepts

This study has permitted us to make one of the most complete series of observations on record of the nutritional and clinical physiology of man in hot weather under strictly controlled conditions. In our opinion, the most important new generalizations are six. (For complete details and discussion, see Sections III. B. 12, III. C. 2, III. D., III. G. 4, and III. G. 5.) First is the possibility of utilizing a fairly simple work test of heat acclimatization based on the fundamental work of W. S. S. Ladell on rate of sweating and changes in rectal temperature. This combined test proved highly discriminatory among

the various regimens and demonstrated the central position of body water in maintenance of thermal balance. Second, for the first time, to our knowledge, we were able to produce, by experimental procedures, the end-point of sweat fatigue in man--total anhidrosis, which was reversible upon administration of water. This fundamentally important observation will lead to a substantial improvement in our understanding of the pathological physiology of heat disease. From an immediately practical standpoint it makes possible a truly realistic estimate of water requirements in the heat. The minimal water requirement must be that which will prevent hypohidrosis. We can imagine no better quantitative criterion for an estimate of minimal water requirements. Third, we have established the fact that there is a truly optimal osmotic intake which will minimize loss of body water in the dehydrated subject. When osmotic intake is too low, the kidney cannot retain water even if available (salt depletion hydropenia); when osmotic intake is too high, the kidney is forced to excrete extra water (obligatory osmotic water loss); at optimal osmotic intake, which we have defined quantitatively, total body water loss is minimal. These observations invalidate the claims of Gamble and others in favor of pure carbohydrate as a survival ration. Fourth, we have established the concept of osmotic balance in nutrition as a consideration equally as important as that of acid-base balance, nitrogen balance, and other nutrient balances. This vitally important concept has not previously been systematically discussed in the literature on physiological and clinical nutrition. Fifth, we have presented for the first time a systematic study of osmotic regulation by the sweat gland, have correlated this with all the important known constituents of sweat and have discovered that there is in many specimens of sweat in quantitatively large concentration, an osmotically active substance or substances undescribed by previous workers and as yet unidentified by us. We have proved that the total osmotic pressure of sweat cannot be calculated from the concentrations of presently known constituents. Finally, we have developed a quantitative scheme for integrating and differentiating among the important interrelated variables upon which an all-purpose survival ration must be based. These variables are caloric balance, water balance, environmental temperature, work load, osmotic balance, specific dynamic action, metabolic water, nitrogen and other nutrient balances. All these are mutually related, affect the efficiency of the castaways, and are finally coordinated on the basis of clinical findings. This generalized scheme will be the subject of WADC TR 53-484, Part 4, now in preparation.

D. IMPORTANT PRACTICAL IMPLICATIONS

Generalizations on the best nutrient regimen for survival in moist heat must be based on consideration of the rank-order in biochemical and physiological data and on the clinical observations. One useful way of examining the rank-order data is in distribution of scores by quartiles (Figures IV. 1 and IV. 2). In the first quartile appear the best features and in the fourth the worst. Numerous scores in the fourth quartile imply defects properly classifiable as "weakest links."

As a result of careful scrutiny of all our data in the light of the above considerations, we have concluded that for moist heat (summer study of 1955) the same facts are true as for moderate cold (winter study of 1954) and temperate

conditions (temperate study of 1953): the best regimen for a survival ration is 2000 calories of a mixture providing 15% of calories from protein of good quality, 52% in carbohydrate, and 33% in fat. Further, the two other important conclusions of the two previous studies are confirmed; viz., no 1000-Calorie regimen ranks as high as the same regimen at 2000 Cal and water restriction is always deleterious. The summer study contributed one other major conclusion: there is an optimal osmotic balance which must not be neglected in survival rations. This optimal osmotic intake can be provided from inorganic constituents and protein.

Our three studies on the physiological and clinical nutrition of the castaway have proven that there is a single nutrient combination which will minimize deterioration of the castaway in temperate, cold, or hot environments. In short, it is possible to produce a single all-purpose, all weather, survival ration. Those responsible for production must not ask for the impossible. No survival ration will prevent deterioration; the best it can do is to minimize deterioration.

SECTION V

SUMMARY

A. Purposes of Study.

1. From June 22, 1955, through July 27, 1955, 100 volunteer airmen served in a field investigation which contributed basic knowledge to the general problem of the all-purpose, all-environment survival ration.

2. The general aims of the study were four:

a. To study comprehensively from the standpoint of total efficiency and the functioning of important organs and organ systems, the reactions of healthy young men to a variety of restricted nutritional regimens under condition of moist heat in a field survival situation.

b. To simulate the two major kinds of survival; viz., escape and evasion (hard work, 12 miles of marching daily) and waiting for rescue (light work, 3 miles of marching daily).

c. To correlate these results with a previous study on subjects under temperate conditions performing moderate work and a study on subjects performing hard and light work under conditions of moderate cold.

d. To study the nutritional problems of recovery after a period of restriction.

B. Method of Study.

1. To establish physiological, biochemical, nutritional, and clinical judgments on the relative effects of water intake, caloric intake, and the ratio of protein, carbohydrate, and fat in the survival ration, numerous observations were made in three two-week periods of adequate, restricted and recovery diets, with luxus amounts of vitamins at all times.

2. In the design of the experiments, four kinds of statistical controls were employed:

a. Starvation and a 3000-Calorie adequate ration represented the worst and best regimens. These were designated as "negative control" and "positive control", respectively.

b. Each subject was considered his own control with respect to changes in pre-periods, experimental periods, and recovery periods.

c. Paired controls were planned for every experimental period, in that for each nutrient combination one subject received unlimited amounts of water and another was restricted to 910 ml of fluids per day.

d. Ideal ration controls, 12 volunteer airmen who subsisted on Field Ration A at all times. They performed daily moderate work and were under the same control as all other subjects.

3. Twenty nutrient combinations included the variables:

a. Calories - 0, 1000, 2000 and 3000 per day.
b. Water - unrestricted and limited to 910 ml of fluid per day.
c. Approximate distribution of calories - 0, 2, 15 and 30% from protein; 0, 20, 52 and 100% from carbohydrate; and 0, 33, 70 and 78 from fat.

4. The actual diets that were used were prepared from components of USAF rations and commercial foods.

a. Pre-periods: 5-in-1 ration.
b. Experimental periods:
(1) 30/0/70: meat bar; high protein, high fat.
(2) 15/52/33: meat bar from the Ration, Special Survival, bread unit (5-in-1), catsup, jam (5-in-1), and raisins; "normal mixture"; protein, carbohydrate, and fat in average proportions.
(3) 2/20/78: oleomargarine and saltine crackers; high fat.
(4) 0/100/0: candy components of the ST Ration; pure carbohydrate.
(5) N-3000: positive control; 3000 Cal/day of 15/52/33.
(6) ST 0: starvation; no food.
(7) FRA: Field Ration A; no restriction on fluid intake.

c. Recovery periods: three days of gradually increased intake followed by seven days of 5-in-1 ad libitum.

5. In the actual scheduling all subjects were at Camp Atterbury, Indiana, throughout. In the experimental field phase all subjects (except the ideal ration controls) simulated survival and were separated into four flights:

Flight 1: hard work, water unlimited
Flight 2: hard work, water limited
Flight 3: light work, water unlimited
Flight 4: light work, water limited

The FRA's made no change in their daily regimen.

6. During the entire six weeks the subjects were under close medical supervision. Continuous quantitative collections were made of urine and feces; and complete dietary records were kept of food and fluid consumption. At regular intervals specimens of venous blood were drawn for analysis, and the subjects were subjected periodically to special biochemical, physiological, and clinical tests.

7. All methodology was validated statistically. For the most part standard

measurements showed no difference among nutrient combinations, or they were autocorrelated with other discriminatory measurements, or they did show differences which are not interpretable at present in terms of "survival potential". They may be categorized as follows:

a. Body composition - body fat, photographs of subjects, and other anthropometric data.

b. Renal function - minute urinary volume, albuminuria in rest, hematuria in rest, minute urinary urea, urea clearance, urinary osmotic excretion, osmotic clearance, minute urinary creatinine, serum creatinine, epithelial cells, white blood cells, and urinary glucose.

c. Endocrines - serum sodium, potassium, calcium, and inorganic phosphate; minute urinary creatine.

d. Liver function - serum total cholesterol; urinary urobilinogen.

e. Circulation - resting pulse rate, resting blood pressure, standing pulse rate and diastolic blood pressure, and electrocardiogram.

f. Respiration - carbon dioxide production, pulmonary ventilation, respiratory rate, tidal volume, and respiratory quotient.

g. Hematology - hematocrit, total leukocyte count, and differential white cell count.

h. Nutrient balances - calcium balance, urinary acidity, titrable acidity, fat intake, and carbohydrate intake.

i. Gastrointestinal function - serum amylase, fecal wet weight, fecal fat, fecal muscle fibers, and benzidine reaction.

j. Central nervous system - passage of time, electroencephalogram.

k. Reactions to work in the heat - pulse rate, skin temperature, all sweat chemistry both quantitative and qualitative, and quantitative and qualitative data on urine during and after heat tolerance test.

4. Daily clinical records were kept and periodic complete physical examinations were made by four medical officers. In the final judgment concerning the relative merits of the 21 nutrient combinations, clinical considerations were given substantial weight, for it is well known that clinically detectable deterioration may precede abnormal changes in physiological, biochemical, or nutritional measurements, and that the clinical severity of a syndrome may not be correlated with the degree of abnormality of those measurements.

a. Of the 100 volunteer airmen five were unable to complete the two weeks of restricted regimen in the field because of the regimen itself; 12 others were removed from the study because of upper respiratory infection or its complications.

b. Those who failed to complete the whole experimental period for reasons related to the regimen were: STO U, two cases of exhaustion, STO L, two cases of exhaustion; 30/0/70 1000 L, one case of incipent heat stroke.

c. Consistent symptoms occurred in relation to some of the nutrient combinations, and these symptoms were aggravated by water deprivation and caloric restriction. The symptoms were chiefly referable to the gastro-intestinal tract and the nervous system, and were present during subsistence on regimens the composition of which deviated widely from the normal mixture (15/52/33).

d. Immediate medical attention was required for 15 subjects at some

accepted methods were used, but in some areas new methods had to be devised. In particular, new tests were introduced to measure the reactions of the men to moist heat.

8. Two kinds of unforeseeable events necessitated two alterations in the test design.

a. Within 36 hours three subjects on limited water ceased sweating (total anhidrosis), a development of grave import previously unreported by investigators in experimental environmental physiology. Immediate increase of water allowance was required: 1820 ml/day of light work and 2730 ml/day for hard work. Thereafter, there were no cases of anhidrosis.

b. Beginning in the first pre-period there was unseasonably high incidence of upper respiratory infection among subjects and technical personnel alike. Conservative medical judgment required termination of the second experimental week on Day 10 instead of Day 14 and omission of respiratory studies and heat tolerance studies for that week.

C. Results of Study.

1. In general, the biochemical and physiological results could be classified according to their pertinence in elucidating the problem of survival rations. Criteria of pertinence included the concepts that the measurement should be predictive of potential deterioration, should discriminate among nutrient combinations tested, and should be interpretable in terms of current clinical thought.

2. Twenty-seven radically different kinds of measurements proved to be valid for rank-ordering the 21 different nutrient combinations in terms of their protection against possible deterioration with respect to efficiency of the body as a whole and the functioning of organs. The 27 may be categorized as follows:

a. Body composition - body weight; body water; water diuresis.
b. Kidney function - the osmotic parameters, 24-hour urine volume and urine/serum osmotic ration; creatinine clearance; serum non-protein nitrogen.
c. Endocrine function - urinary 17-ketosteroid excretion; serum chloride.
d. Liver function - serum cholinesterase.
e. Cardiovascular function - standing systolic blood pressure.
f. Respiratory function - voluntary ventilation capacity; oxygen consumption.
g. Hematology - erythrocyte sedimentation rate.
h. Nutrient balances - calories, water, nitrogen, chloride, sodium, potassium, phosphorus, acid-base (as measured by ketonuria), and osmotic.
i. Reactions to heat during work - rectal temperature, rate of sweating, cylindruria, and hematuria.

3. Many other measurements were made, but not used, in arriving at the final judgments on the relative merits of the 21 nutrient combinations. Either the

time during the experimental period. Not one of these subjects was on a normal mixture regimen; 13 were on a limited water regimen; five were on starvation; five were on meat bar; two were on pure carbohydrate, and two were on 2/20/78. The clinical diagnoses were: anhidrosis, three cases; hypodirosis, eight cases; collapse in heat tolerance test, three cases; and transient blindness, one case.

D. Specific Conclusions from Study.

1. Hard Work.

a. With unlimited water, no nutrient combination ranked as high as the ideal control (FRA) or as low as starvation. However, normal mixture at 2000 and 3000 Cal/day stood close to the ideal controls.

b. With limited water, the two best scores were achieved by 15/52/33 3000 and 2/20/78 2000; and no nutrient combination was as bad as starvation.

c. Regardless of water intake, with a single exception (15/52/33 L), no nutrient combination at 1000 Cal/day ranked as high as the same nutrient combination at 2000 Cal/day.

d. Water restriction worsened the score of all nutrient combinations except 0/100/0 1000, the score of which, in any case, approximated that of starvation.

2. Light Work.

a. With unlimited water, no regimen was close to the ideal control (FRA) and none was as bad as starvation.

b. With limited water, the best regimen was 15/52/33 2000 and none was as bad as starvation.

c. Regardless of water intake, with the exception of 30/0/70, nutrient regimens at 2000 Cal/day scored better than they did at 1000 Cal/day.

d. With limitation of water, scores were decreased in all regimens except 15/52/33 2000 L.

E. General Conclusions from Study.

1. In the present study conclusions for hard work and light work were the same. Furthermore, they agree with conclusions for temperate conditions and moderate cold conditions as studied previously.

2. Although every nutrient combination possessed definite defects, when judged finally upon biochemical, physiological, and nutritional grounds, as well as clinical, the low calorie combination which stood nearest to the ideal control regimen was normal mixture at 2000 Cal/day. Of the 1000-Calorie regimens the least deleterious was also the normal mixture. Comparing the 2000-Calorie regimens one with another and the 1000-Calorie regimens one with another, the normal mixture was the least deleterious even when water was restricted.

3. Contrary to the claims of Gamble and others, pure carbohydrate is an unsatisfactory survival regimen in moist heat.

4. On the basis of the present studies and our previous studies under temperature and moderate cold conditions, it must be concluded that the same nutrient mixture should be used in survival rations regardless of environment. In other words, it is possible to formulate an all-purpose survival ration. The important considerations are:

a. It should provide as liberal as possible an intake of water and calories.

b. It should provide in acceptable form a distribution of calories approximately 15% from protein, 52% from carbohydrate and 33% from fat.

c. It must provide an optimal osmotic intake which will cause an osmotic excretion of 470 micro-osmols/minute.

d. It should provide all known vitamins in luxus amounts.

F. Theoretical Implications of Present Study.

1. This hot weather study has confirmed and extended generalizations established in the previous temperate and cold weather studies. These include the concepts that the "normal mixture" supports organ function better than any other nutrient mixture; an estimate of minimal nutrient requirements; evidence that hot weather as well as cold weather induces a catabolic reaction independently of regimen; the limits of homeostasis; and the statistical necessity for ideal ration controls in any nutritional study.

2. This study has enabled us to obtain one of the most complete series of observations on record of the nutritional and clinical physiology of man in hot weather under strictly controlled conditions. Several important new generalizations have been made. These include: the practicability of a fairly simple work test of heat acclimatization; the first experimental production of the end-point of sweat gland fatigue in man--total anhidrosis, reversible by administration of water; a truly realistic estimate of water requirements, based upon the minimal amount necessary to prevent hypohidrosis; the establishment of an optimal osmotic intake which will minimize loss of body water in the dehydrated subject; establishment of the vitally important concept of osmotic balance as a basic nutritional consideration; a generalizing hypothesis on osmotic regulation by the sweat glands; the discovery of a new, but as yet unidentified osmol in sweat; and finally, the development of a quantitative scheme for integrating and differentiating among the important interrelated variables upon which an all-purpose survival ration must be based.

G. The Remaining Practical Problem.

1. The castaway may be ill or injuried. Very little is known concerning his nutritional requirements. This problem can be solved only by comprehensive hospital studies with emphasis on the efficiency of the body as a whole and the functioning of organs and organ-systems.

SECTION VI

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SECTION VII

ACKNOWLEDGEMENTS

A large number of individuals participated in this investigation. These individuals, both military and civilian, came together from several military and civilian establishments shortly before the field phase began and comprised the team which was responsible for carrying out the many tasks involved in conducting a large scale metabolic investigation.

1. Military (Support) Personnel

Name and Rank	Serial No.	Duty
Lt Col Roy W. Otto	AO 284542	Project Officer
1st Lt Wilmer E. Hussey	AO 1850880	Project Adjutant
1st Lt Frederick J. Kevetter	AO 2254654	Chaplain
M/Sgt Robert C. Evans	AF 16367756	First Sergeant
T/Sgt Charles R. Jordan	AF 35097234	Admin Clk
A/2c William A. Petterson	AF 17310785	Postal Spec
A/2c Eugene L. Wilmot	AF 12410681	Postal Spec
T/Sgt Wilmer L. Watson	AF 20304866	Supply Sgt
A/B Gerald L. Harris	AF 17337771	Supply Sgt
Capt Gerald C. Schroering	22971A	Medical Off
1st Lt Kurt E. Lauer	AO 3001601	Medical Off
1st Lt Laurens N. Garlington	AR 3002265	Medical Off
1st Lt Rufus C. Smith Jr	AO 3001521	Medical Off
1st Lt Leo A. Whitehair	AO 2253671	Liaison Off (WADC)
M/Sgt John R. Bilich	AF 12162495	Med NCO (NCOIC)
S/Sgt Pasquale Padovano	AF 13288034	Med NCO
T/Sgt Robert R. Johnson	AF 14248925	Med NCO
T/Sgt Andrew J. Wash	AF 13222871	Med NCO
T/Sgt Richard Kimberlin	AF 18126273	Med NCO
T/Sgt Kenneth M. Springer	AF 14253191	Med NCO
S/Sgt Charles De Rouen	AF 18329605	Med Tech
A/2c Ralph E. Spencer	AF 22998898	Med Tech
A/2c Richard V. Groy	AF 26381707	Med Tech
A/2c Richard A. Bass	AF 18442794	Med Tech
A/2c John W. Bayliss	AF 15501004	Med Tech
A/2c Milo W. Bowman	AF 15460635	Med Tech
S/Sgt Walter H. Dean	AF 17023767	Mess Sgt
A/1c Harry E. Kelly	AF 13441297	Cook
A/2c Gerald F. Donovan	AF 21264148	Cook
A/2c Oliva P. Luneau	AF 11237830	Cook
A/1c Albert F. Carson	AF 19359610	Cook
A/2c Fred A. Nuevo	AF 28176635	Photographer
A/1c Anthony V. Gauba	AF 19421184	Survival Tech
S/Sgt Antonio C. Duldulaw	AF 39720358	Recreational Spec
A/1c Charles W. Bridge	AF 36370273	Veh Opr (NCOIC)
A/2c Curtis R. Eddings	AF 23177114	Veh Opr
A/2c Arthur R. Larson	AF 16247725	Veh Opr

A/2c Edward J. Robley	AF 16455091	Veh Opr
A/3c Willis G. Wirick	AF 15480952	Veh Opr
M/Sgt Thomas Brown	AF 16055989	Flt Leader
M/Sgt Robert E. Smith	AF 16028556	Flt Leader
M/Sgt Louis Oliver	AF 31179491	Flt Leader (NCOIC)
M/Sgt Jack Richardson	AF 19318698	Flt Leader
T/Sgt Sylvester Labonte	AF 14237675	Flt Leader
T/Sgt Charles W. Lewis	AF 12296436	Flt Leader
T/Sgt August A. Mais	AF 6934049	Flt Leader
T/Sgt Raymond E. Miller	AF 11165992	Flt Leader
S/Sgt George C. Aeschbach	AF 6570241	Flt Leader
S/Sgt Leon C. Davis	AF 36184264	Flt Leader
S/Sgt Loren E. Hayes	AF 17297112	Flt Leader
S/Sgt Floyd Lumpkin	AF 13161044	Flt Leader
A/1c Howard J. Neufer Jr	AF 22971817	Flt Leader
A/1c William F. Graham	AF 17339207	Flt Leader
A/1c Carl J. McGhee	AF 12378052	Flt Leader
M/Sgt Harold Kennington	AF 35171824	Liaison Sgt
S/Sgt Henry H. Hanley	AF 16233352	Meteorological Obsv

2. Volunteer Subjects

Name	Rank	Serial No.
Alley, Thomas E.	AB	AF 14558202
Appleby, Paul E.	AB	AF 17432059
Bartlett, Roger H.	A/3c	AF 12457227
Beardsley, Joe	AB	AF 14549820
Berry, Philip R.	A/3c	AF 11288726
Beshirs, Allen D.	A/3c	AF 17424253
Boozer, Albert Jr	A/3c	AF 14568083
Bowman, Russell W.	A/3c	AF 24651895
Britt, John B.	A/B	AF 14566995
Bufford, Nathaniel	A/3c	AF 18480390
Burns, Milton T.	A/3c	AF 18482568
Burton, Robert M Jr	A/3c	AF 14563401
Cairnes, Leon	A/3c	AF 14566979
Carpenter, Harold D.	A/3c	AF 14566874
Carpenter, Harrison J.	A/3c	AF 14566870
Chapman, Shirley L.	AB	AF 14549823
Christy, Harland P.	A/3c	AF 18479592
Croom, Charles	AB	AF 14568099
Davis, Frank C.	A/3c	AF 17428984
Eisner, Erwin	A/3c	AF 17425371
Ewing, John W.	A/3c	AF 17428936
Felton, Louis E.	A/3c	AF 24916999
Flowers, Charles R.	AB	AF 18477459
Fouse, Clarence	AB	AF 14568113
Fullard, Billy M.	A/3c	AF 14568108

Gabaldon, Manuel	AB	AF 18481326
Garcia, Roberto	A/3c	AF 18479607
Geber, Dale A.	A/3c	AF 17432064
Gibson, Jason C.	A/3c	AF 14560192
Glenn, Julius	A/3c	AF 18477446
Goodman, Earl	A/3c	AF 18483464
Green, Lloyd W.	A/3c	AF 18458007
Grisham, Grant	A/3c	AF 14563432
Hall, Ambrose W.	A/3c	AF 14563353
Hall, James C.	A/3c	AF 14568128
Hamilton, Joe W.	AB	AF 18474359
Harden, Bobbie N.	A/3c	AF 14563394
Harrelson, Ronald K.	A/3c	AF 17440082
Hatcher, Dale W.	A/3c	AF 17424225
Hightower, Kenneth C.	A/3c	AF 13528910
Hill, Clayburn E.	AB	AF 14560122
Hilton, Joe R.	A/3c	AF 14568100
Holley, Bobbie F.	A/3c	AF 14558237
Horne, Jerry L.	A/3c	AF 14568042
Hudson, Larry K.	A/3c	AF 17411896
Hunter, Grover J.	AB	AF 14560113
Johnson, George L.	A/3c	AF 27714101
Johnson, Kenneth D.	A/3c	AF 17424159
Jones, Donald R.	A/3c	AF 14111890
Kelley, Johnnie W.	A/3c	AF 25432107
Kelly, Maynard J.	A/3c	AF 17425999
Knight, Calvin J.	A/3c	AF 24771730
Leach, Thomas E.	A/3c	AF 15535480
Le Blanc, Willie L.	AB	AF 25506726
Lee, John	A/3c	AF 17424267
Lyles, L. C.	A/3c	AF 17411803
McDaniel, Homer B.	AB	AF 14568121
McDaniel, Norman	AB	AF 18458005
McKinzie, George C.	A/3c	AF 25795158
Maddox, Travis E.	A/3c	AF 14563382
Martinez, Ricardo R.	AB	AF 18481328
Melton, Jerry D.	AB	AF 18474367
Moody, Doyle Jr.	A/3c	AF 17411895
Moore, John V. W.	AB	AF 24919345
Moore, Tarvey V. Jr	A/3c	AF 14568105
Morrison, Jackie C.	A/3c	AF 14560188
Mosley, Albert W.	A/3c	AF 18468484
Morales, Armando R. Jr	A/3c	AF 18479572
Newman, Bobbie R.	A/3c	AF 17424254
Nordman, Robert R.	AB	AF 17411812
Olivier, Daniel R.	A/3c	AF 18471024
Parrish, Wilard L.	AB	AF 17430472
Parsons, Gerald A.	A/3c	AF 21277018
Perry, Nathaniel	A/3c	AF 14563337
Perry, Nathaniel	A/3c	AF 14565566

Powell, Joe F.	A/3c	AF 17411898
Pryor, Raymond W.	AB	AF 14568077
Reddie, Charles A.	A/3c	AF 17430509
Rider, Cecil C.	A/3c	AF 18477449
Roberts, Alvie L.	A/3c	AF 18480391
Robertson, Marland J.	A/3c	AF 17440052
Robertson, Thomas E.	A/3c	AF 14568124
Salter, Bradford O.	A/3c	AF 24977108
Sharp, Williams D.	A/3c	AF 17424158
Shaw, John D.	A/3c	AF 14549831
Simpson, Robert E.	A/3c	AF 14549838
Sollars, Charles F.	A/3c	AF 17430464
Stewart, Mylod	A/3c	AF 17411846
Thomas, Durant P.	A/4c	AF 14567002
Viga, John E. Jr	A/3c	AF 18471031
Wagoner, Burl D.	A/3c	AF 25795165
Wallis, Sammie A.	A/3c	AF 25887903
Watkins, William E.	A/3c	AF 14549814
Willborn, Richard N.	A/3c	AF 18458015
Williams, Aubrey L.	A/3c	AF 18477485
Williams, Lonnie Jr	AB	AF 18477437
Williams, Theodore	A/3c	AF 18480425
Wilson, Algire L.	AB	AF 14568068
Worley, Larry E.	AB	AF 13531566
Wright, Lee Q.	AB	AF 18477433

3. University Personnel (Field Phase)

Name	Duty
Doctor Robert E. Johnson	Responsible Investigator
Doctor Frederick Sargent, II	Supervisory Investigator
Mrs. Virginia W. Sargent, II	Chief Research Dietitian
Mrs. Enid J. Meltzer	Chief Clinical Laboratory Technician
Miss Alice Conn	Clinical Laboratory Technician
Mrs. Patricia M. Binkerd	Statistical Clerk
Miss Barbara J. Howell	Graduate Research Assistant
Mr. Richard A. Huntley	Graduate Research Assistant
Mr. Richard Kosmala	Graduate Research Assistant
Mr. S. F. Marotta	Graduate Research Assistant
Mr. Norman Meltzer	Graduate Research Assistant
Mr. Sherwin Mizell	Graduate Research Assistant
Mr. Corwin M. Mokler	Graduate Research Assistant
Mr. Thomas W. Nielsen	Graduate Research Assistant
Mr. Nicholas Sperelakis	Graduate Research Assistant
Mr. Gerald N. Wogan	Graduate Research Assistant
Miss Doris Crist	Research Assistant in Dietetics
Miss Mary Huntwork	Research Assistant in Dietetics
Mr. Ross Adams	Laboratory Assistant
Mrs. Stella M. Montgomery	Foods Assistant

4. University Personnel

(Chemical Analyses and Preparation of Final Report)

Most of the above named individuals continued to work on the observations and specimens amassed at Camp Atterbury. The following individuals were added to the group after the field phase:

Name	Duty
Mrs. Laura M. Sawyer	Clinical Laboratory Technician
Mrs. Barbara Burger	Clinical Laboratory Technician
Mrs. Marilouise Gockel	Clinical Laboratory Technician
Mr. Jack Gockel	Drafting
Mrs. Marie Litterer	Drafting
Miss Audrey Springs	Typist
Miss Janet K. Abell	Typist
Mrs. Frances Carter	Typist
Mrs. Phyllis M. Johns	Typist

In addition to those individuals who actively participated in the investigation there are others whose advice, assistance, and encouragement contributed substantially to the success of the venture. Their help cannot be adequately expressed in words. We will therefore merely list them according to the organizations which employed them.

5. University of Illinois

Business Office

Mr. Lawrence E. Bailey, Supervisor, General Chemistry Stores
Mr. Lester E. Elliott, Senior Purchasing Assistant
Mr. James E. Osborn, Assistant Director of Purchases

Department of Physiology

Mrs. Patricia A. Archer, Secretary
Mr. F. B. Dilley, Jr., Instrument and Measurement Technician
Mr. Russell J. Gillogly, Jr., Storekeeper
Miss Mary Larson, Typist
Mrs. Mary F. Leep, Secretary
Mr. Olen Mackey, Jr., Animal Caretaker

Department of Horticulture

Dr. Dwight Powell, Professor of Plant Pathology
Mr. Cornelius J. Rund, Chief Cold Storage Operator

Audio-Visual Aids, Division of University Extension

Mrs. Lois M. Dilley, Clerk III
Mr. Donald W. Smith, Supervisor

6. Military Organizations

Wright Air Development Center

Colonel Gayle L. Smith, Chief, Facilities Planning Office, Directorate of Support
Mr. Robert L. Mason, Supply and Services Division, Directorate of Support
CWO Joseph Cibere, Supply and Services Division, Directorate of Support

Camp Atterbury, Indiana (5th Army)

Colonel Joseph B. Daugherty, Camp Commander
Captain K. B. Hartung, Adjutant
Mr. Champion, Fiscal Officer

Headquarters, ARDC (Baltimore, Md.)

Captain F. J. Cocharis, Human Factors Division

Headquarters TTAF (Gulfport, Mississippi)

Captain L. D. Butler, Analysis and Procurement Division, DCS/Personnel

Chanute AFB, Illinois

Colonel Grover L. Wilson, Commander, 3345th Technical Training Group
Colonel Andres G. Oliver, Commander, 3345th USAF Station Hospital
Major Robert E. Donnell, Personnel Officer, 3345th Technical Training Wing
Mr. G. J. Miller (deceased), Supply Division

7. Other Organizations

Marchant Calculators, Inc., Indianapolis (Mr. M. Asher, Manager)
Fred W. Amend Co., Danville, Illinois
National Cylinder Gas Co., Indianapolis (Mr. N. W. Nelson, Manager)
Bartholomew County Hospital, Columbus, Indiana
Station Hospital, Fort Benjamin Harrison, Indianapolis
Dispensary, Bakalar Air Force Base, Columbus, Indiana
Waltz Grocery, Edinburg, Indiana



FIGURE VII. 1. PERSONNEL OF FLIGHT 1.



FIGURE VII. 2. PERSONNEL OF FLIGHT 2.



FIGURE VII. 3. PERSONNEL OF FLIGHT 3.



FIGURE VII. 4. PERSONNEL OF FLIGHT 4.

FIGURE VII. 5. STANDING, LEFT TO RIGHT: M/SGT R. C. EVANS, 1/LT F. J. KEVETTER, AND 1/LT L. A. WHITEHAIR. SITTING, LEFT TO RIGHT: LT COL R. W. OTTO AND 1/LT W. E. HUSSEY.

FIGURE VII. 6. FIRST ROW (SITTING), LEFT TO RIGHT: T/SGT R. R. JOHNSON, T/SGT R. KIMBERLIN, M/SGT J. R. BILICH, A/2c M. W. BOWMAN, AND A/2c R. A. BASS. SECOND ROW, LEFT TO RIGHT: S/SGT C. DE ROUEN, S/SGT P. PADOVANO, AND A/2c J. W. BAYLISS. THIRD ROW, LEFT TO RIGHT: T/SGT K. W. SPRINGER, A/2c R. V. GROY, AND A/2c R. E. SPENCER.



FIGURE VII. 5. ADMINISTRATIVE GROUP.



FIGURE VII. 6. MEDICAL NON-COMMISSIONED OFFICERS.

FIGURE VII. 7. FIRST ROW, LEFT TO RIGHT: A/2c E. J. ROBLEY, A/1c C. W. BRIDGE, AND A/3c W. G. WIRICK. SECOND ROW, LEFT TO RIGHT: A/2c A. R. LARSON AND A/2c C. R. EDDINGS.

FIGURE VII. 8. SITTING, LEFT TO RIGHT: A/1c A. F. CARSON, A/2c G. F. DONOVAN, AND A/1c H. E. KELLY. STANDING, LEFT TO RIGHT: A/2c O. P. LUNEAU AND S/SGT W. H. DEAN.



FIGURE VII. 7. MOTOR POOL GROUP.



FIGURE VII. 8. MESS GROUP.