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HUMAN RECOVERY FROM EXPOSURE TO
HOT AND COLD ENVIRONMENTS

I. Recovery from Exposure to Hot Environments.

by

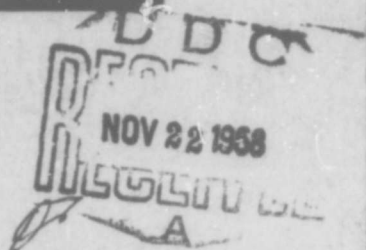
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under Contract No. DA-49-007-MD-943
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DEPARTMENT OF OCCUPATIONAL HEALTH
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FROM EXPOSURE TO HOT AND COLD ENVIRONMENTS

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OFFICE OF THE SURGEON GENERAL,
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Department of Occupational Health
Graduate School of Public Health
University of Pittsburgh
Pittsburgh 13, Pennsylvania

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FOREWORD

While physiological responses associated with quick entry to cold and heat from thermally neutral environments have been explored rather extensively, relatively less is known about events of recovery, or of factors which influence those events. Actually, most observations on human responses to thermal stress have been abruptly terminated upon removal of the stress. Information on effects of alternate exposure to hot and cold ambient environments, with no intervening periods under thermally neutral conditions, is practically non-existent.

The general objective under this contract is to study thermal recovery, i.e., to acquire understanding of the physiologic events associated with recovery from cyclic exposures to heat and cold, and quantitatively to describe influences of factors which affect recovery.

This report deals with two of the specific objectives of the research under this contract. These are: to determine effects of ambient conditions, bodily activity and clothing on rate of restoration of body heat content to pre-stress levels, with view to establishing conditions which promote rapid recovery from exposure to heat; and to investigate cumulative effects of reexposure to thermal stresses prior to full recovery. Results of five relevant studies are reported here.

The potential military significance of research along these lines seems obvious. The arrangement of work performed by military personnel under rigorous hot and cold conditions is now determined arbitrarily by supervisors, or on the basis of trial and error, or on the basis of individual desires. This project should provide a body of information

useful for (a) programming of activities of personnel when thermal stress is a factor, (b) thermal control of shelters, (c) setting safe limits of exposure and standards of performance when conditions demand intermittent exposure to environmental extremes, and (d) recognition of types of physiological and psychological responses which signal imminent injury from exposure.

This work does not represent an isolated effort on behalf of the Office of the Surgeon General of the Army. The studies were performed as part of an on-going program which has the general purpose of providing a more precise understanding of the physiological and psychological effects of heat and cold on man. Nor is it possible to make accurate separation of sources of support for this particular work. Certainly it could not have been performed without the special research facilities provided under a founding grant from the A. W. Mellon Educational and Charitable Trust, and without auxiliary laboratory equipment acquired under NIH grant No. RG-4347. Direct costs of obtaining some of the data contained in this report were shared by this same NIH grant.

RECOVERY FROM EXPOSURE TO HOT ENVIRONMENTS

A substantial number of occupations involve exposure to hot environments in which tolerance time is limited. In these situations either the capacity for sweating or the capacity of the environment for evaporating the sweat may be inadequate to meet the requirement for evaporative cooling. Whichever the cause, the result is storage of heat in the body, manifested by rise in temperature of the body core and skin, and by progressive demand for circulation of blood to carry heat from the body core to the skin.

Physiological responses to acute heat exposures have been described by McConnell, Houghten and Yaglou¹, Blockley and Taylor², and others. Normal events of recovery following exposures are less well known. Although jobs often demand intermittent exposures to high levels of heat, only Brouha³ appears to have provided formal data describing effects of conditions during recovery on responses to subsequent exposure.

In such cases, it is clear that recovery serves the purposes of unstoring accumulated body heat and providing compensatory relief of strain on circulatory and sweating mechanisms. How fast does unstorage occur? Does continued sweating in the recovery environment play an active part in promoting rapid unstorage? What is the effect of temperature level, humidity and air movement in the recovery environment? Is there any simple measure, such as heart rate, which will indicate when recovery has been adequate? The answers to such questions are unavailable or uncertain. The list of factors which may affect recovery is long, and many of the operative factors are interdependent, which complicates design and interpretation of studies of the subject. For example, (a) the dosage of exposure, depending on duration, activity level, ambient conditions and intensity of radiation, may be expected to affect the rate of recovery; (b) clothing may be expected to act

as a "sponge" for sensible and insensible heat during both exposure and recovery; and (c) grade of activity during recovery may affect rate of heat unstorage.

The studies here reported represent an attempt to obtain better understanding of the action of some of these factors. The results provide some leads toward answering the practical question: how may hot jobs best be managed to achieve efficiency of personnel without undue risk of injury to health?

Five studies were undertaken and will be described separately. The plan is first to provide a general description of the methods common to all of the studies, next to describe each study in some detail, and finally to make certain general observations on the basis of the findings.

GENERAL DESCRIPTION OF METHODS

Subjects in these studies were young men who had been acclimatized for work in the heat. Separate rooms were used for exposure to heat and for recovery. Ambient dry and wet bulb temperatures of these rooms were maintained within $\pm 0.5^{\circ}\text{C}$. of specified levels, and vapor pressure within 1 mm. Hg. The subjects wore two different clothing assemblies. The term seminude refers to them when attired only in cotton shorts, socks and shoes. The designation clothed is applied when a tan cotton work shirt and trousers were worn in addition.

Rectal temperature was measured with a thermistor probe; skin temperature, at 12 points, with copper-constantan thermocouples. Readings were obtained at four minute intervals. Storage of body heat was estimated from change in mean body temperature (with rectal temperature weighted $4/5$ and skin $1/5$):

$$\begin{array}{cccc} ^{\circ}\text{C.} & \text{Kg.} & \text{Spec.Ht.} & \text{KCal} \\ \Delta T \times \text{body wt.} \times 0.83 & = & \text{storage} & \end{array}$$

Sweating was estimated from changes in nude weight, determined on a balance to ± 10 grams, and corrected for water intake. In some cases values were inferred from changes in clothed weight on the basis of knowledge, from other exposures, of the course of sweat uptake in the clothing.

Heart rates were obtained by EKG and/or palpation of arterial pulse for 30 second periods, not less often than each five minutes. Thermal comfort was graded, at similar intervals, on a 9 point scale covering the range from intolerably cold (-4) to intolerably hot (+4).

Metabolic heat production was estimated from measurements of oxygen consumption with a closed circuit apparatus, over a 10-minute period while resting and over 5 minutes during work.

STUDY ONE

The purpose of this study was to describe the response in four different recovery environments after exposure to a standard heat stress.

Methods

Each of four subjects was observed seminude in four recovery environments and clothed in three.

The conditions of exposure are summarized in Table I. After a 30-minute equilibration period the subjects walked at 4.8 kilometers/hour in the hot environment. The heat load exceeded evaporative capacity, with the result that thermal balance was not maintained. Immediately following 30 minutes of exposure the subjects moved to the recovery room for 60 minutes, during which they sat on the balance. Recovery conditions were selected to be warm-humid A, neutral-humid B, neutral-dry C, and cool-dry D, for seminude men. Heart rates were counted during the last five minutes of the equilibration period and from the 2nd through the 15th minute of the recovery period.

Table I

CONDITIONS DURING EXPOSURE AND RECOVERY (Study One)

<u>DURATION</u> min.		<u>ACTIVITY</u>	<u>AIR AND WALL</u> <u>TEMPERATURE</u> °C.	<u>VAPOR</u> <u>PRESSURE</u> mm Hg	<u>AIR</u> <u>VELOCITY</u> meters per min.
30	EQUILIBRATION	Sitting	36	25	30
30	EXPOSURE	Walking 3 M.P.H.	51*	12	67
60	RECOVERY A	Sitting	36	25	30
60	RECOVERY B	Sitting	30	25	30
60	RECOVERY C	Sitting	30	12	30
60	RECOVERY D	Sitting	24	12	30

* Walls at 66°C.

DATA FROM A TYPICAL EXPOSURE
Subject 3, Exposure C

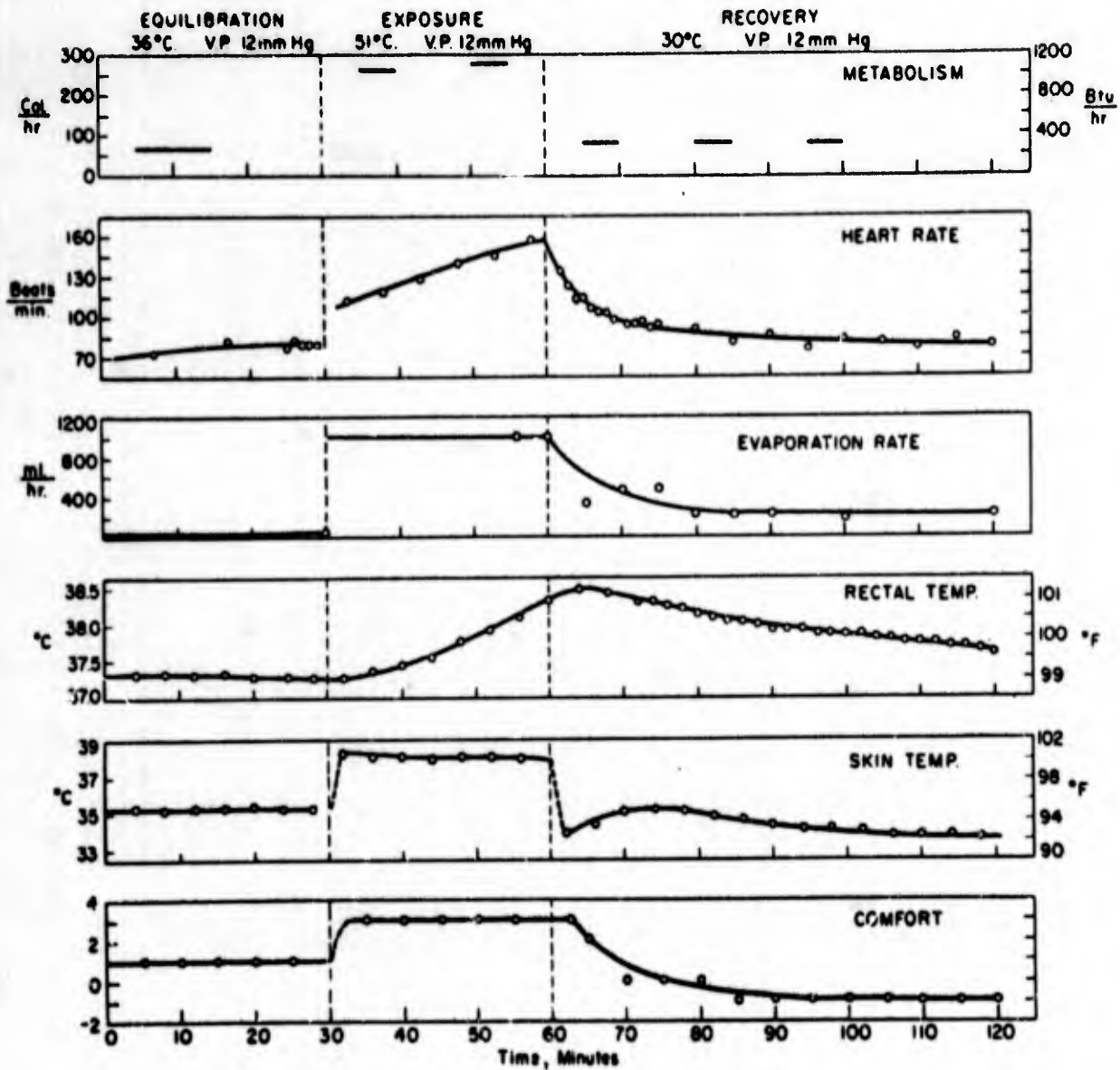


FIGURE 1. Study One. Responses during a typical exposure followed by rest in environment C.

Evaporation was estimated by weighing a subject (as clothed) 10 times during each experiment: at the beginning and end of the equilibration period, at the beginning and at 5 minute intervals during the first 30 minutes of the recovery period and at the end of the recovery period. Nude body weight and clothing weight were determined at beginning and end to provide data on sweating.

Results:

Each exposure yielded data of the type shown in Figure 1. In this case the subject was seminude, and recovery took place in the neutral-dry C environment. Metabolic rate apparently rose slightly during the exposure; this response was quite usual and presumably is related to concurrent elevation in body temperature. The heart rate increased steadily to about 150 beats per minute, and returned to the pre-exposure level in approximately 20 minutes. Evaporation occurred at a rate of 1100 g./hour during the exposure and remained above the pre-exposure rate throughout the recovery period. The initial high rate of evaporation observed during the recovery period may be attributable to evaporation of accumulated sweat, while the persisting slight elevation in evaporation may be the result of evaporation of previously secreted sweat from the clothing, or to continuation of active sweating. The rectal temperature rose steadily during the exposure, a total of one Centigrade degree; it continued to rise for a few minutes after the recovery period had started, then slowly fell. The skin temperature had risen to a peak of 38.5°C. within the first five minutes of exposure, following which it declined somewhat, probably as a result of initiation of evaporative cooling. The rapid fall in skin temperature following exposure may be partly the result of rapid evaporation of residual sweat.

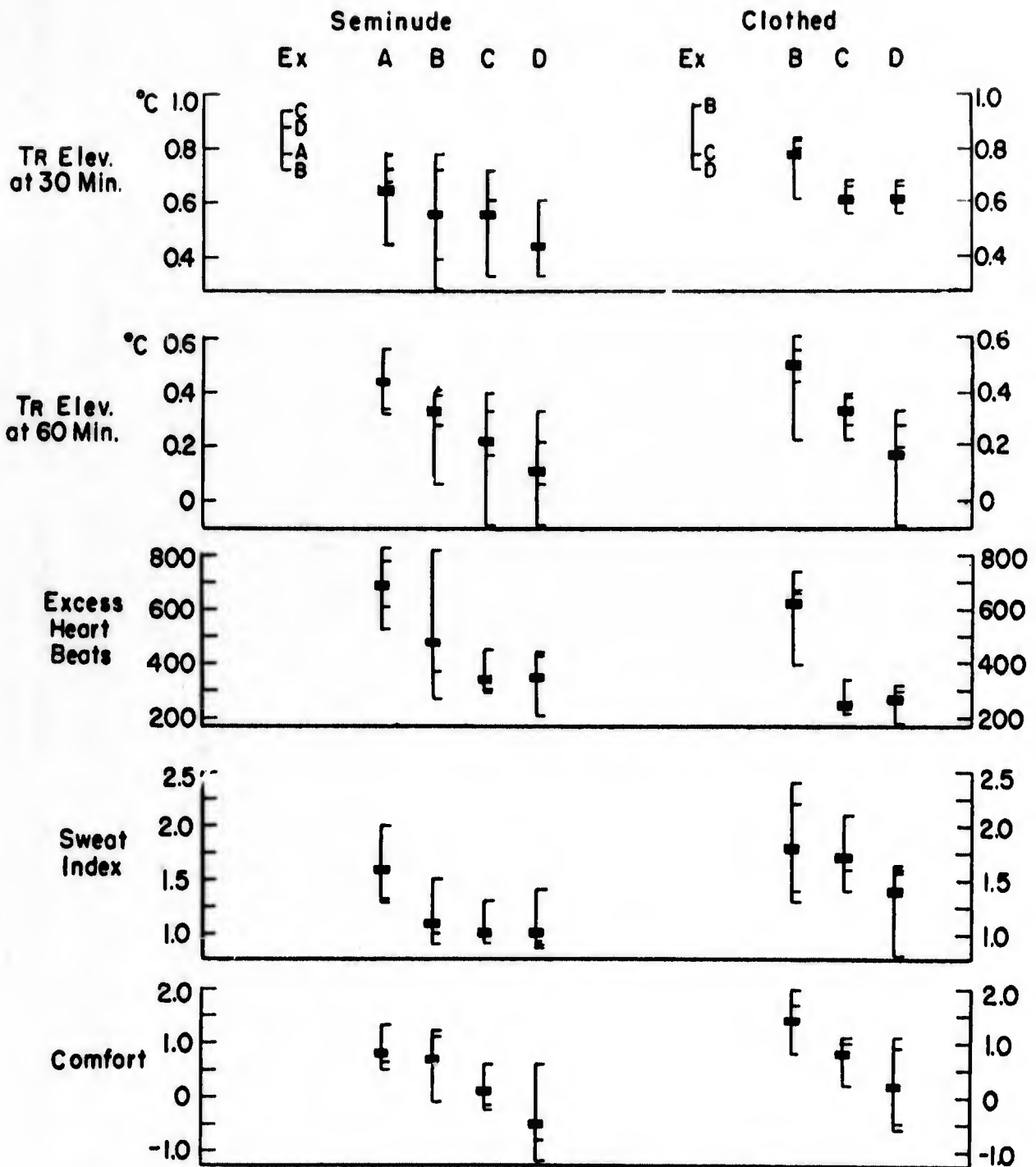


FIGURE 2. Study One. Recovery from heat in four environments, A, B, C, D. Four subjects. Vertical line shows range of response. Heavy crossbar shows group mean.

The subject's rating of his comfort, +1 before exposure, changed to +3 during, and fell to -1 in this recovery environment.

The responses to the half hour of exposure to heat as shown in Figure 1 for one subject were representative of those observed in all exposures of all four subjects. The pattern subsequent to exposure, however, was affected by the recovery environment. The findings during recovery are summarized in Figure 2, in which the range of the values is indicated by vertical lines, the individual values by light horizontal marks, and the mean for the four subjects by a heavy cross-bar. Five criteria of recovery are presented: residual elevation of rectal temperature (T_r) after 30 and after 60 minutes; the number of heart beats in excess of the number observed during the equilibration period; the ratio of sweat production to the least observed on the same subject when seminude; and average comfort. These criteria are based on the assumption that physiological strain is less when there is (a) rapid unstorage of stored heat, (b) rapid fall in heart rate, (c) lower rate of sweat production, and (d) greater thermal comfort.

Consider first the findings when the subjects were seminude. By all criteria, the hot-humid environment, A, was least desirable. By most criteria, the rank order of goodness was D, C, B, and A. Note that the cool-dry recovery environment, D, may have had some advantage for achieving fall of rectal temperature, but was no better than C from the point of view of heart rate, sweat rate, and comfort. The return of rectal temperature was surprisingly slow: after an hour of rest in the less favorable environments rectal temperature was still 0.2°C or more above the pre-exposure level. After 30 minutes in the most favorable environments, it was still 0.4°C . above the pre-exposure level.

Now consider the effects when clothed. Strains of the exposure itself were similar to those when seminude. Recovery condition A was not specified, on the basis that it had already been established as disadvantageous. By all criteria, B was less desirable than C or D. In this study the rank order of goodness was D, C, and B. Note that in environment B the wearing of clothing represented a definite handicap. Since this handicap was not apparent at the same ambient temperature in C, it must be related to the higher vapor pressure in B, and the fact that the clothing was impeding evaporative cooling.

The data are considered to provide convincing evidence that return to pre-exposure physiological base line is faster when recovery takes place in thermally neutral-dry surroundings. The advantages represented by 0.3°C . lower rectal temperature, 340 less heart beats, 150 gms. less sweat and a full scale unit of comfort are considered striking and important. It will be noted that any additional effects of exposure to a really cold environment were not tested in this study.

The fact that rectal temperature continued to rise during the first minutes of post-exposure was noted in Figure 1. This same phenomenon was observed in 17 out of 19 exposures, and is the reverse of the response often noted on going from a cold to warm environment. However, the reason is less clear than in the cold to warm situation. It might be because reflex vasoconstriction of cutaneous vessels after leaving the heat temporarily reduces skin conductivity so much as to actually cause a build-up of body heat. It also might be a result of true lag of rectal temperature behind general core temperature. Lag would be expected if blood flow to the rectum were curtailed, because heat would then be transferred through the rectal wall primarily by conduction, a much slower process than convective transfer via blood flow.

STUDY TWO

Practical evidence of the desirability of a thermally neutral-dry environment for recovery was sought. Such evidence might be found in the ability to accomplish more work in the heat with no greater overall physiological strain.

Methods

The same four subjects submitted themselves to the same levels of work and heat as in the first study. However, they attempted to work for 60 rather than 30 minutes, by working during three 20 minute periods interspersed with recovery periods of "minimum" duration. Since heart rate is generally regarded as the most sensitive convenient criterion of circulatory strain resulting from heat exposures it was specified that duration of each recovery period would be only equal to the time required for the heart rate to return to within five beats per minute of the value observed at the end of the equilibration period (plus two additional minutes required in preparation for reentering the hot room).

Hot-wet, A, and neutral-dry, C, environments were specified for rest between the periods of work. The subjects were seminude.

Results:

The findings are summarized in Table II. There were outstanding differences in ease of completion of the work, in time required for rest and in objective measures of strain. All four subjects found the routine relatively easy when the neutral-dry environment was available for rest and this conclusion is supported by the fact that heart rate, rate of evaporation of sweat, rectal temperature and skin temperature were at about the same levels

Table II

STRAINS OF INTERMITTENT HEAT EXPOSURES WITH RECOVERY IN TWO ENVIRONMENTS (Study Two)

SUB- JECT	RECOV. ENVIR.	BASE HEART RATE (min.)			RECOVERY TIME (min.)			EXPOSURE HEART RATE (min.)			EXPOSURE RECTAL TEMP. (°C.)			EXPOSURE SKIN TEMP. (°C.)			TOTAL SWEAT (g)	SWEAT EVAP. (g)
		I	II	III	Total	I	II	III	I	II	III	I	II	III	In	Heat		
RY	A	68	19	37	47	132	142	136	103	37.8	38.4	38.2	37.4	37.3	37.2	2690	1480	2410
RY	C	69	10	14	12	115	126	123	36	37.6	38.1	38.0	37.4	36.8	36.7	1770	1360	1640
RW	A	80	14	24	39	138	140	144	77	37.4	38.1	38.2	38.2	38.6	38.9	1500	1070	1510
RW	C	69	19	37	47	131	151	152	93	37.4	37.9	38.1	38.5	38.2	38.3	1410	1030	1340
FM	A	90	12	>38	--*	130	134	--*	>88	38.0	38.7	--*	37.8	37.9	--*	>1525	>1110 ^f	>1420 ^f
FM	C	80	13	13	9	130	124	130	35	37.7	38.0	38.1	38.1	37.5	37.9	1290	940	1200
JC	A	80	46	>84	--*	143	145	--*	>214	37.8	38.1	--*	36.9	38.5	--*	>1980	>1260 ^f	>1920 ^f
JC	C	75	26	23	31	132	138	142	80	37.4	37.7	37.8	37.3	37.7	37.6	1510	1000	1410
Ave.	A	80	23	>46	--*	136	140	--*	>120*	37.8	38.1	--*	37.6	38.1	--*	>1949	>1215	>1815
Ave.	C	73	17	19	24	127	135	137	60	37.6	37.9	38.0	38.4	37.6	37.6	1495	1083	1398

* Subject was able to complete only two periods of work

^f Based on 3/2 x amount observed

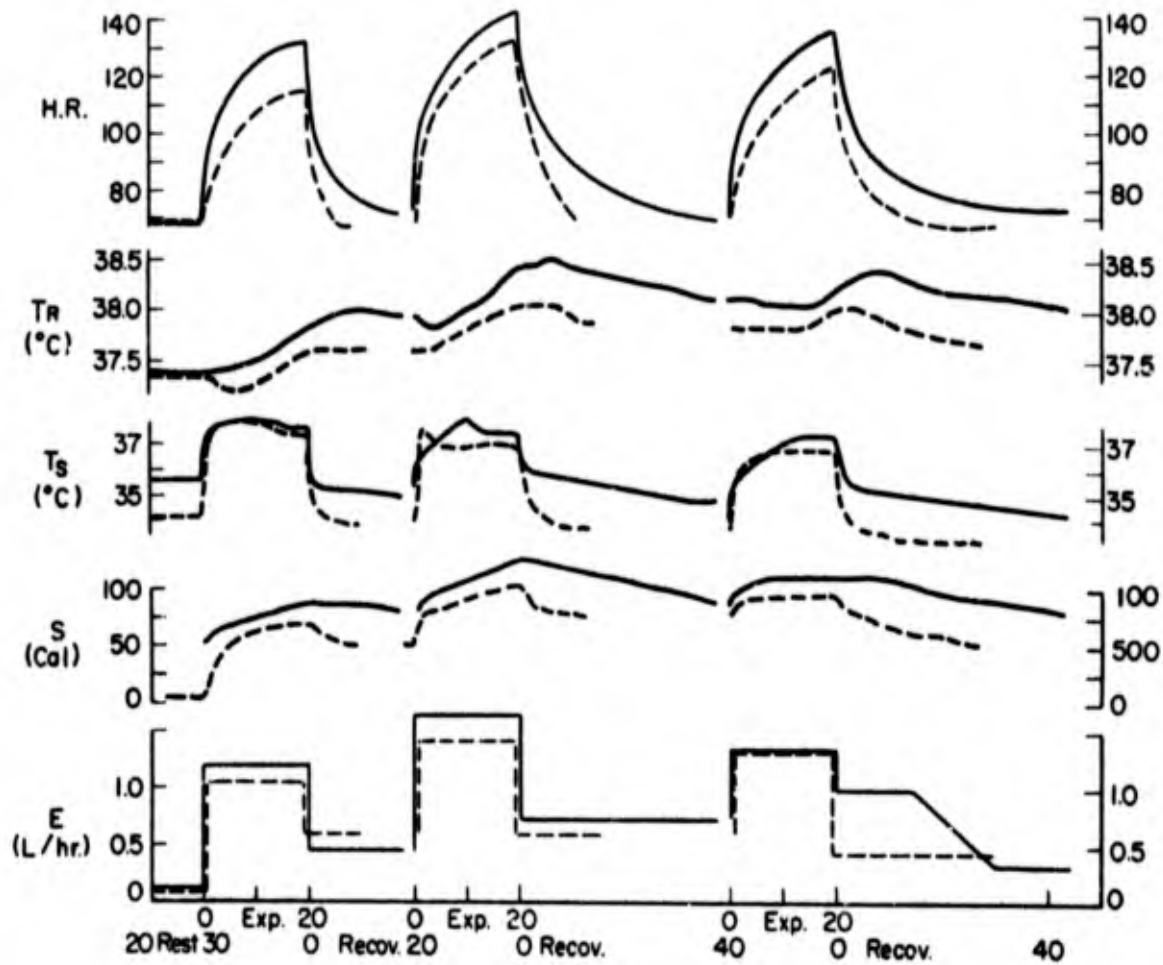


FIGURE 3. Study Two. Strains of three exposures to heat when each was followed by rest (a) in a warm-humid environment (solid lines), and (b) in a thermally neutral-dry environment (broken lines). Subject RY.

at the end of the third period of exposure as at the end of the second, and were within limits commonly regarded as safe. The pattern of the broken lines in Figure 3, which shows the data on one subject, is representative of the time-course of responses when the neutral-dry recovery environment was used.

The results of exposures when rest occurred in the warm-moist environment were dramatically different. Even though the rest periods were substantially longer, two of the four subjects were unable to undertake a third exposure, and in fact one of these suffered real heat exhaustion. Rectal and skin temperatures rose to higher levels and sweat production was greater. Time required for subsidence of heart rate (i.e., by definition, recovery time) was generally longer.* The pattern of responses of one of the subjects who was able to finish (solid lines of Figure 3), and whose base line heart rate was about the same in both environments, indicates that with access to A for rest he required 3.7 times as much recovery time, had 1.6 times as many heart beats above the base level, had 2.1 times as many degree minutes of elevated rectal temperature and produced 1.5 times as much sweat. Although it took him 1.7 times as long to accomplish the hour of work, he was nevertheless under much greater strain.

*The fact that heart rate at the end of the pre-exposure period was used as the reference base line for "recovery" and that pre-exposure equilibration occurred in the same environment, A or C, that was later to be used for recovery, makes it unfair to use these recovery times as a quantitative criterion of relative strain. It will be noted that the base heart rate was on the average 7 beats/minute higher in environment A.

STUDY THREE

Another possible measure of adequacy of rest allowances is the amount of work that can be accomplished in the heat without exceeding a prescribed level of strain. The objective in this third study was to see how a four-fold variation in recovery time would affect the length of work-exposure achievable before an "excessive" heart rate was reached.

Methods

Three young men were utilized in this series. They were clothed. On the basis of pilot studies, three recovery times were specified: 7 1/2, 15 and 30 minutes. The neutral-dry recovery environment C was specified, an environment that, as the result of the first study, was known to favor recovery.

The program called for four consecutive exposures at an air and wall temperature of 50°C., with 100 m/minute air speed and 25 mm. Hg vapor pressure. The work consisted of walking at 4.8 km. per hour. It had previously been established that four consecutive exposures were tolerable with the shortest (7.5 minutes) rest periods if heart rate was not allowed to exceed a critical level. The critical level for two of the subjects was 130 beats per minute; for the other it was 115. These rates were adopted as the criteria for termination of individual exposures.

With four work-recovery cycles, it was possible to regard responses during the first cycle as the result of "warming up" to the task, then to assess deterioration by comparison of responses in the fourth cycle with those in the second.

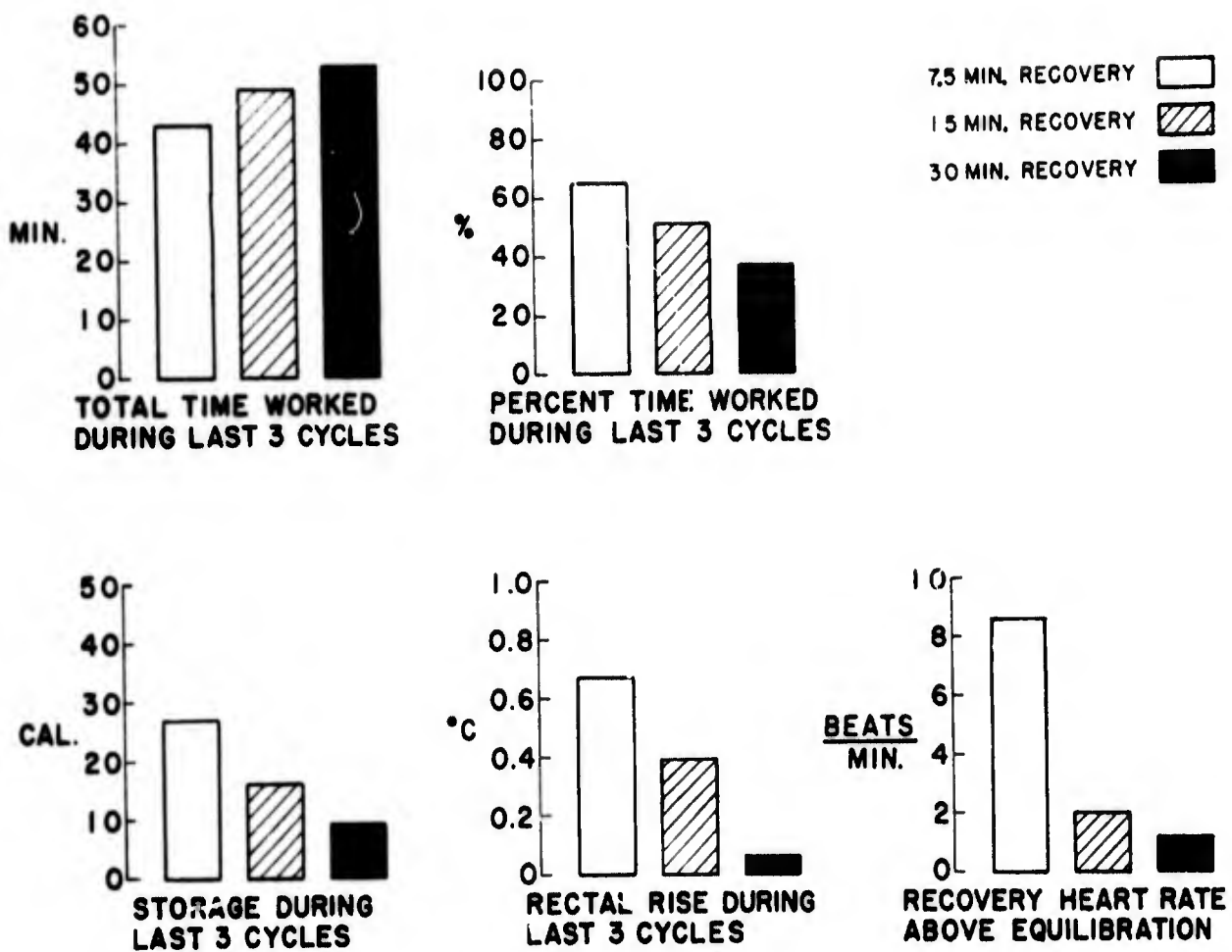


FIGURE 4. Study Three. Time at work and physiological responses when three durations of recovery were specified. Averages based on three subjects.

Results:

The data on the three subjects were not completely consistent (Table III); trends are indicated in Figure 4, which shows average values for items selected as indices of performance and strain. The average amount of work per period which was based on duration of exposure before reaching the critical heart rate, increased from 43 to 53 minutes, when the rest period was lengthened from 7 1/2 to 30 minutes. However, the amount of effective work, expressed as percentage of time spent at work, was greater with the shorter rest periods, 66 per cent for the 7 1/2 minutes, 51 per cent for the 15 and 38 per cent for the 30 minute recovery periods.

Substantial deterioration showed up with the shortest recovery period in terms of progressive storage of body heat and rising heart rate in the recovery period. The unanimous conclusion of the subjects that 7 1/2 minutes of rest was insufficient and 30 minutes was unnecessarily long corroborates the objective findings.

These results do not constitute an endorsement of the 15 minute rest period in other work situations. They do demonstrate the use of physiological criteria for finding the arrangement of a particular hot job that may raise efficiency of work and help to put the strain of work within specified limits.

STUDY FOUR

If ambient conditions where men recover from severe heat exposures are to be controlled, then the optimum setting for control should be known. The first study revealed an advantage for neutral-dry recovery conditions over warm-humid or neutral-humid ones. Study Four was designed to provide preliminary information on the goodness of two new recovery environments, one

Table III

LENGTH OF RECOVERY PERIOD IN RELATION TO TOLERANCE FOR SUBSEQUENT WORK AND TO STRAIN (Study Three)

SUBJECT	LENGTH OF RECOVERY PERIODS (Min.)	TOTAL TIME WORKED DURING LAST 3 CYCLES (Min.)	PER CENT TIME WORKED DURING LAST 3 CYCLES (%)	STORAGE DURING LAST 3 CYCLES (Kcal)	RECTAL TEMP. AT END OF W. (°C)	RECTAL TEMP. DURING LAST 3 CYCLES (°C)	INITIAL HEART RATE (Bts/Min.)	FINAL RECOVERY HEART RATE ABOVE EQUILIBRATION (Bts/min.)
PM	7.5	41	65	29	36.99	0.94	72	10
ET	7.5	49	68	40	37.06	0.67	78	6
RY	7.5	39	64	12	37.28	0.39	62	10
Mean		43	66	27	37.08	0.67	71	8.7
PM	15	45	50	1	37.34	0.03	70	2
ET	15	55	55	20	37.11	0.53	87	-5
RY	15	49	48	29	36.84	0.61	61	9
Mean		50	51	17	37.10	0.39	73	2.0
PM	30	48	35	8	37.28	0.22	72	0
ET	30	65	42	30	37.34	0.33	80	0
RY	30	45	33	-12	37.11	0.00	62	4
Mean		53	38	8	37.24	0.18	71	1.3

* Equivalent to time required for heart rate to reach 130 beats per minute in case of PM and ET and 115 beats in case of RY.

relatively cold (16°C.) and one warm-dry (32°C.), in relation to a neutral-dry environment (24°C.) quite similar to that of Study One.

An added feature of this study was an attempt rapidly to follow skin temperature changes in moving from one environment to another. Interest in this was occasioned by impressions, gained in our previous work, that skin temperatures peak rapidly after entering heat and later fall as sweating and evaporation supervene, and that after entering a cooler environment skin temperatures fall rapidly to their lowest point, presumably due to rapid evaporation of residual sweat from skin and clothing, then rise gradually.

Methods

In this series the three subjects were clothed. The protocol called for equilibration for 8 minutes followed by four cycles, each involving 16 minutes of exposure and 8 minutes of recovery, for a total time of 104 minutes. Exposure and recovery conditions are given in Table IV. The subjects walked at 5.6 km./hour during 15/16 of each exposure (energy production at rate of 300 KCal/hour) and were seated quietly for 7/8 of each rest period (M at rate of 100 KCal/hour), the remaining time being used for moving between the two rooms.

Measure of effects of utilizing the three recovery environments was to be obtained by comparison of resulting strains.

The attempt rapidly to follow changes of skin temperature upon entering a new environment involved modification of the established procedure of obtaining skin temperatures at 12 points consecutively, at 15 second intervals. The lag in initiating a record when entering a new environment was half to 3/4 of a minute, with the result that the first average skin temperature was most representative of a time about 2 1/2 minutes after

Table IV

ENVIRONMENTAL CONDITIONS AND DURATION (Study Four)

	<u>AIR TEMP.</u> <u>°C.</u>	<u>VAPOR PRESS.</u> <u>mm. Hg</u>	<u>AIR SPEED</u> <u>m/min.</u>	<u>DURATION</u> <u>minutes</u>
EQUILIBRATION	Same as in the recovery environment.			
HEAT EXPOSURE	46	25	130	16
RECOVERY ENVIR. E Warm-dry	32	12	30	8
RECOVERY ENVIR. F Neutral-dry	24	12	30	8
RECOVERY ENVIR. G Cold-dry	16	12	30	8

entry. In the present series six thermocouples on one side of the body were connected in parallel to register an average skin temperature alternately with six matching couples on the opposite side. In this way average skin temperature was determined for each side of the body each 30 seconds. This was continued over the first four minutes after entry into a new environment. The parallel connections were then broken for the usual rotational registry of temperatures at the 12 individual sites. The later record for separate points indicated whether any thermocouples were inoperative in the parallel arrangement.

Results:

The overall results in the three environments are summarized in Table V. Heart rates during work and during rest were lowest when recovery took place in the 16°C. and highest in the 32°C. environment. Total sweat production followed the same order. Less confidence may be had that other observed differences were real, but altogether the results suggest that strain of the prescribed routine was least when the coldest environment was available for recovery. While this environment is known to feel uncomfortably cool for prolonged stay while inactive, none of the subjects objected to it for the eight-minute rest periods. Actually, one subject felt that this 16° environment was cooler than comfortable (-2), another regarded it as cool but comfortable (-1) and the third as neutral (0). It is of interest that one subject was consistently more sensitive than the others in that he rated 16°C. as -2 and 24° as +1; while the others generally regarded both 20° and 24° as 0. All three subjects reported transient sensation of coolness almost immediately after leaving the hot room.

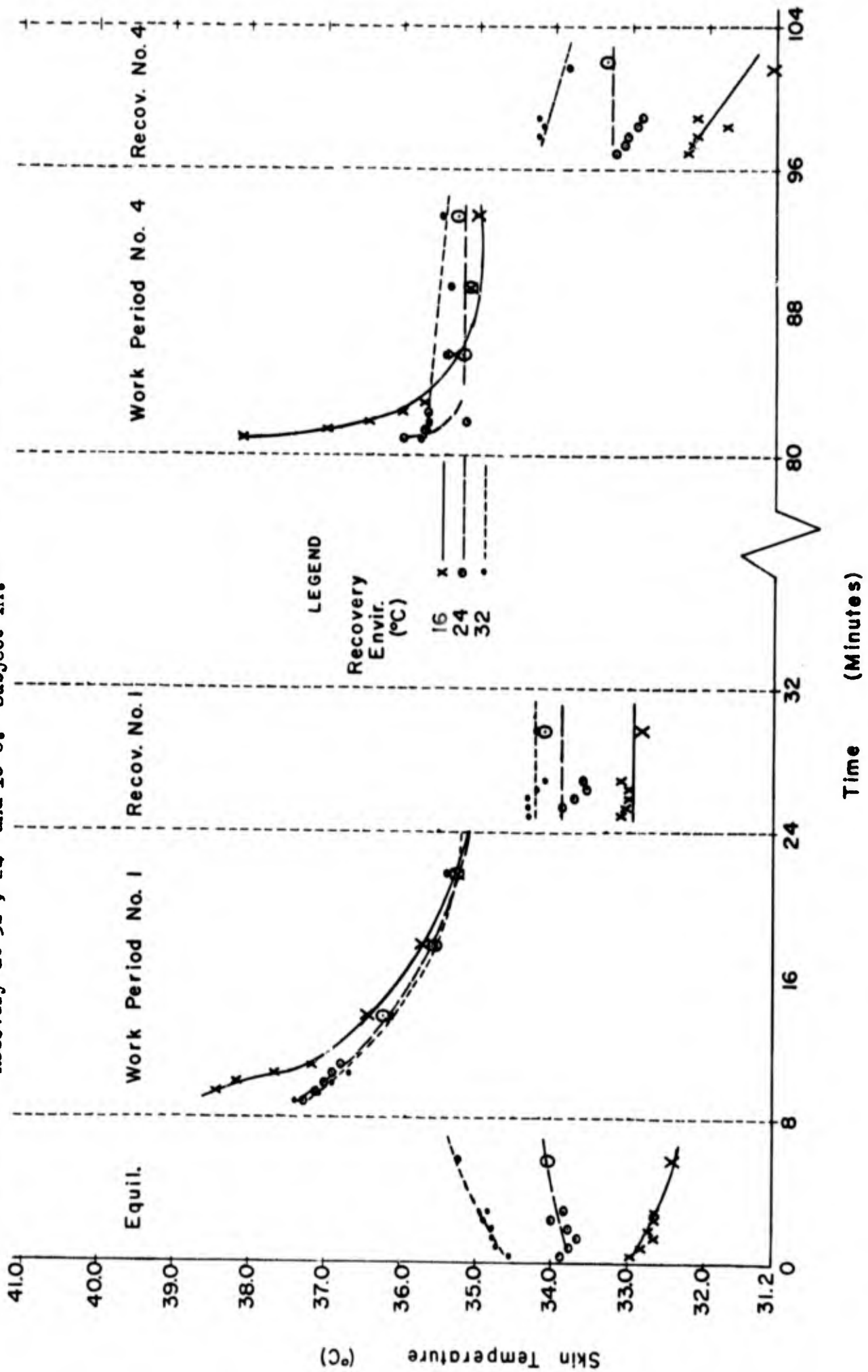
Table V

STRAINS OF FOUR 16-MINUTE EXPOSURES TO HEAT WHEN INTERVENING
8-MINUTE REST PERIODS WERE TAKEN IN ONE OF
THREE AMBIENT TEMPERATURES (Study Four)

	RECOVERY ENVIRONMENT			SIGNIFICANCE OF DIFFERENCE
	E (16°)	F (24°)	G (32°)	
HEART RATE, per minute				
DURING WORK	105	111	114	*
DURING REST	60	74	91	*
INCREASE 4th WORK OVER FIRST	7	8	9	
INCREASE 4th REST OVER FIRST	1	0	2	
FINAL RECTAL TEMP. °C.	37.5	37.6	37.9	
TOTAL SWEAT g.	1060	1120	1300	*
COMFORT	-1.3	-0.3	+0.3	*

*5 per cent level of confidence or better

FIGURE 5. Study Four. Mean skin temperature during and after exposures at 46°C. Recovery at 32°, 24° and 16°C. Subject TM.



A partial record of average skin temperatures obtained on one of the subjects during his work in the heat and during his recovery in each of the three environments is shown in Figure 5. Because response was similar from cycle to cycle only data of the first and last cycles are given.

During rest in the equilibration period, skin temperature approached a level dependent on the exposure temperature. When in the warm environment this was about 35°, in the neutral it was 34° and 32°C. in the cold.

Upon moving to the hot room and commencing work there skin temperatures rose sharply. Within the first minute temperature rose to levels at or higher than body core temperature, then fell over succeeding minutes to about 35°C. Entry from the cold environment resulted in a rise to a higher level upon first entering the heat. Within a minute after return to the recovery room, skin temperature had fallen to a level not greatly different from that of the equilibration period. The rapid response, and subsequent stability, suggest that during the exposure, the sweat was being evaporated as rapidly as it was secreted; it may further mean that sweat production is cut off rapidly, more rapidly than it is initiated. During the subsequent three cycles the responses of skin temperature during exposure and recovery were much the same.

Actually, these findings contribute little to our knowledge of the patterns of response upon entry into new environments. The greater rise of skin temperature upon entering the hot environment from the cold one must be attributed to a greater lag in onset of sweating.

STUDY FIVE

Any observer of men who work on jobs requiring exposure to extreme heat is impressed by the relatively large amount of duty time lost in rest.

From the economic viewpoint such time would often be better utilized at productive work in the recovery thermal environment, and this raises the question of physiological effects of such work. It can be argued on the one hand that since circulatory strain of moderate physical work in heat may be equivalent to that of hard physical work in thermally neutral surroundings, the need for inactivity during recovery from heat is at least as great as for recovery from hard physical work. On the other hand it may be argued that unstorage of body heat is the principal objective in recovery and that if work during recovery does not interfere with such unstorage, it can be physiologically justified. Special factors to be considered in investigation of this subject are the extra heat production involved when work is performed during recovery, and the possibility that unloading of heat during such work may be facilitated by the stimulation which work provides for sweating and for cutaneous circulation. A pilot investigation was conducted to find out what kinds of differences in strain would be observed between men recovering from heat while resting and while continuing at light work.

Methods

Two clothed subjects were used in the study. On two occasions, each subject walked at 4.5 km./hr. while recovering from a standardized exposure to heat, and on two others, he sat quietly during recovery. The room used for initial equilibration and later recovery was operated at 30°C., with 12 mm. Hg vapor pressure and 30 m/minute air speed. The room used for the heat exposures was operated at 49°C. with 12 mm.Hg vapor pressure and 100 m/minute air speed. The schedule called for a 30-minute equilibration period while sitting. followed by three 36-minute exposure- recovery

cycles, each involving 20 minutes in the hot room and 16 in the recovery environment.

Results:

The results are summarized in Table VI.

Average overall level of energy expenditure per hour of exposure-recovery was 210 KCal. when recovery took place at rest, and 280 KCal. when at work. Both of these levels are classified by Christensen⁴ as representative of light work. By this metabolic criterion, the subjects should have been able to continue indefinitely whether resting or working during recovery. However, additional criteria must be applied.

As stated above, the real questions here are (a) whether the extra cost of working during recovery is reflected in overstrain when work is resumed, or conversely (b) whether as good or better unloading of heat occurs when men are active during recovery.

Actually, the extra heat stress when the men walked during the 48 minutes of recovery (calculated by two independent methods) was approximately equivalent to the extra metabolic cost of 130 Cal/hour for the work. The net rise in rectal temperature for the period and the heart rate during exposure were not significantly affected by activity during recovery. The extra sweating that occurred as a result of the walking during recovery was almost exactly equal in cooling potential to the energy requirement for the extra work. The subjects felt neither better nor worse when they had worked during recovery.

Thus, in this pilot study, there were no signs of overstrain when the subjects were active during recovery, nor was there evidence that activity during recovery affects unloading of heat. The results would not necessarily be applicable for more severe exposures.

Table VI

AVERAGE STRESS AND STRAIN WHEN SUBJECTS WERE AT WORK AND AT REST
DURING RECOVERY FROM EXPOSURE TO HEAT (Study Five)

(Four periods in heat, total 60 minutes;
four periods of recovery, total 48 minutes)

	ACTIVITY DURING RECOVERY		
	<u>Rest</u> 4	<u>Walk</u> 4	
NUMBER OF STUDIES			
HEAT STRESS			
BY METHOD #1 (total evaporation plus storage)	510	770	KCal/exposure
BY METHOD #2 (metabolism + radiation + convection ²)	520	670	KCal/exposure
STRAIN			
TOTAL SWEATING	710	860	KCal/exposure (heat equiv. if evaporated)
TOTAL METABOLISM	380	510	
TOTAL SWEAT MINUS TOTAL METABOLISM (sweat due to environment)	330	350	"
RISE IN RECTAL TEMPERATURE TO END OF LAST EXPOSURE	0.6	0.7	°C.
TO END OF LAST RECOVERY	0.7	0.8	°C.
SKIN TEMPERATURE			
IN HEAT	36.0	35.8	°C.
DURING RECOVERY	33.8	31.5	°C.
HEART BEATS			
DURING EXPOSURES	120	120	Beats/minute
" RECOVERY	79	101	"
OVERALL AVERAGE	106	114	"

DISCUSSION AND CONCLUSIONS

Obviously the problem with which we are dealing is as complex as others in which fatigue is a factor⁵. The attempt to find effects of any one factor presumed to influence the well-being of workers on hot jobs is difficult because of complex interaction with other factors. This makes generalization from the results of such laboratory studies as these a hazardous undertaking.

In this particular area it seems particularly difficult to perform the simple scientific experiment in which only one factor is varied. For example, in the fourth study, when we wished systematically to vary recovery time we either had to accept variable total length of experiment, or specify exposure times which were complementary to the recovery periods. The second alternative was unacceptable because it would have meant the longest exposure with the shortest recovery time, but in using the first we accepted a confounding factor. In the second study the practical test of the relative usefulness of two recovery environments was partly vitiated by the fact that we were simultaneously testing heart rate recovery as an index of readiness for re-exposure.

As a result of such difficulties, these studies cannot be considered completely definitive. Nevertheless, inferences such as those in the paragraphs which follow may be drawn.

Rapid recovery from exposure to heat is favored in a thermally neutral or cool environment having low humidity. This effect has previously been reported by Brouha³ on the basis of field studies, and seems obvious. The only theoretical counter-arguments are (1) that prevalence of some heat stress during recovery may facilitate the unloading of heat stored in the body by favoring persistence of cutaneous

vasodilatation and sweating, and (2) that the thermal shock of moving from one environment to the other will be excessive. Our observations provide evidence against these arguments. The case for provision of air-conditioned recovery rooms for workers on hot jobs in hot-humid climate is further supported by the findings of the second study, in which dramatic improvements in well-being and savings of time were found.

There is need for a simple physiological criterion for establishing time limits for exposures. The use of heart rate for this purpose is complicated by individual differences in response and by the fact that the meaning of a particular rate depends on the work level at which it is observed. The individual differences were seen in the third study, when one fit subject who exhibited bradycardia at rest repeatedly demonstrated symptoms of circulatory shock when his walking heart rate exceeded 120, whereas the two others did not run into this difficulty until their rates reached 140 or more. The effects of work level are not illustrated by these formal data, but in terms of incipient collapse of a given subject it may be that a rate of 100 while inactive (e.g., 70 to support metabolism and 30 for heat) has about the same effect as 125 while walking slowly (e.g., 95 + 30) or as 150 when walking rapidly (e.g. 120 + 30). These considerations lead us to suggest that a heart rate criterion of overstrain might be developed on the basis of an individual's resting rate in comfortable surroundings corrected by an increment for grade of activity. No attempt has been made to develop such an index.

Our concern over efficiency of utilization of man power on hot jobs is a reflection of proper management concern over the cost of idle time. The fact that criteria for rest allowances are unavailable has made the matter an issue for the bargaining table. The present studies indicate

ways in which recovery allowances might be established on a sound physiological basis. Heart rate and body core temperature are measures of vital functional states. Ability to maintain these states on a level throughout a work day may be taken as indication of adequate homeostasis under heat stress.

It will always be difficult to extrapolate from laboratory situations to real jobs, because laboratory exposures will not show cumulative effects over weeks or years, because incentive for performance will be different, and because such characteristics as age and physical ability cannot be matched. We are convinced that the best source of data on responses to work in heat are yielded by field studies of men at their jobs. It is regrettable that practical considerations frequently prohibit such experimental manipulations of conditions of exposure as are described in this report.

SUMMARY

Five different laboratory studies have been conducted in an effort to find the ways in which allotted time of work in the heat, recovery time and recovery thermal environment affect men. Neutral-dry or cool-dry recovery conditions were shown to favor rapid unloading of accumulated body heat.

The usefulness of heart rate as a practical criterion for termination of exposures and for establishing duration of recovery periods was examined. Better understanding of the meaning of heart rate responses is required before this criterion can be adopted.

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