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Report No. 208

PHYSIOLOGY OF LOAD-CARRYING II

Quartermaster Climatic Research Laboratory

Research and Development Division
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Department of the Army
OFFICE OF THE QUARTERMASTER GENERAL
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Environmental Protection Branch
Report No. 208

ENERGY COST OF WEARING ARMORED VESTS AND CARRYING PACK LOADS ON TREADMILL, LEVEL COURSE, AND MOUNTAIN SLOPES

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ENERGY COST OF WEARING ARMORED VESTS AND CARRYING PACK LOADS ON TREADMILL, LEVEL COURSE, AND MOUNTAIN SLOPES

Abstract: The energy cost of wearing an eight-pound, laminated nylon, armored vest with zipper closed was measured while the subjects were walking, with and without a 40-pound pack load, on a treadmill, on a level course, and climbing slopes of from three to 22 degrees.

The armored vest imposed a measurable increase in metabolic rate when worn over the fatigue uniform. These increases became greater as the steepness of the slope increased. Wearing of the vest under the pack had a negligible or, perhaps, even favorable effect on carrying loads on the three- and six-degree grades in some individuals, but on the steep slopes it caused an increase in the metabolic rate about equal to that imposed by the vest alone. The extra load and binding effect of the armored vest became of greatest importance at high activity levels, such as rapid climbing over a steep grade.

Report I of this series on the physiology of load-carrying, published in March 1953, as Environmental Protection Branch Report No. 203, was entitled "Energy Cost of Carrying Three Load Distributions on a Treadmill."

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F O R E W O R D

This report continues the presentation of data from research studies designed to describe the physiological responses of man to load-carrying, and to furnish basic information that may help in the development of more acceptable load-carrying equipment and techniques.

The soldier in the pursuit of his duties must frequently walk or run on surfaces that range from the level ground to difficult and steep mountainous slopes. This must be done even when carrying heavy loads. The energy cost of doing such tasks and the relation of the efficiency of doing the task to the severity of the work are important in determining the length of time the individual will be able to perform the work. From such information, it is possible to predict how much activity the individual can be expected to maintain.

Another important part of this report is the comparison of the energy cost of walking on a motor-driven treadmill to walking on a level, hard-surfaced road. Most of the data in the literature on the physiology of exercise and performance capacity have been derived from experiments using a treadmill. With this comparative data, it will now be possible more accurately to extrapolate treadmill experiments to more common work situations.

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Figure 1: Energy cost of walking being measured while wearing eight-pound armored vest and carrying 40-pound pack over vest.

Figure 2: Climbing steep (17.5°) slope on Mount Whiteface, New Hampshire, while carrying 40-pound pack.

ENERGY COST OF WEARING ARMORED VESTS AND CARRYING PACK LOADS ON TREADMILL, LEVEL COURSE, AND MOUNTAIN SLOPES

1. Introduction

a. Military development has made it possible for the soldier to have a remarkable array of weapons and special equipment to protect himself from the elements and from the enemy. The major limitation on the use of these items of special equipment is the load which the man himself can carry when operating away from motor transport, as is required in front line operations.

b. Since a great many combat casualties are caused by low velocity missiles, such as are found with the fragmentation of mortar shells and hand grenades, the use of relatively light armor has come into intensive development and evaluation.* The use of large masses of lightly armed infantrymen make the determination of the possible limits of usefulness of infantry armor materials of urgent interest.

c. The stresses which armored jackets, in this case jackets of laminated nylon, (Armor, Vest, Nylon, T 52-1) impose upon a man are those of extra weight load, interference with movement, interference with circulation, uncomfortableness because of local pressure during certain activities, and, perhaps most difficult of all to overcome, added heat stress. The impermeable nature of these materials limits evaporative cooling of the body in the areas where the vest is worn. It is expected that the interference of these vests with evaporative cooling will determine the upper limits of activity and of environmental temperature at which the armor may be used.

2. Methods

a. Studies were conducted in a constant temperature room of the QM Climatic Research Laboratory, maintained at 70°F. ± 2°. The six subjects walked on a motor-driven treadmill at 3.5 mph for 30 minutes twice daily for five consecutive days. On the first four days, the morning and afternoon trials were duplicated with or without vest armor. On the fifth day, each subject walked once with and once without the vest. This schedule gave five determinations of metabolic rates for each man with vest and five without vest. The subjects wore cotton herringbone twill fatigue uniforms and combat boots. Oxygen consumption was measured with a closed system Tissot spirometer between the 20- and 30-minute point of each walking period. The same technique was used for the comparison

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*Holmes, R.H. Wound ballistics and body armor. J.A.M.A. 150:73, 1952.

of the energy cost of carrying a 40.25-pound (18.25 kg.) load with and without the eight-pound vest, and for comparing the energy cost of walking with the vest on to walking with the same weight of eight pounds carried on the back.

b. Studies were also conducted on a level cinder track at the Lawrence (Mass.) Memorial Stadium employing Douglas bags for collection of expired air. The rate of walking was maintained at 3.5 mph by pacing the subjects over measured distances by a practiced test observer.

c. Mountain studies were carried out on Mount Whiteface, New Hampshire, from 26 to 30 May 1952. The subjects walked over a course of 2.34 miles which required approximately one hour to complete. During the course of this walk, three energy expenditure measurements (Figure 1) were made by the Douglas bag method on each man on the various slopes described below. This mountain course provided a rather heterogeneous set of surface materials including gravel, soil, rock, leaves, water, mud, twigs, sand, pebbles, moss, etc. Slopes on the mountain were selected to provide a 400-yard course on a slope of three to four degrees, a 300-yard course of six degrees, and a 200-yard course of a 17.5-degree steep slope (Figure 2). Angle of slope was measured with stakes, string (accuracy approximately ± 2°), and a protractor. The speed was not controlled, but it was measured. Comparisons were made between the cost of climbing the slopes with and without the armored vest, and between the 40.25-pound (18.25 kg.) pack with and without the armored vest. For the gas analyses, the Haldane apparatus was set up in the QM Climatic Research Laboratory mobile laboratory truck.

d. Age and physical characteristics of the test subjects are given in Table I:

TABLE I: CHARACTERISTICS OF TEST SUBJECTS

Subject	Height	Weight		S.A.	Age
	cm.	kg.	lbs.	m^2	yrs.
MA	167.8	61.4	135	1.70	22
ME	168.1	62.3	137	1.70	23
PE	169.2	64.3	141	1.74	22
GI	170.6	66.8	147	1.76	22
CO	178.3	104.0	229	2.22	21
PA	165.8	60.4	133	1.67	25
AD	165.9	63.3	139	1.70	27

3. Results of Treadmill Experiments

a. The metabolic rates for walking at 3.5 mph on the horizontal motor-driven treadmill are shown for men with and without the armored vest in Table II. Each value in the table is the average of four or five individual measurements.

TABLE II: ENERGY COST WALKING ON THE TREADMILL (3.5 mph)

Subject	$Cal/m^2/hr.$			cc. O_2/min.	
	Without Vest	With Vest	Difference	Without Vest	With Vest
ME	180	195	+15	1061	1152
PE	203	209	+6	1225	1260
GI	156	163	+7	955	997
CO	201	213	+12	1550	1645
PA	164	173	+9	951	1003
AD	166	180	+14	980	1065
Mean	178.3	188.8	10.5	1120.3	1187.0

Average Difference = 10.5 $t = 6.899$
$P = .001$ Highly Significant

The metabolic rates are expressed as cc. O_2/min./man and also as $Cal/m^2/hr.$ While walking with the armored vest, the oxygen consumption per minute averaged 67 cc. higher than without the vest. When expressed as $Cal/m^2/hr.$, the average difference in metabolic rate was 10.5 Calories.

b. The added energy cost resulting from the weight and restricting effect of the armored vest was therefore readily demonstrated at this speed on the treadmill. The average increase in $Cal/m^2/hr.$ is 5.9 percent, and when expressed as cc. O_2/min./man the average difference is 6.0 percent.

c. In Table III, the sweat loss during half an hour of walking on a treadmill at 3.5 mph is indicated. Sweat loss is measured as the change in nude body weight and, therefore, includes insensible water loss and the ineffective sweat that is lost into the clothing but not evaporated.

TABLE III: SWEAT LOSS (in grams) DURING ONE-HALF HOUR WALKING ON TREADMILL (3.5 mph)

Subject	Pack Without Vest*	Pack With Vest*	Difference
GI	130	190	+60
ME	186	255	+69
PE	220	290	+70
CO	365	370	+5
PA	182	205	+23
AD	215	232	+17
MA	140	226	+86
Mean	205.4	252.6	47.1

Average Difference = 47.1 grams   t = 3.96
P = .01 Highly Significant

*Average of four trials each

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d. As indicated in Table IV, there was no significant difference in pulse rate after walking at 3.5 mph for one-half hour on the treadmill with and without the armored vest.

TABLE IV: FINAL PULSE RATES (beats/min.) AFTER ONE-HALF HOUR WALKING ON TREADMILL (3.5 mph)

Subject	Pack Without Vest*	Pack With Vest*	Difference
GI	115	115	0
ME	116	121	+5
PE	124	133	+9
CO	129	131	+2
PA	118	122	+4
AD	128	124	-4
MA	122	121	-1
Mean	121.7	123.8	2.1

Difference not statistically significant
*Average of four trials each

e. The energy cost of walking with the armored vest was compared to walking on the treadmill with the same weight carried on the back. The results are given in Table V:

TABLE V: ENERGY EXPENDITURE FOR WEIGHT CARRIED AS VEST AND WEIGHT CARRIED ON BACK WHILE WALKING ON TREADMILL (3.5 mph) (cc. O_2/min.)

Subject	Weight as Vest				Mean	Same Weight on Back				Mean
GI	992	1024	918	950	971	972	1009	903	995	970
ME	1210	1216	1013	1198	1159	1176	1225	1081	1134	1154
PE	1228	1317	1170	1170	1221	1181	1192	1143	1124	1160
CO	1613	1599	1558	1622	1598	1698	1727	1556	1592	1643
PA	1059	1127	926	940	1013	931	1017	971	930	962
AD	981	908	1081	1039	1002	1059	1091	981	994	1031
Mean					1161					1153
Mean (Cal/m^2/hr.					185					184

The small difference between the two methods of carry is not Statistically significant.

f. The energy expenditure of carrying a 40.25-pound (18.25 kg.) load with and without the eight-pound armored vest on the treadmill at 3.5 mph is indicated in Table VI. No statistically significant differences were found.

TABLE VI: ENERGY COST OF CARRYING 40.25-POUND (18.25 kg.) LOAD WITH AND WITHOUT THE ARMORED VEST WHILE WALKING ON TREADMILL (3.5 mph)

Subject	Cal/m^2/hr.			cc. O_2/min.	
	Pack	Pack and Vest	Difference	Pack	Pack and Vest
GI	179	186	+7	1092	1136
ME	225	233	+8	1329	1374
PE	237	240	+3	1433	1449
CO	228	236	+8	1758	1819
PA	201	198	-3	1166	1149
AD	209	205	-4	1234	1210
MA	183	196	+13	1082	1154
Mean	209	213	4	1299	1327

Average Difference = 4 t = 1.95
P = .10 Not Significant

g. In four subjects a comparison was made between the energy cost of walking with the armored vest on a treadmill at 3.5 mph with walking on a cinder track at 3.5 mph. The subjects were paced by a practiced observer over a measured course on the Lawrence (Mass.) Memorial Stadium cinder track. The metabolic rate expressed as cc. O_2 per minute and as Cal/m^2/hr. are compared in Table VII:

TABLE VII: COMPARISON OF ENERGY COST OF WALKING ON THE TREADMILL AND WALKING ON THE TRACK (3.5 mph)

Subject	cc. O_2/min.		Cal/m^2/hr.	
	Treadmill	Track*	Treadmill	Track*
GI	997	1186	163	194
PE	1260	1254	209	208
ME	1151	1153	195	195
MA	1023	1282	173	217
Mean	1108	1219	185	204
Difference	111		19	
	t = 1.66 P = .20		t = 1.64 P = .20	

*Average of two readings

The average for walking on the cinder track at 3.5 mph is slightly higher than the average for walking on the treadmill at a belt speed of 3.5 mph, but in the above four individuals the difference is not statistically significant. The treadmill observations probably constitute a lower limit and walking over all natural surfaces will probably have a higher energy expenditure.

4. Results of Load-Carrying on Mountain Slopes (Figure 3)

a. In the mountain studies the subjects climbed a 400-yard slope of three to four degrees, a 300-yard slope of five to six degrees, and a 200-yard slope of 15 to 22 degrees. The energy cost of climbing these various slopes is indicated in Tables VIII and IX.

b. In the lower portion of Table VIII, it is seen that while the rate of walking was not accurately controllable on these slopes on each grade, the range of speed is comparable for each subject, and when expressed in units of surface distance covered the energy cost is probably comparable. Values calculated in surface distance units are given in Table IX.

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c. In Table IX it is readily seen that while the three men do not show a consistent pattern, the average metabolism of the three men is slightly higher when wearing the vest than when walking without the vest. Comparison between different slopes using distance units rather than time units serves to reduce the effect of velocity differences, as given in Table IX. From this table it is calculated that on the average the vest adds a 7.3 percent increase to the energy cost of walking without pack on the three to four degree grade, a 3.8 percent increase on the six degree grade, and 8.1 percent on the 17.5 degree grade.

d. When studying the effect of pack loads and armor, it was observed that two of the three men had a lower energy cost with the combination of pack plus armored vest than with the pack alone. This was true on all three slopes tested. On the steepest slope one of the subjects failed to complete the course and his values are omitted from the averages. On the three to four degree slope, the pack plus vest combination averaged 7.7 percent lower than pack alone, despite the additional eight pounds contributed by the vest. On the six degree slope, the energy cost of the combination averaged 1.3 percent less than the pack alone. On the steep slope, 17.5 degrees, in one of the subjects who completed the slope, the apparent saving was 1.4 percent, and in the other, the vest added 5.2 percent to the energy cost of covering 1000 feet of surface.

e. During the high exercise rates involved in climbing the 17.5 degree slope, high respiratory quotients were found which were probably related to hyperventilation associated with severe exercise.*

f. When the increase in measured metabolic rate (no measure of oxygen debt) for the climbing studies is compared to walking on the level, an interesting relationship is observed. When expressed as percent increase in metabolism per degree of slope, the values for all combinations of armored vest and load ranged from 12.1 to 16.6 percent increase, with an average of 14.0, in metabolism per degree slope. Because oxygen debt was not measured, and the accuracy of the slope measurement was not as great as desired, further study will be required to determine if this is a general relationship.

5. Summary and Conclusions

a. The added energy cost of wearing an eight-pound, laminated nylon, armored jacket (Armor, Vest, Nylon, T 52-1) with zipper closed has been studied in the activities of walking on a treadmill, walking on a level road, and climbing slopes of three, six and 17.5 degrees.

*Unpublished data on file at QM Climatic Research Laboratory.

TABLE VIII: ENERGY EXPENDITURE MEASUREMENTS MADE ON MEN CLIMBING THREE SLOPES WITH AND WITHOUT ARMORED VEST AND PACK (Cal/m²/hr.)*

Subject	Slopes											
	Slight (3°-4°)		Moderate (6°)		Steep (17.5°)		Slight (3°-4°)		Moderate (6°)		Steep (17.5°)	
	Without Vest	With Vest	Without Vest	With Vest	Without Vest	With Vest	With Pack	Pack and Vest	With Pack	Pack and Vest	With Pack	Pack and Vest
MA	279.2	266.3	378.5	299.5	584.5	511.2	227.0	223.0	354.6	291.9	538.0	488.7
ME	323.5	289.0	308.6	381.1	503.1	506.2	257.6	348.3	313.3	369.2	441.1	507.5
PE	259.2	327.9	338.4	399.0	574.9	640.3	441.8	322.0	364.4	357.2	**	533.1
Mean	287.3	294.4	341.8	359.8	554.1	552.5	308.8	297.7	344.1	339.4	489.5	509.7
	Speed During Test Trials (mph)											
MA	3.55	3.48	3.71	3.35	3.14	2.72	3.24	2.95	3.31	2.97	2.55	2.40
ME	4.09	3.66	3.54	3.71	3.27	3.09	3.51	3.75	3.41	3.54	2.33	2.55
PE	3.47	3.52	3.40	3.72	2.90	2.70	3.68	3.42	3.05	3.22	**	2.33
Mean	3.70	3.55	3.55	3.59	3.10	2.83	3.48	3.37	3.26	3.24	2.44	2.45

*Oxygen debt not measured
**Subject did not complete climb

TABLE IX: TOTAL COST IN CALORIES PER MAN OF COVERING 1000 FEET OF SURFACE
(Oxygen debt not measured)

Subject	Slopes											
	Slight (3°-4°)		Moderate (6°)		Steep (17.5°)		Slight (3°-4°)		Moderate (6°)		Steep (17.5°)	
	Without Vest	With Vest	Without Vest	With Vest	Without Vest	With Vest	With Pack	Pack and Vest	With Pack	Pack and Vest	With Pack	Pack and Vest
MA	25.27	24.62	32.76	28.74	59.78	60.33	27.46	24.30	34.41	31.54	67.72	65.36
ME	25.45	25.36	28.00	32.99	49.47	52.58	23.61	29.05	29.57	33.50	60.73	63.88
PE	24.53	30.36	32.70	35.28	65.28	75.79	39.49	30.24	39.32	36.44	*	75.12
Mean	25.08	26.78	31.15	32.34	58.18	62.90	30.19	27.86	34.43	33.82	64.23	68.12

*Subject did not complete climb

These studies have been conducted with and without a 40-pound pack load.

b. In nearly every instance, the armored vest added approximately six percent to the metabolic cost of walking and carrying loads. This is of little importance at low activity levels, but may become of great importance at very high levels of energy output. The increase in metabolic cost presumably is caused both by the weight of the load and the binding effect of the armored vest on certain motions in walking and climbing. The increase is not of an order of magnitude which will be evident in routine testing.

c. It was not demonstrated that a load carried as a vest with a wide distribution and balance of the weight around the center of gravity of the body was significantly more efficient than carrying this same weight of eight pounds in a pack load distribution. Whether this would also apply to much larger weights carried in this way is not known.

d. There is a suggestion that the use of the vest may actually decrease the total energy cost of the pack-carrying when climbing slight and intermediate grades. A slight decrease in energy cost when carrying a pack was also noted in two cases of the study on the horizontal treadmill comparing pack with a pack plus vest combination. This will require further study.

e. The principal complaints of the subjects about wearing the item were those related to its rigidity, pressure on the neck when bending forward, etc. These effects are not apt to show in the energy cost of walking, but may be of considerable importance when other activities are studied.

f. The increase in energy cost resulting from wear of the armored vest, being approximately six percent, is not expected to be the limiting factor in the use and acceptability of the item. Interferences with heat loss is expected to be the important factor which might limit the use of the item.

6. Recommendations

a. That, inasmuch as additional energy cost of wearing the armor does not limit the use of this item except at extremely high activity near the level of maximum energy output, vest interference with heat loss be studied.

b. That design features, including the tendency for pack straps to slip off the shoulders, for the top of the vest to jab into the neck during certain activities, etc., be given high priority consideration.

7. Acknowledgements

The technical assistance of R.F. Byrom and J.A. Vaughan during the mountain phase of the study is greatly appreciated. Appreciation is also expressed to Miss J.A. Klimas for the statistical analysis of the data, and for the cooperation of Sgt F.A. Sheehan during the mountain study. The enlisted men who volunteered as subjects in the study are as follows: Sgt H.E. Parker, Cpl J.D. Adair, Pfc R.D. Combs, Pfc T.L. Gilmore, Pfc C.G. Matiash, Pfc V.H. Meinert, Pfc C.E. Peay.

DISTANCES, ANGLES, AND TERRAIN FEATURES OF SLOPES ON MOUNT WHITEFACE, NEW HAMPSHIRE, MAY 1952
(course totaled 6179 feet or 1.17 miles; however, subjects climbed in both directions for a total of 12,358 feet or 2.34 miles)

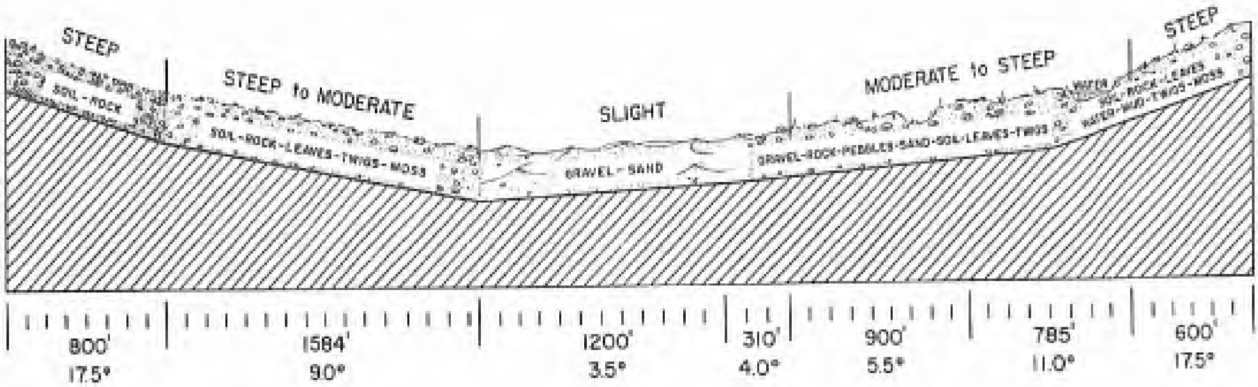

FIGURE 3