AD NUMBER: AD0021003
CLASSIFICATION CHANGES
TO: Unclassified
FROM: Restricted
AUTHORITY
E.O. 10501 dtd Nov 1953

ENVIRONMENTAL PROTECTION BRANCH

Report No. 212

PHYSIOLOGY OF LOAD-CARRYING III

Quartermaster Climatic Research Laboratory

Research and Development Division
Office of The Quartermaster General
June 1953

[redacted]
Security Information

Department of the Army
OFFICE OF THE QUARTERMASTER GENERAL
Research and Development Division

Environmental Protection Branch
Report No. 212

SOME EXPERIMENTAL LOAD DISTRIBUTIONS STUDIED ON THE TREADMILL

By

Jan H. Vanderbie
Physiologist

From
Quartermaster Climatic Research Laboratory
Lawrence, Massachusetts

64-12-001
64-12 002

June 1953

[redacted]
Security Information

SOME EXPERIMENTAL LOAD DISTRIBUTIONS STUDIED ON THE TREADMILL

ABSTRACT

The energy cost of carrying loads of 15 and 45 pounds, in five different distributions, has been studied on a horizontal, motor-driven treadmill maintained at 3.5 mph. The hypothesis that extra energy is required for accelerating and decelerating loads that are attached to body parts which undergo rapid changes in velocity during walking has received support from the findings of this study.

The feasibility of loads balanced fore and aft on the upper thorax is suggested. Measurements of pulmonary function are in no way different from those obtained for the other experimental distributions.

Two groups of test subjects, a "fat" and a "lean" group, have followed an identical schedule. It has been found that the "fat" group has a slight disadvantage in carrying a given external weight, as compared to "lean" carriers.

Jan H. Vanderbie
Physiologist
QM Climatic Research Laboratory

FOREWORD

This is the third in a series of reports on the physiology of load-carrying. The present report has been based on a number of experiments on carrying loads distributed at different places on the body while walking on a treadmill. Some of these distributions are of considerable interest. Trousers cargo pockets at mid-thigh have been a controversial point in clothing design. The findings of this study, which show that 15 pounds carried on mid-thigh cost as much energy as 45 pounds carried on the back, demonstrate the inappropriateness of carrying weights in this position while walking. Pockets in this area for sedentary men and for paratroopers during descent, of course, are not affected by these considerations.

Carrying of loads from a shoulder pole is so common on the Continent of Asia and in the islands of the Pacific that it may be assumed that more loads are carried every day on the surface of the earth by the "pole" method than by the pack system employed by western armies. The theoretical advantages of loads carried on flexible poles are three-fold: (a) they do not have to be lifted far from the ground at the beginning of carry and can easily be set down for brief periods of rest; (b) the center of gravity of the load is well below the center of gravity of the body, thereby enhancing rather than diminishing stability while walking; and (c) a flexible pole presumably "evens out" some of the energy cost of the vertical lift during walking.

Fore and aft balance of military loads at the waist has been highly recommended by U.K. investigators and is now incorporated into new designs of U.S. Army load-carrying systems. The apparent feasibility of carrying fore and aft loads higher on the body is, therefore, of considerable interest in that it increases the range of possibilities for those concerned with designing radically new load-carrying systems.

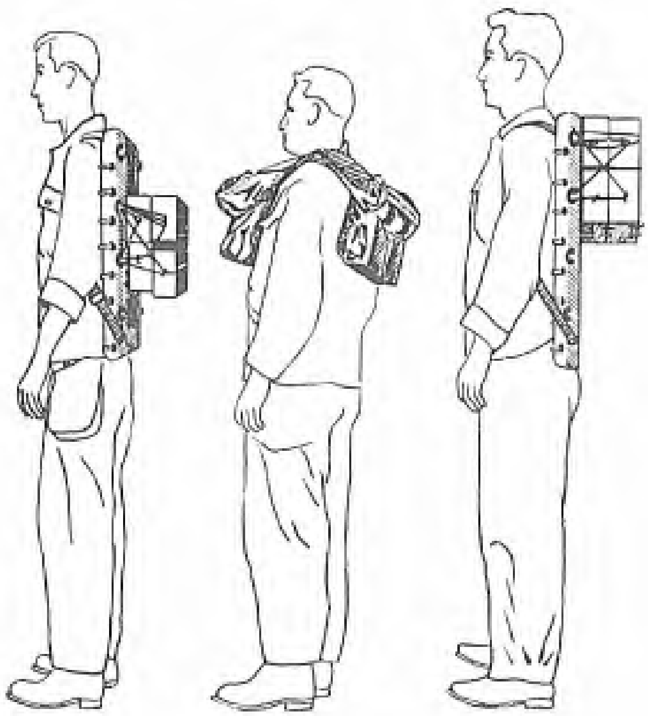
The differences between the "Lean" group and the "Fat" group in this study are just another in the many pieces of evidence indicating the handicaps of obesity.

Farrington Daniels, M.D.
Head, Physiology Branch
QM Climatic Research Laboratory

AUSTIN HENSCHEL, Ph.D.
Director of Research
QM Climatic Research Laboratory

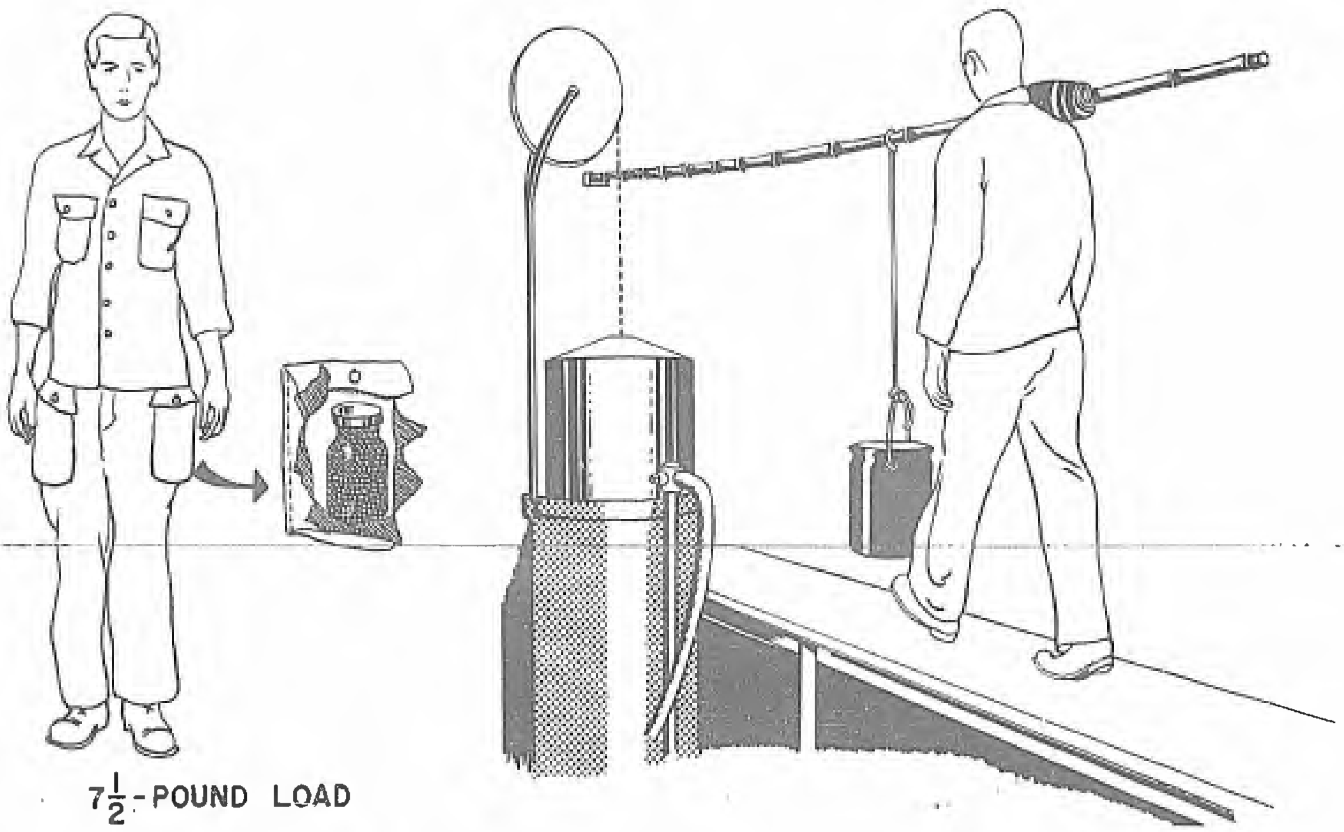
ALBERT H. JACKMAN
Lt. Colonel, QMC, Chief
Environmental Protection Branch

APPROVED: WILLIAM D. JACKSON
Colonel, QMC, Chief
Research and Development Division



45 POUNDS LOW PACKBOARD, LIFE PRESERVER PACK & HIGH PACKBOARD

"LOW PB" "NECK" "HIGH PB"



$7\frac{1}{2}$-POUND LOAD IN EACH CARGO POCKET

"THIGH"

45 POUNDS CARRIED ON A BAMBOO POLE

"POLE"

SOME EXPERIMENTAL LOAD DISTRIBUTIONS STUDIED ON THE TREADMILL

1. Introduction

a. Comparative studies of three different load distributions carried on a treadmill have been reported,[3] the energy cost curves for loads ranging from 25 to 78 pounds developed, and the concept of an optimum load discussed in relation to those data. In continuing the collection of general background information on load-carrying other distributions have been studied.

b. In the first report of this series,[3] loads carried high on the back, low on the back, and around the waist were studied. The existing pack-carrying ensembles are mostly combinations and variations of these three basic types.

c. The hypothesis developed by Daniels, et al[3] was to the effect that the differences in energy cost for carrying given loads in different distributions were related in part to the requirements for acceleration and deceleration of the load. Walking involves a complex series of motions with vertical bounce of the body as a whole, swinging of arms and legs, and torsion of the hips, in addition to the forward progression of the body. For reasons of analysis, the horizontal progression of the body may be distinguished from the other movements. Other motions are herein termed "extra" movements, whether these motions are supporting the walking action or are completely extraneous ones. When a load is attached to the body, in such a way that the load also moves through these "extra" movements, extra energy for acceleration and deceleration is required, and this energy can be responsible for a higher metabolic rate. Fenn[4,5] has observed that in running, 13.9 percent of the energy cost goes into acceleration and deceleration of the extremities.

d. In the first report,[3] it was determined that the angle of forward lean of the body varied with different distributions. This suggested that a fore and aft balance of a load could be an important factor in the energy cost of carrying the load. Bedale[1] has demonstrated the extra energy cost of carrying loads by methods which cause either a lateral or an anterior displacement of the body from the normal posture. However, the design of a load balanced fore and aft, other than "waist distribution," would conflict with the opinion that no loads should press on the chest which might interfere with breathing. In order to investigate "balanced" loads and to determine whether light to moderate weights resting on the chest interfered with pulmonary function sufficiently to preclude some form of carry in this area, a "life preserver" pack was constructed and included in the experiment.

e. The fact that natives of Southeast Asia carry heavy loads on a bamboo pole suggested that this method of load-carrying might have desirable features. It was, therefore, included in the present experiment so that comparison could be made with other methods of load-carrying.

2. Methods

a. Experimentation was conducted at the QM Climatic Research Laboratory from 20 October to 8 November 1952. Eight subjects walked at 3-1/2 mph on a horizontal motor-driven treadmill for 30 minutes daily for eight days. They wore herringbone twill fatigue uniforms and leather combat boots. Some physical characteristics of the test subjects are given in Table I. A designed experiment using a randomized block was employed. The studies were carried out at a temperature of 70°F. ±2°, after the subjects had completed a full week of conditioning by carrying the loads for one hour each day. The final pulse rates were taken during the last minute of walking on the treadmill. Expired air was collected from the 25th to the 28th minute of each trial, using an open Tissot spirometer. Gas samples were analyzed with a Beckman Oxygen Analyzer (Model E-2) for oxygen content and, by reanalysis following carbon dioxide absorption, the carbon dioxide content was determined. The accuracy of this procedure, has been discussed by Behrmann.[2] The respiratory quotient so obtained was used in calculating the caloric equivalent of oxygen.

TABLE I: CHARACTERISTICS OF TEST SUBJECTS

Subject	Age	Height	Weight	Body Fat	Surface Area Based on Total Weight	Surface Area Based on Fat-Free Weight
		in.	lb.	%	m^2	m^2
A	22	66-1/2	156	12.7	1.82	1.73
B	33	64-1/2	190	17.0	1.92	1.77
C	24	70-1/2	211	14.4	2.15	2.00
D	43	67-1/4	203	16.7	2.03	1.88
E	23	64-1/4	123	5.6	1.60	1.56
F	24	71-3/4	152	3.8	1.89	1.85
G	23	67-3/4	149	6.9	1.79	1.75
H	28	71	149	2.5	1.86	1.84

b. The skin-fold method for determination of body fat was used to select the subjects, four being definitely "lean" (less than seven percent body fat), and the other four being "fat" (more than 12 percent body fat). These two groups followed an identical schedule.

c. The following experimental variables were introduced:

(1) Fifteen-pound loads distributed as follows:

(a) Around the "waist", in saddle bags.

(b) Around the "neck", in a "life preserver" belt, balanced fore and aft.

(c) In the cargo pockets of the trousers, at mid-part of the "thigh", antero-laterally, 7-1/2 pounds on each thigh.

(2) Forty-five-pound loads distributed as follows:

(a) Around the "waist", in saddle bags.

(b) Around the "neck", in a "life preserver" belt, balanced fore and aft.

(c) "High" on the packboard at about thoracic vertebra 1 to 7.

(d) "Low" on the packboard from the lower thoracic vertebrae to about the third lumbar vertebra.

(e) Suspended from a carrying "pole", 14 feet long, attached at one end to the wall while the free end of the bamboo pole was supported by the subjects. The load was suspended from the middle of the pole with the center of gravity about 20 inches from the treadmill belt.

Differences between the various methods of carry were evaluated by variance analyses.

3. <u>Results and Discussion</u>

a. <u>Comparison of Metabolic Rates</u>

(1) Table II presents the metabolic rates observed with the different distributions of the load.

TABLE II: ENERGY COST REQUIREMENTS FOR THE VARIOUS LOAD DISTRIBUTIONS CARRIED ON TREADMILL AT 3.5 mph

($Cal/m^2/hr.$)

Sub-jects	Walk-ing	"Fat"							
		15 Pounds			45 Pounds				
		"Waist"	"Thigh"	"Neck"	"Neck"	"Low"	"High"	"Waist"	"Pole"
A	124	155	187	156	225	206	189	213	270
B	215	206	217	188	215	201	196	253	262
C	121	194	208	178	205	198	215	196	255
D	188	231	223	218	226	221	257	260	293
Mean	162.0	196.5	208.8	185.0	217.8	206.5	214.2	230.5	270.0
"Lean"									
E	178	183	188	191	217	192	220	242	261
F	156	200	216	168	188	208	190	223	216
G	152	225	204	202	209	224	210	241	268
H	147	167	181	175	179	159	173	192	193
Mean	158.2	193.8	192.7	184.0	198.2	195.8	198.2	224.5	234.5
Com-bined Mean	160.1	195.2	203.0	184.5	208.0	201.2	206.2	227.5	252.2

Variance analysis performed on each group separately.
F = 11.18 ("Fat" Subjects) and 5.47 ("Lean" Subjects).
P = .01 for both groups.
Critical Difference at five percent = 22.65 ("Fat" Subjects) and 21.34 ("Lean" Subjects).

---

(2) The rank order of these loads, from low to high energy expenditure for both "lean" and "fat" subject groups, is identical and is presented in Table III with significant differences at the five percent level of probability indicated. The most revealing differences are those between 15 pounds "neck" and 15 pounds "thigh" for the "fat" group, and the difference between 45 pounds "low" and 45 pounds "waist". The carrying "pole" as used here turned out to be a very uneconomical way of carrying loads on a treadmill.

(3) It is believed that the observed difference between 15 pounds "neck" and 15 pounds "thigh" is consistent with the hypothesis that extra acceleration and deceleration are factors in the energy requirements of different load-carrying systems. The same can be said of the difference between the 45 pounds "waist" pack and the other

45-pound distributions, where the "waist" pack apparently interferes with rotary movement of hips about a vertical axis during walking. In the 45-pound category, the "low" distribution was generally preferred by the subjects; this corresponds to its position in the ranking, although the 45-pounds "neck" ranked a close second. The 15 pounds "neck" distribution apparently was below the level of interference with respiration. On the basis of metabolic rate, the 15 pounds "neck" was undoubtedly the most favorable distribution.

(4) The poor performance of the "pole" distribution demands an explanation; undoubtedly, this mode of transportation requires a great deal of training. This "strange" way of carrying loads is not easily mastered; severe stress and pain in the shoulder which supported the pole were the usual complaints. Only when subjects have adjusted themselves fully to this technique can this distribution be compared to the more familiar methods of load-carrying. It is also possible that this method of carry is not adaptable to walking on the treadmill.

TABLE III: RANK ORDER OF ENERGY COST FOR DIFFERENT LOAD DISTRIBUTIONS

Load Distribution		Differs at the 5% level from:	
		"Fat" Group	"Lean" Group
1.	15 "Neck"	All others, except 15 "Waist" - 45 "Low"	45 "Waist"-45 "Pole"
2.	15 "Waist"	45 "Waist"-45 "Pole"	45 "Waist"-45 "Pole"
3.	45 "Low"	45 "Waist"-45 "Pole"	45 "Waist"-45 "Pole"
4.	15 "Thigh"	15 "Neck" - 45 "Pole"	45 "Waist"-45 "Pole"
5.	45 "High"	15 "Neck" - 45 "Pole"	45 "Waist"-45 "Pole"
6.	45 "Neck"	15 "Neck" - 45 "Pole"	45 "Waist"-45 "Pole"
7.	45 "Waist"	15 "Neck"-15 "Waist" 45 "Low" - 45 "Pole"	All others, except "Pole"
8.	45 "Pole"	All others	All others, except "Waist"

b. Subjective Comments. Subject B, carrying 45 pounds "neck": "Nicest way to carry a load." Subjects A and E, carrying 15 pounds "Waist": "For 15 pounds, waist pack is not bad at all." Almost all the men complained about discomfort of 15 pounds on "thigh" and liked 15 pounds "neck". All except one subject found the "pole" a very uncomfortable mode of carry, and liked the "low" packboard best in the 45-pound category.

c. Pulse Rates. The pulse rates at the end of the work period, presented in Table IV, are further suggestive evidence of the above-mentioned rank order of difficulty. The pulse rates show considerable variability and statistically significant difference are not obtained. The averages may be grouped into four categories ("Fat") and five categories ("Lean"):

"Fat" Group

113 beats/min. ±2 beats	Walking 15 "Neck"
120 beats/min. ±2 beats	15 "Waist" 15 "Thigh" 45 "Low" 45 "High"
126 beats/min. ±2 beats	45 "Neck"-45 "Waist"
135 beats/min.	45 "Pole"

"Lean" Group

105 beats/min.	Walking
115 beats/min. ±2 beats	45 "Neck"-15 "Waist" 15 "Neck"
120 beats/min. ±2 beats	15 "Thigh"-45 "Low" 45 "High"
125 Beats/min.	45 "Pole"
131 beats/min.	45 "Waist"

The rank order is approximately the same as obtained on the basis of metabolic rates. The only exception is that in the "Lean" Group the 45 "Waist" distribution has changed places with the 45 "Pole" distribution; this does not occur in the "Fat" Group. (Fat people probably walk with more fixed hips; during load-carrying they experience less interference from "waist" pack, compared to lean carriers.) The favorable place of 45 "neck" in the "Lean" Group is generally supported by the subjective remarks. It is suggested that there exists a difference in the mechanics of walking between the "Fat" and "Lean" subjects.

d. The average pulse rates for the "Fat" subject Group for "walking" were higher than those of the "Lean" Group. This difference does not appear in the metabolic rates when they are presented as Cal/m^2/hr., based on total weight. If the surface area is computed from the DuBois

TABLE IV: PULSE RATES (Beats/min.) WHILE CARRYING VARIOUS LOAD DISTRIBUTIONS

Subject*	Walking	15 Pounds "Thigh"	15 Pounds "Neck"	15 Pounds "Waist"	45 Pounds "Neck"	45 Pounds "Waist"	45 Pounds "Low"	45 Pounds "High"	45 Pounds "Pole"
"Fat"									
A	116	100	114	124	120	116	112	108	140
B	128	144	128	132	150	150	128	130	155
C	88	104	100	112	112	122	120	112	108
D	120	138	116	116	124	130	116	140	136
Mean	113	121.5	114.5	121	126.5	129.5	119	122.5	135
"Lean"									
E	104	116	120	106	108	128	125	124	112
F	104	124	112	120	108	128	112	115	122
G	112	108	120	120	122	136	132	120	144
H	104	136	116	120	120	132	120	120	122
Mean	106	121	117	116.5	114.5	131	122	120	125
Combined Mean	109.5	121.2	115.8	118.8	120.5	130.2	120.5	121.2	130.0
Rank Order	1	7	2	3	5.5	9	5.5	4	8

nomograph on the basis of "lean body" weight, and the metabolic rate is presented as Cal/m^2/hr., then the average metabolic rates for both groups shows a difference, Table V, corresponding to difference in pulse rates.

e. The presentation of metabolic rate as Cal/m^2/hr. based on "lean body" mass is probably the more accurate one, since excessive body fat is not an actively metabolizing tissue. If this body fat is treated as a load to be carried, it appears, in our limited data, as a highly economical way of carrying a load. If this same amount of weight were added to the "Lean" Group as external weight, the metabolic rates would undoubtedly be higher than the value obtained for "walking" of the "Fat" Group. It seems, however, practically impossible to approach this body fat distribution by external load distributions. However, no matter how ideal this body fat distribution may be, "fat" load carriers have a slight disadvantage as compared to "lean" persons when the same external weight is carried.

f. In order to determine whether loads "around the neck" interfere with breathing, the minute volumes of expired air and the respiratory efficiency for the 15- and 45-pound distributions are compared (Table VI) for the two subject groups.

TABLE V: ENERGY COST OF VARIOUS DISTRIBUTIONS CALCULATED ON BASIS OF "LEAN BODY" MASS ($Cal/m^2/hr.$)

Group	Walking	15 Pounds			45 Pounds				
		"Waist"	"Thigh"	"Neck"	"Neck"	"Low"	"High"	"Waist"	"Pole"
"Fat" Average	174	211	226	199	235	221	230	248	290
"Lean" Average	161	198	201	188	202	200	202	229	239

TABLE VI: MINUTE VOLUME AND RESPIRATORY EFFICIENCY OF "NECK" DISTRIBUTION COMPARED TO OTHER LOAD DISTRIBUTIONS

(Minute Volume = liters/minute)
(Respiratory Efficiency = cc. O_2 removed/liter expired air)

Subject	15 Pounds "Neck"		Other 15 Pounds		45 Pounds "Neck"		Other 45 Pounds	
	M. V.	R. E.	M. V.	R. E.	M. V.	R. E.	M. V.	R. E.
"Fat"								
A	22.56	41.30	21.25	50.60	31.76	45.40	25.56	46.86
B	27.11	47.30	30.23	44.60	30.33	48.10	32.84	44.60
C	21.39	61.70	24.95	60.25	25.73	58.50	26.73	55.65
D	28.54	55.00	30.75	52.45	35.26	43.20	36.36	45.68
Average	24.90	51.32	26.80	51.98	30.77	48.80	30.37	48.20
"Lean"								
E	20.80	49.10	21.39	48.05	25.20	48.30	24.70	48.43
F	23.32	47.70	26.42	49.80	28.40	49.10	27.94	47.35
G	24.74	50.80	28.82	50.55	24.39	52.40	25.14	58.30
H	21.41	53.00	21.90	51.60	23.05	50.00	22.51	50.40
Average	22.57	50.15	24.63	50.00	25.26	49.95	25.07	51.12

---

g. The average values for minute volumes of expired air do not disclose any statistically significant difference; neither do the figures for respiratory efficiency. The present data at hand is not adequate to make definite conclusions as to whether weights carried on the chest interfere with pulmonary function. Since, however, there does not appear to be any significant group difference between the 15-pound "neck" and the other 15-pound distributions, or between the 45-pound "neck" and the other loads, it is believed that the "neck" distribution warrants a further investigation. Whittenberger and Forbes[8] studied the effects of restriction of chest movement on the pulmonary function of resting subjects. Whether the restrictive force is constant (i.e., compression in an air tank) or exerts its greatest power during inspiration (such as is the case when wearing an elastic vest), the respiratory measurements showed a rather surprising lack of change. Only when inelastic vests were worn did apparently significant changes occur.

h. This information is suggestive in regard to the contention that "neck" distributions, as used in this experiment, did not grossly interfere with pulmonary function.

4. Conclusions

a. Fifteen pounds carried in mid-thigh cargo pockets, i.e., 7-1/2 pounds per thigh, were demonstrated to lead to energy expenditure equivalent to carrying 45 pounds on the back. Carrying loads in pockets of this type is extremely inefficient and fatiguing in respect to carrying a given weight. The same principle probably applies to all loads carried on the extremities which undergo rapid acceleration and deceleration during locomotion.[7]

b. Loads balanced fore and aft on the thoracic region were better tolerated than anticipated and should be investigated further.

c. On the basis of the criteria used, the packboard is still an acceptable way of carrying loads up to 45 pounds. Loads on the back compare favorably with loads around the waist, which is consistent with the hypothesis of "extra" energy, since the waist goes through more extra movements than the back.

5. Recommendations

a. That the method of load-carrying in cargo pockets of trousers (situated at mid-thigh) be abandoned for military personnel when running or walking activity is necessary.

b. That further studies be undertaken to evaluate load-carrying systems based on fore and aft balance at the neck, as well as at the waist.[6]

6. Acknowledgments

The advice and stimulating suggestions offered by Dr. F. Daniels, Jr., Head, Physiology Branch, in evaluating and writing up the data are gratefully acknowledged. Appreciation is also expressed to Messrs. H.E. Hanson and O.W. Roush for their assistance in the analyses of the expired air samples; Miss J.A. Klimas for her cooperation with the statistical analyses; Dr. R.W. Newman, Head, Anthropology Branch, for anthropological measurements on which basis the "Fat" and "Lean" groups of subjects were chosen.

7. References

1. Bedale, E.M. The effects of posture and rest in muscular work. Great Britain Industrial Fatigue Research Board. Report No. 29, 1924.

2. Behrmann, V.G. and F.W. Hartmann. Rapid CO_2 determination with the Pauling O_2 analyzer. Fed. Proc. 10:1, 13, 1951.

3. Daniels, F., J.H. Vanderbie, & C.L. Bommarito. Physiology of load-carrying I. EPB Report No. 203, March 1953.

4. Fenn, W.O. Frictional and kinetic factors in the work of sprint running. Am. J. Physiol. 92:583, 1936.

5. Fenn, W.O. Movements of the center of gravity within the body and foot pressure on the ground. Am. J. Physiol. 93:433, 1930.

6. Lippold, O.D.J. and P.F.D. Naylor. The design of load carrying equipment for the soldier in battle. Great Britain Army Operational Research Group. Report No. 11/50, 1950.

7. Russell, H.D. and H.S. Belding. Metabolic cost of wearing various types of footwear. Harvard Fatigue Laboratory. Report No. 164, July 1946.

8. Whittenberger, J.L. and W.H. Forbes. Quartermaster Research and Development Annual Technical Progress Report, December 1952. Project 64-12-002.