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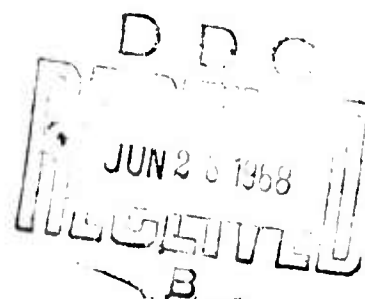
REVIEW OF RESEARCH ON LOAD CARRYING

by

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and

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FOREWORD

Throughout military history intermittent efforts have been made to reduce the weight of equipment carried by individual soldiers. Although technological advances have made possible occasional reductions in the weights of particular items, reduction has been balanced consistently by increases in the items of specialized equipment and the amounts of ammunition carried. While these changes have increased fire power, the individual soldier's lot, as a beast of burden, has not improved since the time of Alexander the Great, King of Macedon.

During World War II, a great deal of attention was given to reducing the load carried by the individual, but significant progress in this direction was not actually made. In fact, with the additional requirements for protecting the soldier under extreme environmental conditions, and with the need for operating at greater distances from bases, there was a tendency toward increasing the weight. For example, the situation reached a point where men going overseas took with them two large duffel bags filled with equipment. In theory, this equipment was dropped when they entered the combat zone with the expectation of its being returned to them at the proper time. In practice this seldom occurred and only limited amounts of this clothing and equipment were recovered; most rotted on the beaches or was lost through pilferage.

The history of the soldier's individual pack and the equipment carried on his person shows a tendency toward building up the load without adequate recognition that the soldier in combat divests himself of everything he can do without, with no particular concern as to what happens to it.

Attempts during World War II to deal with the problem of reducing the load carried by the soldier under fire led first to the development of a jungle pack. This pack consisted of a duffel type bag adjustable in length and girth and a small pouch. The duffel bag portion contained a waterproof bag for clothing (Bag, Clothing, Waterproof) which could be dropped prior to entry into battle, leaving the small pouch containing only the items essential in combat.

To meet the requirements of mountain troops who had to operate at long distances from their base, a large pack identical in principle was developed under the title of Pack, Field for

mountain troops. Later this pack was standardized in general issue in lieu of the so-called Haversack, Pack Carrier Roll.

This solution, however, was not regarded as satisfactory and later a two-pack system, the Pack, Field, Combat and Pack, Field, Cargo, was developed. These items were designed so that the Pack, Field, Cargo could be detached and left behind when the soldier entered combat. It could also be used as a kind of overnight bag. Many questions were raised as to the practicability of this system, especially of the return of the Pack, Field, Cargo to the individual soldier. It was felt that no consideration was given to how much of a load the soldier could carry and still remain effective. In addition, there was a fundamental question as to whether the load was placed on the men properly from a physiological and biomechanical standpoint, with respect to his musculature and skeletal frame work, and center of gravity in marching and running.

At the end of the war, it was agreed that future progress in this field would be dependent on basic studies of the proper location of a carrier's load, of the soldier's tolerable load limit, and of the maximum load he should be expected to bear.

In general, it may be said that the lack of progress in this field has been due to inadequate study of the problem by all concerned and unwillingness to face the reality of man's behavior under combat conditions with respect to his equipment.

Recently this problem has come under intensive study. This report summarizes the problem and presents the information available to date in this field in a convenient form for use by future investigators. It is believed that this is an appropriate time to reconsider the subject both from the standpoint of design and materials to be used in developing a suitable load carrying system and from the standpoint of the equipment the soldier in the field will actually need in combat.

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February 1952

A B S T R A C T

This report contains summaries of most of the major studies that have been concerned with man while carrying loads. In reporting these investigations, the writers have used two major headings, physiology and military. Upon completion of this presentation the report points out the areas where future investigations should focus.

I. INTRODUCTION

For many years military leaders have been confronted with the problem of bringing superior fire power to bear upon the enemy where, when, and as long as required by the tactical situation. The classic phrase that the battle falls to those "firstest with the mostest" leaves out the vital quality of duration. Unless troops are able to make an equal or greater fire power felt as long as or longer than an enemy, they will be defeated. This property of duration is dependent on the supplies carried into battle by individual soldiers, supplemented by re-supply. The determination of what portion can be carried on the initial assault and how it can best be carried, is vital. Therefore, it is apparent that two major problems must be solved; first, development of a system for carrying loads in the best possible manner from the standpoints of minimizing strain and permitting freedom of movement; second, the reduction of the weight and number of items carried into combat by individual soldiers.

There are few examples of action taken by earlier military leaders on this problem. An interesting one is found in the Napoleonic Wars in 1812 when the typical load carried by foot soldiers was approximately sixty-five pounds. "There was so much wasted equipment along the road of march that General Davoust, of the French Army, recommended that all knapsacks be inspected and all soldiers with missing equipment be shot. In 1861, the Military Commission of France fixed the normal load of a foot soldier at 60 pounds and designated 66 pounds as the maximum load. (6)

During World War II concern over this problem resulted in the Soldier's Pay Load Plan conceived by Captain H. W. Taylor while working under the direction of The Quartermaster General. The object of this plan was to decrease the characteristic load of the soldier by issuing to him only those items actually needed in combat. Since World War II there has been a tendency to increase an already too heavy combat load.

The portable equipment requirements of soldiers for different combat functions and the development of an improved system for carrying this equipment were discussed at a meeting held on 19-20 September 1951 at Fort Benning, Georgia, attended by members of Army Field Forces, Infantry Board No. 3, the Infantry School and the Office of the Quartermaster General. As a result of the meeting, it was decided that a report should be written on previous load-carrying studies. It is hoped that after studying past research and development, a system of transporting soldiers' loads with a minimum of effort can be designed.

II. PREVIOUS RESEARCH

A. Physiological Studies

Walking and marching experiments have been made in the past on a small number of virtually unladen subjects. Clearly there are important differences between unburdened subjects and combat soldiers in the number of pounds moved and in the time consumed in traversing a given distance. In analyzing the data on unladen subjects, one must realize that the center of gravity has not been disturbed, whereas the load borne by combat soldiers may have the effect of shifting the center of gravity.

Beginning in 1850, a few physiologists investigated the relationship of metabolism to muscular work. Of these, the first extensive investigation into the influence of muscular activity upon carbon dioxide production was made in 1851 by Edward Smith. In 1866, Speck designed a spirometer in which expired air could be collected for later analysis.

In 1901, a long series of observations on military marching was carried out by the British. (8) They concluded that the energy cost in marching increased almost proportionally to the mass moved, but that under favorable conditions the superimposed load required less energy per pound moved for forward progress than the weight of the unloaded body. They also pointed out that prime consideration must be given to the position of the load with reference to the body.

In 1912 other investigators who attempted to solve the problems of load carrying found that a velocity of 87 to 95 yards per minute was maximum from the standpoint of energy conservation. (5) In addition, their data showed that the energy cost was not significantly affected by loads up to 46 pounds. This would indicate that one can transport loads equal to approximately 30 percent of body weight without an excessive increase in energy cost. The same investigators showed that heavier loads require an excessive increase in energy cost; they maintained, however, that it was more economical to increase the load than to increase the velocity of the march.

In 1914 these results were re-examined in an endeavor to derive a mathematical formula for general application. (8) This resulted in the following conclusions: (1) The energy cost per horizontal

kilogrammeter traveled is independent of speed within moderate rates of progression and is smallest at 0.5 gram calorie per kilogrammeter for loads of approximately 42 pounds;* (2) The energy cost increase for loads in excess of 42 pounds is proportional to the square of the load difference.

In 1915 different rates of walking were studied by measuring energy costs. (3) It was concluded that a velocity of 159 yards per minute, the energy cost per horizontal kilogrammeter was 0.486 calories, a figure greater than that when the subject ran instead of walked.

A particularly interesting phase of this investigation was the determination of the energy cost of raising the body vertically during forward progression. This energy cost, which could be termed wasted effort when referring to forward progress, was concluded to be approximately 23 percent of the total energy consumed.

In 1916 the British conducted a study of the energy expenditures of infantry recruits in training. (7) The investigation was carried out under field and laboratory conditions. In the field test eight different subjects carried three different types of loads the drill (34 pounds), the fighting (45 pounds), and the marching (55 pounds). The heaviest, the marching load, varied from 32 to 54 percent of the body weights of the test subjects.

In determining the energy cost for each load, the rate of marching selected was 100 yards per minute on a level road. It was found that the average cost in gram calories per horizontal kilogrammeter for the three loads was 0.543 for the lightest, 0.638 for the medium, and 0.672 for the heaviest.

The second series of observations were carried out in a laboratory on a single subject weighing 138 pounds. The loads carried were 24, 35, 46 and 57 pounds respectively. In addition to varying the load, the investigators varied the velocity of marching.

* The terms kilogrammeter, calorie, and gram calorie will be used in this report to correspond with standard physiological measurements. One kilogram equals 0.7 foot pound; one meter equals 1.09 yards; one gram calorie equals approximately 0.004 B.T.U.

The results are summarized in the table below:

TABLE I
Energy Cost of Marching at Various Speeds
with Various Loads

Velocity* (MPH)	Energy Cost (gm.cal./horiz. kilogrammeter)				
	Load (lb.)*	24	35	46	57
2.125		0.52	0.45	0.49	0.48
2.73		0.56	0.51	0.57	0.55
3.41		0.60	0.61	0.60	0.63
3.72		0.66	0.65	0.65	0.70
4.09		0.69	0.71	0.71	0.72
5.45		0.85	0.84	0.89	
6.25		0.85	0.81	0.83	

* The load and velocity figures have been converted to the English System for convenience.

In 1922, experiments on metabolism for different grades and speeds of walking were carried out at the Benedict Laboratory. (13) The primary objective of this investigation was determination of the energy cost of lifting the body to a definite elevation by walking up-grade. A special apparatus was utilized to collect the respiratory gases and to record the body temperatures of a subject walking on a treadmill. To substantiate Benedict and Murchhauser's work of 1915, the percentage of the total energy required for lifting the body while walking was calculated. These data, which appear below, would be of primary importance if the problem of conserving energy by altering the velocity of the gait should arise.

Velocity (Yards per minute)	Percent of total energy expended for lifting the body.
47 to 52	9 percent
57 to 63	11 percent
65 to 74	15 percent
77 to 80	16 percent
83 to 85	18 percent

In 1922, an investigation of the energy expended in marching with various loads was described in the British Army Hygiene Advisory Committee Report No. 3, "The Maximum Load to be Carried by the Soldier," (8) In the first part of the study, the investigator carried out two types of marching tests, one in which the load was increased as the time of marching increased, and one in which the load remained constant during the total march. The first test was for 2½ hours, during which the load was increased from 25 to 65 percent of the body weight. The second test consisted of 9 one-hour marches, each with a different load, the loads varying in increments of five percent from 25 to 65 percent of body weight. During each of these tests, four determinations of energy expenditure were made.

As can be seen from figures 1 and 2, there is a definite fall in the energy expenditure when the load is increased from 25 to 40 percent of the body weight, and a rise in the cost when the weight load is increased beyond 40 percent.

That loads of forty percent of the body weight are less costly than lighter loads may be explained by the hypothesis that marchers may not feel encumbered by lighter loads, and may not conserve their energy.

In the second part of the study the researchers investigated the effects of varying rates of marching on the energy cost. They conducted a series of tests with the same subjects carrying loads equal to 35, 40, and 45 percent of the body weight and marching at the following velocity rates per minute: (1) fast, 120 yards; (2) normal, 100 yards; (3) slow, 80 yards; and (4) very slow, 60 yards. In each experiment with each load two samples of expired air were taken and analyzed.

From an analysis of the data, the authors concluded that from 80 yards per minute an increase in the velocity of marching raises the energy expenditure rapidly and that the rate of increase in expenditure is greater than the rate of increase in velocity. The average cost in gram calories for all loads were: (1) fast, 0.76; (2) normal, 0.53; (3) slow, 0.42 and (4) very slow, 0.41. These data are plotted in Figure 3. This evidence supports the contention of Durig, Brezina, and their co-workers that the most rapid economic rate of marching lies in the neighborhood of 90 yards per minute.

In the third phase of the study, the effect of various lengths of stride on the energy cost of marching was investigated.

FIG. 1
**OXYGEN INTAKE OF MEN MARCHING
 (CONSTANT RATE)* WITH VARIOUS LOADS**

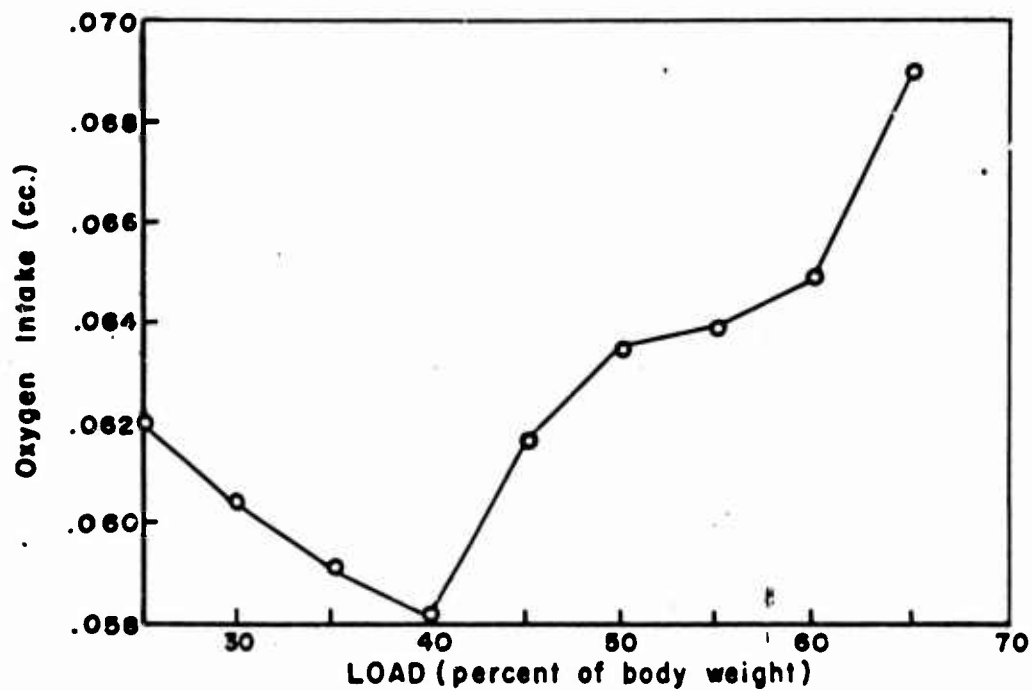
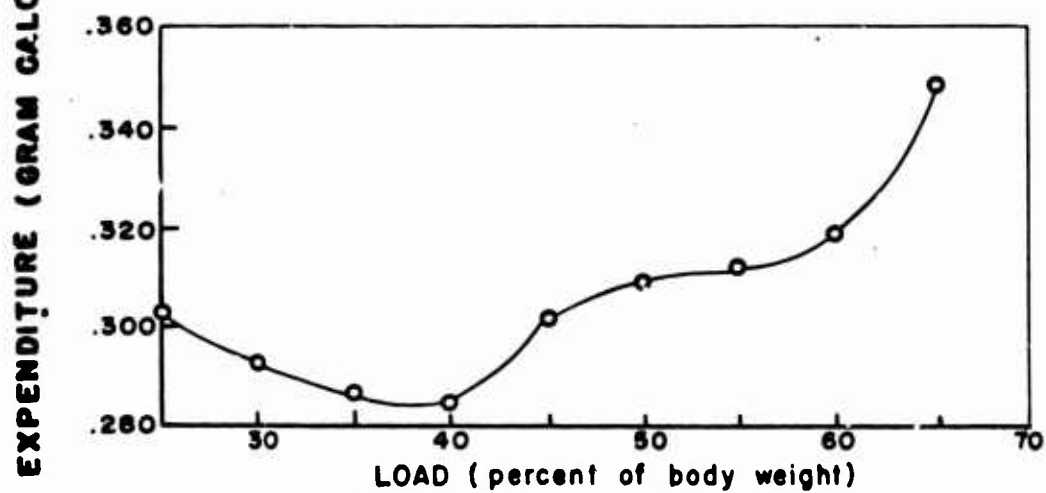
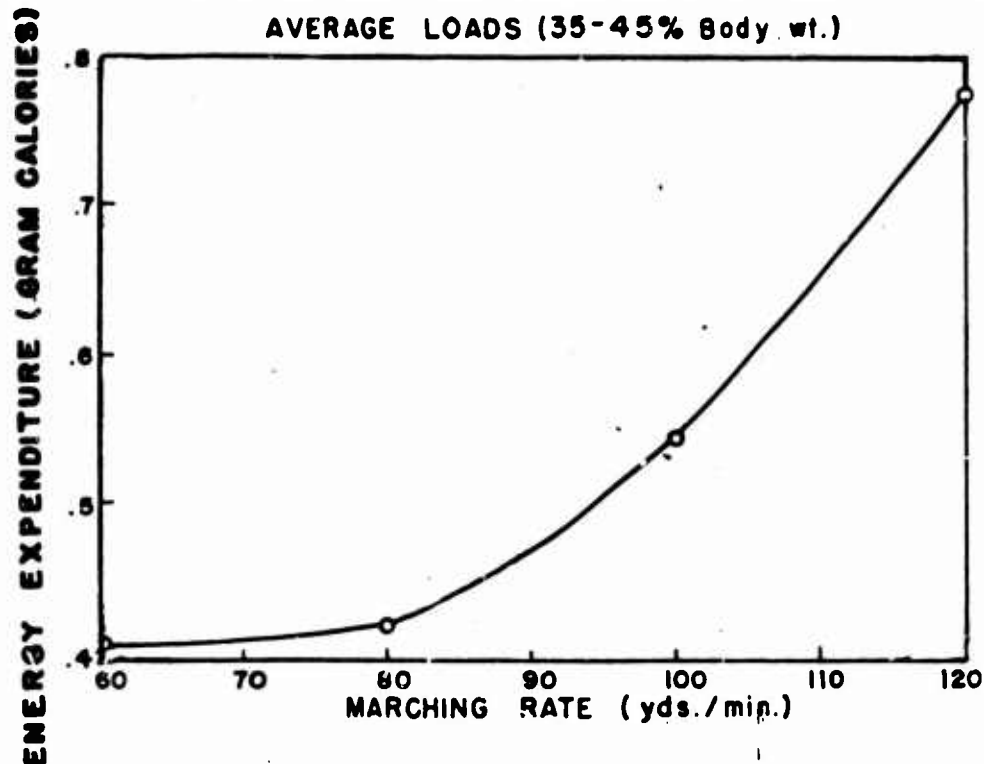


FIG. 2
**ENERGY EXPENDITURE OF MARCHING
 (CONSTANT RATE)* WITH VARIOUS LOADS**



* Constant Rate of 5050 yards per hour.

FIG. 3
ENERGY EXPENDITURE OF MARCHING AT VARIOUS RATES
 AVERAGE LOADS (35-45% Body wt.)

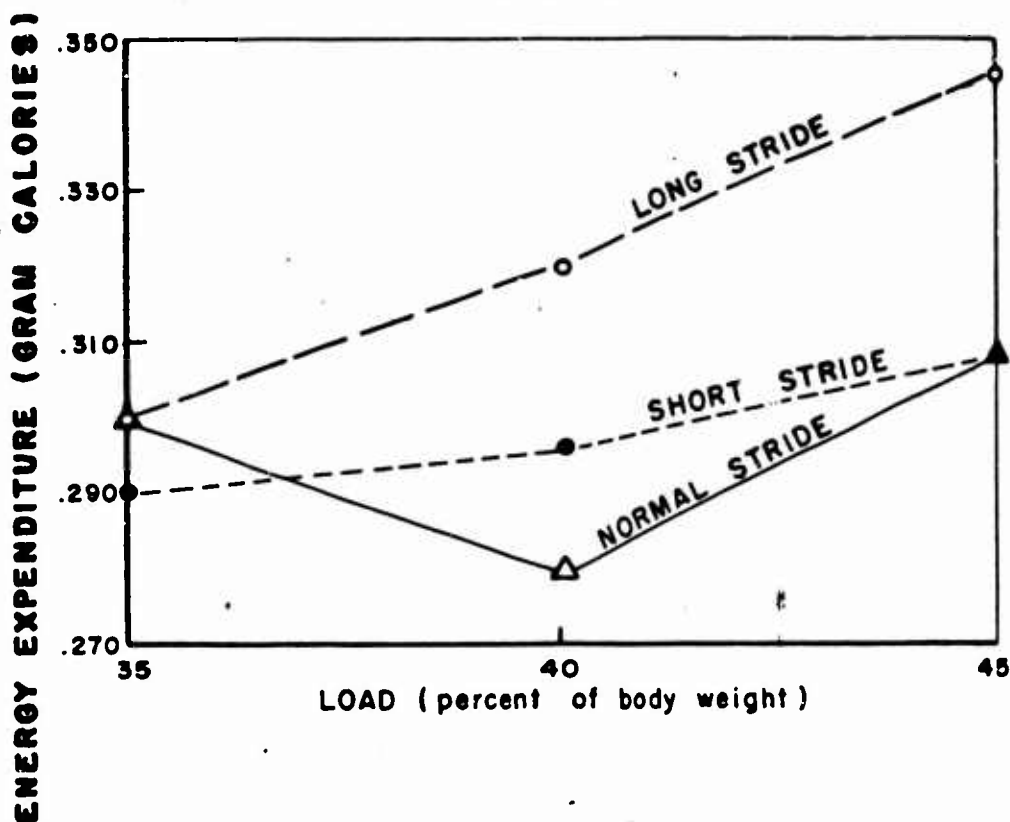


In this phase the same subjects were utilized and the rate of marching was held constant at 100 yards per minute, but the length of the stride varied. Each subject marched for at least one hour at a normal, long and short stride carrying loads of 35, 40 and 45 percent of his body weight. During each of these marches three samples of expired air were taken and analyzed.

An analysis of the expired air indicated that it is most economical to carry the light load with a long stride, the medium load with a normal stride and the heavy load with a short stride. In other words, it would seem that for energy economy in transporting loads, the length of the stride should be inversely proportional to the weight of the load.

The energy expended in gram calories at the different paces for the normal load follows the same general curve as before but with the long and short strides the curve follows a different pattern, as shown in Figure 4.

FIG. 4
ENERGY EXPENDITURE OF MARCHING WITH VARIOUS
STRIDES



In the fourth phase of the study, the researchers investigated the following question: Is it less costly to march at a moderate rate straight through a given distance without rest or to speed up the rate of marching leaving time for a rest period at the completion of the march? This was accomplished for two distances; (1) 3905 yards and (2) 5450 yards. Each test period consisted of one hour and the rates of marching were varied to give rest periods of 0, 5, 10, 15 and 20 minutes at the completion of the march. Metabolic measurements were taken and analyzed a half hour before, and at the sixteenth and sixtieth minutes after, marching started. From the analysis of the results in terms of cost per horizontal kilogrammeter, it was observed that (1) in the 3905 yard series, there was a definite reduction in the cost of performance in the post-rest period; whereas in the 5450 yard series, there was a comparable rise in cost in the same period and (2) the cost per horizontal kilogrammeter remained approximately constant up to a rate close to the economic maximum of 87 yards per minute.

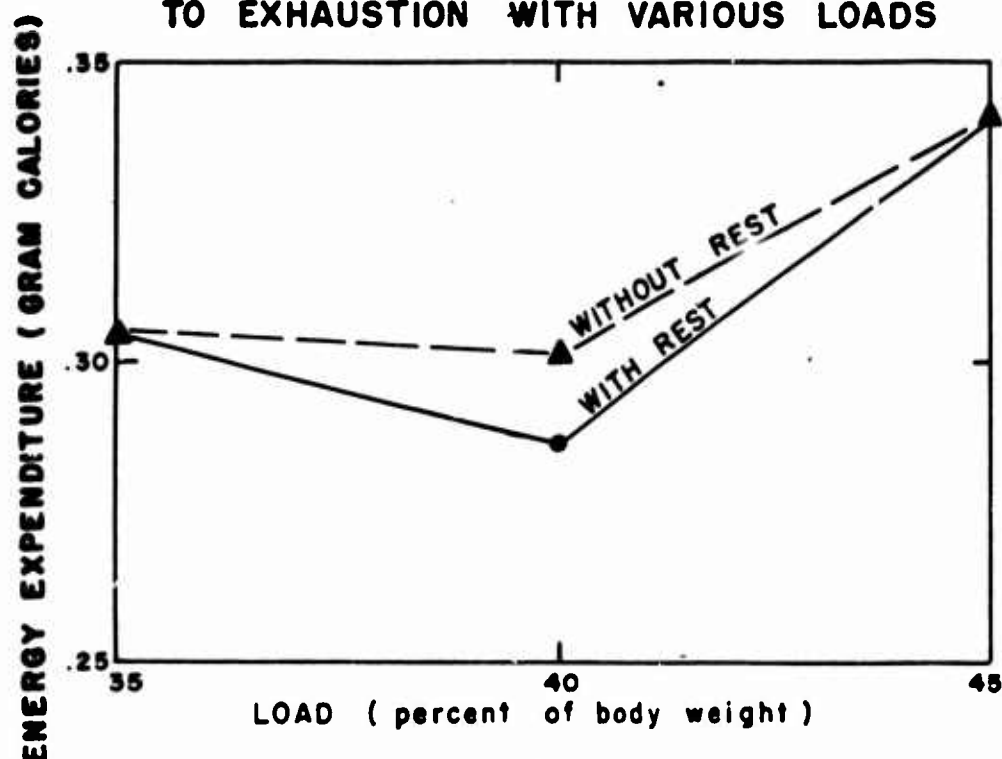
In the final phase of this study, an investigation was made of the amount of energy expended in marching to a state of exhaustion while carrying various loads. Loads of 35, 40, and 45 percent of body weight were carried in two series of marches, one of which was made without rest and the other, with periodic rest intervals. As shown in Figure 5, the energy expenditure varied only slightly in the two series, and it was lowest in each case with a load equal to 40 percent of body weight.

In 1928 a single factor was determined which could be multiplied by the body weight of an individual and the distance traveled to give the energy cost of walking on the level. (4) For the English system the constant is 0.56. Thus: Energy cost (gram calories) = Weight (pounds) x Distance (miles) x 0.56.

In 1929 a series of motion pictures of sprinters was made to show how either a change in direction or velocity affects the energy cost of running. As would be expected, a change in either or both caused an increase in the energy cost. (9)

In 1940 it was demonstrated that shifts in the center of gravity of standing subjects produce stresses which must be balanced by muscular contraction. When unbalanced packs are carried, therefore, muscular strains will result. (10)

FIG. 5
ENERGY EXPENDITURE OF MARCHING
TO EXHAUSTION WITH VARIOUS LOADS



In 1942 the effect of training on men while at work and rest was investigated.⁽¹²⁾ Fourteen subjects were studied over a period of six months during which time the subjects followed a training regime for middle distance runners. As anticipated an increase in physical conditioning was accompanied by an improvement in work efficiency. In order to obtain valid results in load carrying research, the physical condition of the test subjects must be comparable to that of the final users.

In 1944 at the Laboratory of Physiological Hygiene, investigators worked on the energy requirements of subjects walking on a motor-driven treadmill.⁽¹¹⁾ Observations were made on two men at all combinations of the following walking speeds and grades: speeds of 2.5, 3.0 and 4.0 miles per hour, grades of 0, 5.0, 7.5 and 10 percent. The data presented in the study can be used as background information for investigations on controlled work output for anyone utilizing a treadmill.

In October 1950, the Army Operational Research Group (England) published Research Report No. 11/50, entitled "The Design of Load Carrying Equipment for the Soldier in Battle."⁽²⁾ This group investigated the physiological effect of load disposition on muscle activity and fatigue. The purpose of this work was to find the optimum position on the body for a load 35 percent of the body weight* so that the center of gravity would not be displaced and the resultant local strain, which would cause isostatic attempts by muscle groups, would be eliminated.

In order to determine the magnitude of muscular activity, amplified muscle action-potentials were recorded. A comparison was made between muscle activities when loads were carried on the shoulder and when loads were carried on the hips. It was found that the former position caused continuous contraction of the neck and upper back muscles whereas the latter caused none. In addition the shoulder load resulted in more activity in the muscles of the small of the back. A load carried high on the back is farther from the dynamic center of gravity and results in a longer work arm necessitating an additional force.

* Five percent less than that shown as the optimal load in the previous research referred to in this paper.

From these results, the group predicted that a load carrying system compatible with body balance and its natural center of gravity will prove efficient in conserving the carriers' energy.

B. Military Research

The global nature of World War II presented the Army with the problem of operating in unfamiliar environments. To cope with these conditions, specialized carrying equipment such as haversacks, rucksacks, battle pouches, jerkins, packboards, etc. were developed. This equipment was inadequate, because sufficient physiological and biomechanical information was not available to the specialists who designed it. In the subsequent development of these items many design principles were formulated and construction techniques devised which should be examined as a basis for constructive analysis.

To accomplish this, several items contributed after 1940 were extracted from the vast number of those subjected to engineering, design and field tests. Prior to 1941, the Army's standard equipment for transporting the soldier's load consisted of the cartridge belt and a suspender-supported haversack pack carrier and roll, as shown in Figure 6.

Fig. 6



Soldier's full equipment with overcoat
and raincoat (Prior to World War II)

This equipment was based on the principle that each item was to be packed in a specific place. This enabled field commanders to inspect combat equipment rapidly prior to entry into battle.

During World War II the great emphasis placed upon the weight of soldiers' led to a series of test on experimental load carrying systems. In 1943 a typical field test was carried out by a group from the Quartermaster Climatic Research Laboratory, Lawrence, Massachusetts, (14) who spent a period of twelve days under field conditions in the mountains of northern New England. They evaluated the Yukon packboard, the Bergen rucksack, the jungle pack, and the sleeping bag-pack subjectively while carrying approximately 2000 pounds of equipment over extremely rugged terrain. Packs were shifted among personnel at least once on the trip. All the men used the packboard or the rucksack to transport the extremely heavy loads (50 pounds or more). Neither the jungle pack nor the sleeping bag-pack was judged adequate for heavy loads. The Yukon packboard was preferred to the rucksack in this experiment by ten out of the twelve men for carrying extremely heavy loads. While both the packboard and rucksack caused pressure on the back and hips, the packboard produced less discomfort from this source.

It was suggested that the barracks bag could very easily be modified to be used with the packboard, making a practical means of transporting equipment.

In 1946 a similar test was carried out by the Harvard Mountain Club on the Mount Saint Elias expedition. In this test six men carried loads of 45 to 120 pounds six miles each day for 19 days. When using a plywood packboard to transport heavy loads, two of the six experienced occasional pain between the shoulder blades. However, they all stated that the discomfort was caused by the shoulder strap and could have been reduced by padding. It was suggested as a result of the trial that the packboard be made two inches longer so that it could be occasionally supported with the hands in order to relieve the shoulder strain. (15)

In December, 1948, Army Field Forces, Board No. 3 published a report entitled "Study and Test of Loads Carried by the Individual Soldier and Methods of Carrying." This was a result of renewed interest by Military men in the problem of carrying loads, and served as a forerunner of the present military investigations. (1)

In the Army Field Forces report it was pointed out that the loads carried in the tests did not represent the wide differences in the tactical loads which must be borne by various members

of a combat unit; and secondly that various methods of load carrying were not considered to determine which were most suitable under different climatic conditions. To overcome these shortcomings, the group undertook further investigations with the following objectives:

"1. To analyze the loads of individual soldiers required by virtue of their positions within the tactical organization.

"2. To carefully investigate all known methods of load carrying and from them select those which would be most useful in transporting the prescribed load."

To determine the loads of individual soldiers, a detailed analysis was made of Table of Organizations and Equipment 17, 9 December 1947; and Table of Organization and Equipment 8-7 N, 6 January 1948. It was found that the individual soldier's loads varied from 58 lbs. for a rifleman, to 111 lbs. for an ammunition bearer and that the normal cargo load which is dropped prior to entering combat is approximately 24 lbs. Upon determination of the basic load, consideration was given to the problem of environmental conditions and how they affect the choice of items to be carried and the design of equipment necessary to carry them.

In the second part of the project the investigators made a survey of many known methods of individual load transport. Four were chosen for detailed testing. They were:

1. Cargo and combat vest 10 oz. duck
2. cargo and combat vest 7.9 oz. duck
3. M-1945 cargo and combat field pack
4. Experimental M-1945 field jacket with pack pouch

As a result of field tests it was determined that the cargo and combat pack was the only one of those actually tested adaptable to the varying loads imposed by tactical assignment or climatic conditions, and that the principles on which the cargo vests and jacket were designed should be given no further consideration.

Upon conclusion of this phase, the project was expanded in 1950 to investigate further the problem of individual load transport. (1) The premise was established that the present system of logistic support for infantry soldiers is impractical and unrealistic, resulting in tremendous waste and impairment of the soldiers' fighting efficiency.

It was proposed that the loads of foot soldiers be reduced to those that can be carried efficiently. To determine the limits of these weights, a study was undertaken in cooperation with the Surgeon General's Office. It was proposed that the load carrying capacity of the soldier be arrived at indirectly by determining the maximum amount of energy available for this function. For this purpose the metabolic potential was used which is a direct function of the caloric value of the food intake. Because of the nutritional and physical limitations imposed on the soldier by combat (fatigue, footsores, state of mind, etc.) the maximum caloric intake is probably less than 5000 calories a day. This can be broken down as follows:

Estimated maximum caloric intake in 24 hrs.	5000 - 6000
Basal metabolism requirement 24 hrs	1680
Moderate activity 8 hrs 8 hrs	<u>640</u>
Expended energy	<u>2320</u>
Energy available for all other activity	2680-3680 Kilogram Callories

The energy available for marching therefore certainly cannot be expected to exceed 3680 calories. Although reserve of energy can be summoned for short periods, the average man cannot maintain an energy expenditure of 700 calories per hour for more than an hour. For any amount of available energy, the rate and distance which can be traveled is a function of the weight to be carried or vice versa.

The Surgeon General's Office also quoted the following figures from Morehouse and Cherry:

Weight of Load (lbs.)	Rate of March (mph)	Energy Expenditure* in (Kilogram Calories/hr.)
44	2½ (walking)	240
53	4.3 (trotting)	510
44	5 (running)	750

* In excess of basal requirement.

On this basis, Board No. 3 made the following recommendations:

"1. That 40 pounds be adopted as the combat load to be carried by the soldier employed under the most trying conditions, i.e. the rifleman.

"2. That 45 pounds be adopted as the combat load to be carried by soldiers other than riflemen whose combat functions normally require movement on foot.

"3. That 55 pounds be adopted as the load to be carried by any soldier when march conditions prevail.

"4. That the loads of other soldiers en route to and employed in the combat zone be limited to 55 pounds without regard to the type of unit to which assigned or method of movement."

If consideration is not given to the physical limitations of men, it is probable that upon completion of a march and arrival at the line of fire their physical condition would be such that their efficiency would be considerably reduced.

A second phase of the project was carried out in order:

a. To determine the kind and quantity of supplies and equipment which the individual soldier must have in his possession under various conditions of employment and environment.

b. To determine the weight of the items considered to be necessary and to compare this with the maximum load which should be carried as determined in Study No. 1.

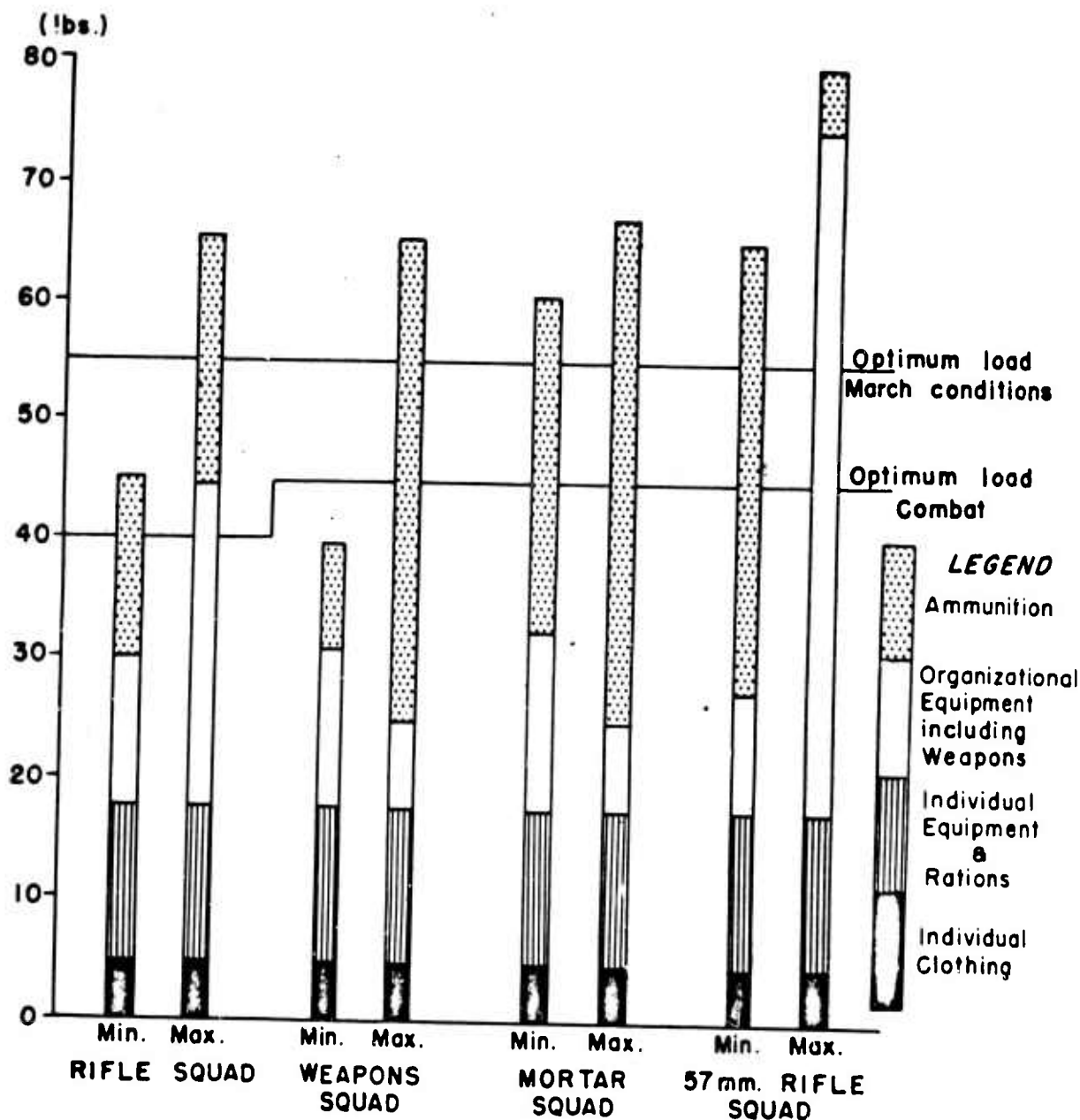
c. To determine what further action should be taken to reconcile the actual weight of the load with the desirable weight.

This phase was accomplished by studying publications which stated the current Department of the Army policy with respect to ammunition weapons, clothing, and equipment which the soldiers must carry. The Infantry School was requested to study the individual and organizational equipment presently prescribed for a rifle company and to indicate those items which are absolutely essential.

From this, the aggregate weight of all equipment and ammunition considered necessary was compared with the loads prescribed in the first phase, as shown in Figure 7. Included in

FIG. 7

**RANGE OF AGGREGATE WEIGHTS OF LOADS OF RIFLE
COMPANY SOLDIERS WHEN ENTERING COMBAT***
(CLIMATIC CONDITIONS - SUMMER SEASON, SOUTHERN, U.S.)



*Adapted from Report of the Army Field Forces Board No. 3, August 1950

this phase was a discussion of the further action which should be taken concerning the problem.

A third phase of the study dealt with the individual and organizational clothing and equipment which soldiers do not normally carry in combat. For the first time in the history of load carrying research consideration was given to the interdependent relationship among soldiers, what they carry, and the intricate service, supply, and storage operations which support them.

In 1950, the British Commonwealth Joint Services Committee, Subcommittee on Clothing and General Stores Development published a report of qualitative requirements on which to base a functional load carrying system. (16) These were to serve as a basis for improving the equipment used in temperate and tropical climates. The investigators also realized that there are physiological limits for a load and that the greatest gain would come not through redesign of the carrying system but by reducing the number of items carried and their individual weights. In addition, stress was laid on the interaction of the carrying equipment with both clothing and other equipment. On these principles, they hoped to develop a logistically and tactically functional carrying system.

III. COMMENTS ON PHYSIOLOGICAL APPROACH TO THE PROBLEM.

Up to the present time most physiological studies in this field have been conducted under laboratory conditions without specific reference to the varying tactical loads carried by soldiers. This restricts the application of the findings to a very limited portion of the military problem. Therefore, in future investigation, it is suggested that work be conducted under conditions approaching those of combat, utilizing the equipment usually transported by soldiers.

Previous studies have been based largely on the metabolic data collected on subjects walking on a treadmill. These data have contributed to our present knowledge, but in conducting future research, it should be realized that the combat soldier is not limited to the normal gait. His progress is characterized by intermittent dashes, abrupt changes in direction, sudden stops, hitting the ground and crawling. Each time the soldier changes his pace or direction, he utilizes additional energy to overcome inertia. This implies that the soldier is not using energy at a

constant rate as in walking, but rather consumes energy in spurts, often working at his physiological limit. The differences outlined above create unique problems, not heretofore considered, which influence the soldiers ability to work or transport loads. Therefore, in future investigations an attempt should be made to measure the energy cost of various systems of transporting typical loads during field maneuvers. Such a procedure has had its limitations in the past because of the necessary interruptions of activity to make physiological measurements. The advent of telemetering permits the transmission of data on physiological activity under field conditions. These new techniques should make possible definite progress in the solution of the physiological difficulties surrounding this problem.

As can be seen, the criteria in the majority of this work have been derived from metabolic determinations. The limitations of these criteria lie in the difficulty of obtaining accurate results. In future investigations it is suggested that other criteria be utilized, such as breathing, gait, "fatigue," perspiration, and other factors listed in Appendix A.

Metabolic data have also been utilized in calculating the caloric intake of the soldier to determine the amount of energy available and the load he can transport. Much of the energy expended under combat conditions is nervous in nature and does not contribute to the soldier's work. In addition, it was learned during World War II that soldiers' food intake was restricted while under fire, thus reducing the energy available for activity. Therefore, attempts to analyze the problem without considering such factors may lead to findings that will not prove valid for combat conditions.

Another restriction of previous research is that its findings have been based on limited observations of a small number of subjects. The probability of obtaining a true sample with so few cases is extremely small. Due to the limited number of subjects, the distribution curves for weight, height, strength and physical conditions have not followed those normal for Army troops. In future research, consideration should be given to the number, state of training and the many physical characteristics of the test subjects.

In addition to the characteristics described above, the psychological reactions of combat soldiers as they apply to this problem have not been adequately studied. Undoubtedly, the only

way that all of these reactions can be obtained is by testing in combat. Cognizant of these facts, the investigator should make every effort to simulate the conditions of combat while testing and to be aware of the limitations of his results.

IV. MILITARY CONSIDERATIONS AFFECTING LOAD CARRYING DESIGN

Military considerations will finally determine to what extent theoretical findings can be applied to the development of individual carrying equipment. Previous studies having direct military application have been largely limited to the following:

1. Establishment of military characteristics
2. Staff studies
3. Observations of combat and field exercises
4. End-item comparison tests.

The theoretical background resulting from the work has made possible the broader viewpoint acquired since World War II and several entirely new approaches to the problem have been proposed, as suggested by the notes in Appendix B.

A. Accessibility

The accessibility of tactically important items, such as ammunition and aid packets, is of prime importance in combat. Under fire, the limitation of the soldier's movements will prevent him from reaching a poorly placed item of his equipment. Equipment design must make it possible to reach such vital equipment and obtain it quickly. The varying loads should be analyzed, therefore, on the basis of combat need, making possible the assignment of some items to positions of greater accessibility. Although these may conflict with desired biomechanical and physiological principles, reducing the biological efficiency of the soldier, they may add to his total military effectiveness.

B. Items Carried Into Combat.

Before a solution can be reached concerning the weight and distribution of a basic load, it is necessary to determine the essential articles which should comprise it. Once this has been determined, studies can be initiated to reduce the weight through redesign. The problem is intensified by the varying tactical

missions of soldiers and the wide range of environmental conditions in which they must operate. In addition the problem is further complicated by the hour-to-hour changes in the functions of the individual soldier. If a minimum load in terms of items can be established which will meet the majority of the requirements, it can serve as a firm foundation on which to base future work.

C. Tactical Supply

The problem of the individual soldier's combat load is directly related to the method of daily resupply needed in a tactical situation. The policy for replenishing ammunition, rations, water, and for providing sleeping equipment will govern the components of the basic loads. Infantrymen will be required to carry. Unit supply policy should be aligned with the idea that the most efficient group will be carrying the lightest load compatible with their tactical responsibility. However, in designing any load-carrying system and in formulating the accompanying resupply policy, it must be remembered that each, of necessity, has to change to meet variations in terrain, weather, enemy interference and numerous other factors; and therefore, both must be as adaptable as the varying situations require. It is important that the problem of combat resupply be restudied in order to prevent the Infantryman from having to dispose of an incapacitating burden, the more important elements of which may be needed later as the situation changes.

D. Functional Equipage

Military appearance tends to assume more importance in peacetime development due to preponderance of post, camp and station activities. Wartime experience has shown that such equipment is not suitable for combat and that functional efficiency must take precedence over appearance. Military leaders must realize that the characteristics of the peacetime and the combat load are quite different. In peacetime maneuvers extreme loads are often only simulated. Thus weaknesses in design may not be uncovered. In actual combat, certain situations may arise which require adjustments in the load carrying system which were not considered in the design. For example, soldiers will often for psychological reasons make additions to their loads such as, extra ammunition and weapons which will more than offset the weight of any items which they may have discarded because of excess weight. Variation in weight over a period of time is also more of a problem in the combat load. As ammunition and food are expended load balance may change, thus upsetting any

optimum positioning which might have been obtained. The tactical responsibility of a unit within a military organization remains the same regardless of personnel losses. This may necessitate the carrying of additional weight by the remaining individuals in order for the unit to accomplish its mission.

Any combat load transport method which may result from the present investigation should be based in large part on the concept of functional adaptability. It should allow any component part to be removed quickly and easily, and be transferred if necessary to another carrier. By means of additions or expansions it should be capable of coping with various tactical load situations. These modifications should not upset the biomechanical and physiological efficiency resulting from well-balanced loads.

The emphasis in this discussion has been chiefly on combat loads. However, the principles discussed in this paper are certainly applicable to the overall problem of load carrying. Any system which will allow soldiers to move and fight must be based on sound biomechanical, physiological, psychological and logistical principles. It is hoped that by carrying out the investigations suggested in this critique the necessary knowledge will be obtained and applied to the development of a functionally efficient load carrying system.

APPENDIX A

FACTORS TO BE CONSIDERED IN FUTURE RESEARCH ON LOAD CARRYING

Physiological:

1. Total loadweight
2. Weight distribution
3. Breathing
4. Interference with circulation
5. Shoulder pressure
6. Sweating
7. Gait and rate march
8. General Fatigue
9. Localized fatigue
10. Strength of Individuals
11. Posture (dynamic)
12. Energy expenditure
13. Interference with evaporation of sweat

Functional:

1. Relationship to body clothing
2. Adaptability to different climates

Biomechanical:

1. Freedom of movement
2. Skin pressure, friction (chafing)
3. Relationship of load to center of gravity
4. Load bounce
5. Effect of compression on clothing

Military:

1. Actual equipment requirements
2. Easily detachable parts
3. Camouflage
4. Adaptability to combat purposes
 - a. availability of equipment
 - b. ease of converting from field to combat pack
5. Lightness of weight
6. Water repellancy
7. Current requirements and characteristics.

Psychological;

In considering the problem of load carrying with respect to the above factors one must be also aware of the psychological implications of:

1. loss of appetite
2. loss of strength
3. physical cost of mental fatigue
4. lack of sleep
5. fear - (perspiration etc.)
6. desire to be unencumbered

APPENDIX B

LOAD CARRYING SYSTEMS TO BE CONSIDERED IN THE FUTURE

1. Belt-Suspender Suspension System

In this system all of the combat equipment will be hung from a suspender and a supported belt. This system is presently being adopted by the Canadians and should be studied by the United States.

The equipment must be easily attached and must be available to the soldier when needed. In addition, care should be taken to design the equipment in light of biomechanical and physiological knowledge.

2. Factory Packaged Ammunition System

This is a system which would eliminate the use of the cartridge belt by means of factory packaged ammunition in an expendable "package-carrier." It would be the Q.M.'s problem to develop a means of transporting this carrier in addition to developing means for carrying the remainder of the combat load.

3. Clothing System

The first consideration to be made here is of a system of pouches and pockets built in the outer layer of the clothing.

The second is of a separate unit, for instance a jacket such as the British Jerkin or the Assault Jacket which will have pockets, pouches and means of attaching the units of the soldiers' load.

4. Sleeping Gear Utilization

This would be a blanket roll type of system. Pouches and/or pockets built into the outer side of the sleeping gear when rolled for transport.

5. Material Consideration

Packs would be made of lightweight, loosely knit nylon net with polyethylene bags for carrying items within.

6. Combination System

The designer will evolve from the other systems the best of each and incorporate these into another possible system.

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