ARMY HYGIENE ADVISORY COMMITTEE REPORT No. 3.

On the Maximum Load to be Carried by the Soldier.

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I.—Introduction.

(1) "It must therefore be the aim of every Commander to ensure that his Infantry reach their goal in the best possible condition for engaging in the hand to hand combat."—F.S. Regs. II.

(2) "The power of undertaking long and rapid marches without loss of numbers and energy is essential to success in war."—Inf. Training I.

War, quite properly perhaps, has always been thought of in the light of victory or defeat, of the triumph of strategy and tactics. In the public eye it is the ultimate end which has loomed largest and it will always be so. Even amongst those who do know, the actual engagements and the end bulk so very large that the fact is apt to be minimized, that the pawns in the game are men who must be fed, who are killed and must be replaced, if the war is to be waged successfully. Obviously it is no more possible to conduct a war without casualties than to make an omelette without breaking eggs, yet the wastage of war is just as great behind the lines as in the front trenches. An army to be fit for its job must be recruited from healthy men of good physique but these men must be kept fit. The human organism is not capable of enduring a limitless strain. The soldier must be well fed: he is. The soldier must be well clothed: he is. The soldier must be well trained: he is. The soldier

must transport a reasonable amount of equipment and personal belongings, *but* there is a limit to his performing the dual rôle of beast of burden and fighting soldier.

It certainly falls within the province of those entrusted with the actual conduct of a campaign to direct the army to attack this or that objective, but if in the course of the campaign, as in the late war, due to the inclemency of the weather, the nature of the terrain or the evolution of new modes of warfare additional equipment is demanded and issued, they have no physiological right to demand that, as the load of the man is steadily added to, the soldier will remain effective as a fighting unit. The fighting value of a soldier is in inverse proportion to the load he carries.

The problem is infinitely more far reaching than the mere fatal diminution of the fighting value of the soldier. As the load the man is made to carry increases, the cost in energy for transportation increases. This energy comes from food alone, therefore the Q.M.G. is called on for more supplies. Not only so but other branches of the supply department are taxed as with the increase of the load the desire, and even the need of the man to shed part when and where he can, increases. (Vide the roads in France in the War.) Nor must it be forgotten that the over-fatigued man, especially if it be fatigue induced by the carriage of unduly heavy equipment, is usually a man of low morale. Yet "success in war depends more on moral than on physical qualities"—F.S. Regs. II. The resources of the A.G. are also severely taxed. The man power of the country is limited, the division between men required for fighting and for manufacture of essential munitions is nicely balanced. The overloaded man can easily become a physical wreck before he is even near the front line. Another pensioner is added to the country's post-war burden and the A.G. has to find a new man for the line.

The two following quotations express the same idea. Thus in the Report of the Committee "appointed to inquire into the effect on health of the present system of carrying the accoutrements, ammunition and kit of Infantry Soldiers," Report II, 1867, it is stated, "We need not discuss a matter notorious to all the world, but may state without fear of dispute that the conditions of modern war demand that the marching powers and endurance of the soldier must not be lessened by unnecessary weight or by a defective mode of carrying the weight. *Cæteris paribus* the army that is least weighted and that can move with the greatest rapidity must have the advantage." Also "we are of opinion that his (the soldier's) efficiency and health suffer far more from his carrying too many things than from his occasional and temporary absence from any two or three articles of his kit."

Parkes, one of the greatest of all authorities on Army Hygiene, who was a member of the above War Office Committee, also expressed himself in his textbook as follows: "In time of war it is most important to have

the soldier as little weighted as possible. The long and rapid marches which have so often decided wars have never been made by heavily laden men. The health also suffers. It is of national importance that the soldier should be as healthy and efficient as possible, as the fate of a nation may be staked on the prowess of its army. The line which the weight of his necessaries should not exceed should be drawn with the utmost care; if his health suffers more by carrying some extra pounds of weight than it benefits by the comfort the articles give, why load him to his certain loss? The overdoing of necessaries of the soldier has always been a fault in our army. Robert Jackson, cited by Parkes, noticed it seventy years ago. 'It is a mistake,' he says, 'to multiply the equipment of the soldier with a view of adding to his comfort.'"

It is very obvious then that the determination, if it be possible, of the maximum economic load, i.e., the maximum load which may be transported by a man who can yet after a march remain an effective soldier, is most desirable. On this capacity of the man to remain effective will pivot all possible plans for offensive action drawn up by the general staff.

II.—Load.

Lothian in his admirable historical report on "The load carried by the Soldier," has destroyed the mythical stories of tremendous marches of soldiers carrying extraordinary loads, such as that of the famous sixty pound load reputed to have been carried by the Roman legionary on his long marches. Parkes too had previously doubted some of these stories. He states in his textbook that the famous march of Craufurd's Light Division (43rd, 52nd and 95th Regiments of Foot) at the Battle of Talavera, of sixty-two miles in twenty-six hours with only seventeen stragglers, which both Napier and Moorzom state was carried out with the men carrying loads between fifty and sixty pounds, was done because the men carried only a shirt and a spare pair of either boots or soles. His authority was Lord Clyde who informed Professor Longmore (Army Medical Service), that he had seen the Division come in.[1]

It is the faulty account of such marches that has encouraged the belief that men can, if they are called upon, perform wonderful feats. These wonderful marches may be possible with carefully selected units, but they are not possible of accomplishment by the average units. It is largely a question of physique.

Lothian also dealt with the relation of the load to the physique of the soldier and pointed out the evil results which follow from overloading not only the healthy normal recruit, but, more particularly, the soldier who has been debilitated by disease and exposure. Excellent as was the hygiene, in the broadest sense of the word, in the late war, great as may

[1] Oman ("Hist. Penin. War," II, p. 560) says "forty-three miles in twenty-two hours with fifty pound load."

be the advances which will yet be made, hygiene can never be so perfect—the exigencies of war will certainly not permit it—as to eliminate completely the effects of exposure and the ordinary normal debilitation which must result when recently incorporated and trained men are put in the field. The problem of the exhausted man will never be solved even in the most perfect army put into the field for a prolonged campaign. The harder the fight the greater the resulting exhaustion. We must count then in the assessment of the maximum economic load on a gradual deterioration of the physique.

The load too must be correlated with the weight of the soldier, indeed it may be regarded as a function of the weight. Lothian has given a good account of the loads which have been carried by soldiers since historical records were available, and how this load has fluctuated with the changes in the art of war. His graph (fig. 18 in the Report) demonstrates in a most vivid fashion the gradual but steady increase of weight which has taken place in army equipment. His figures are no mere fanciful estimations; they are based on actual data.

The result of the various developments in offensive measures, in addition to the fact that the war in France, at least, was mainly stationary, led to the soldier being overloaded. Probably the average load of the infantry soldier in France was equal to about sixty per cent of his body weight, and it was not uncommon to find individuals carrying, or rather staggering under, a load which was equal to seventy-five per cent and even more of his body weight. In calculating the load of the soldier it is very frequently forgotten that a march on a wet day over muddy roads, or even a good heavy shower of rain will bring about a very material increase in the weight of the load borne. For instance, if the greatcoat gets well soaked, exclusive of adherent mud, this will mean an addition of about twenty pounds to the load and the addition of mud, together with the water in wet equipment, trousers, puttees and boots, adds at least an additional fourteen pounds. Thus if a soldier started out with an initial load of say sixty pounds on a march on a wet day through muddy country, he would finish with a load of ninety-four pounds or more.

This steady taxation of the soldier is not confined to Britain, as reference to Lothian's report, for example, will show.

The question as to whether there has been an increase in the physique of the soldier which would justify the steady increase in the load naturally arises. It can very definitely be stated that there is no such increase; indeed, with the increasing urban population and decreasing peasantry, there is actually a steady decline in physique. Pre-war, the average recruit of 19 years weighed about 127 pounds, whereas post-war the average weight, according to Sylvester Bradley's figures, is 122 pounds. Obviously, with the improved feeding and steady army training the recruit puts on weight, and we are inclined to agree that the figure put forward by Lothian for the average weight of the trained soldier, of 135 pounds is approximately

correct. If this figure be accepted as the average body weight of the British infantry soldier it is now essential to determine the maximum economic load in terms of the percentage of the body weight.

III.—Previous Work.

The great majority of the observations which have been made on the subject of forward progression (walking or marching) have been carried out with the virtually unloaded subject. These experiments, however, are of considerable, indeed of vital, importance, because after all, no matter if the subject be stripped naked, walking entails the forward movement of weight. The difference between the naked pedestrian and the loaded soldier is only a matter of the number of kilos to be transported, although of course in the one instance it is more or less evenly distributed live weight and in the other an external load is added, which may or may not alter the centre of gravity of the body, and hence the position of the load is important. A load which could be carried with readiness if properly placed on the back of the subject would obviously so handicap as to render him useless if it were attached, let us say, mid-way between the knees and the hips.

A very full discussion of the earlier literature, on the energy transformation during horizontal walking is given in Benedict and Murchhauser's (1915) monograph. Using the horizontal kilogrammetre as the unit it is found, as Durig (1911) had previously maintained, that, if the normal rate be held to be from 80 to 90 metres per minute, the gramme calorie value per kilogrammetre lies between 0·3 and 0·7 with a very distinct tendency to approach a mean value of 0·55 gramme calorie. The experiments, on which this mean figure is based, include marches done with and without loads.

The most important of these investigations for the present report will now be briefly discussed. Zuntz and Schumburg (1901) carried out a long series of observations on the energy expenditure involved in military marching.

They came to the conclusion that, speaking generally, the energy cost in marching increased almost proportionally to the mass moved, but, that under favourable conditions (the *position* of the load being of prime importance) the superimposed load cost less for forward progression than that of the body in an unloaded condition. They found, however, in certain experiments, that the amount of the superimposed load did materially influence the cost.

The experiments also of Brezina and his associates are of primary importance as the question of the influence of load is fully discussed. Brezina and Kolmer (1912) confirmed the finding of Durig, viz.: that the maximal economic velocity is approximately eighty to eighty-five metres per minute. They also found that the cost was not influenced by loads up

to twenty-one kilograms, i.e., this amount of extra dead weight could be carried as economically as so much extra live weight. As their subject weighed seventy-one kilograms this means that, under their conditions, loads equal to approximately thirty per cent of the body weight might be regarded as being equivalent to so much body weight. Heavier loads they found brought about both an absolute and relative increase in the energy output. They also maintained that it was more economical, as regards energy output, to increase the load than the speed at which it was carried, i.e., the maximal economic velocity fell with loads increasing above thirty per cent of the body weight. Brezina and Reichel (1914) re-examined these results in an endeavour to obtain a mathematical statement which would allow of generalization. They came to the conclusion that: (1) for moderate rates of progression the cost per horizontal kilogrammetre was independent of the speed and is smallest at 0·5 calorie for loads of approximately nineteen kilograms, i.e., about twenty-seven per cent of the body weight, and (2) the energy increase for loads exceeding nineteen kilograms was proportional to the square of the load difference. When the maximal economic velocity was exceeded they held that the metabolic cost increased in geometrical ratio to the arithmetical increase.

Cost in Gramme Calories per horizontal Kilogrammetre.

Load in kilos.	March rate metres per minute				
	44·7—49·7	68·9—73·3	89·9—92·0	111·4—118·1	141·0
3	0·48	0·60	0·57	0·77	0·93
14	0·48	0·47	0·62	0·93	—
24	0·57	0·52	0·59	0·91	—
36	0·59	0·53	0·64	0·91	—
46	0·58	0·56	0·81	—	—
56	0·59	0·59	0·77	—	—

Benedict and Murchhauser (1915) published an exhaustive study of two subjects walking at different rates both before and after food. They found that in ninety-one experimental periods after food, with an average velocity during the period of 68·2 metres per minute, the heat output per horizontal kilogrammetre was 0·486 gramme calorie. The cost when the average speed was 111·4 metres per minute rose to 0·606 gramme calorie and at 146·3 metres per minute reached 0·907 gramme calorie, a figure greater than that when the subject ran instead of walked.

One of the very interesting determinations in this research was the measurement of the energy required for raising the body vertically during the act of forward progression, the elevation due to step movement. They found that one of their subjects, weighing seventy-three kilos, when walking with a velocity of seventy-six metres per minute expended 2·81 calories per minute above his standing basal metabolism, of which 0·65 calorie was expended in raising the body through a distance of approximately four metres per minute. This means that about twenty-three per cent of the total expenditure was required for elevating the body.

Cathcart and Orr (1919) in their study of the energy expenditure of the infantry recruit in training studied the cost of marching with varying loads and velocity under field and laboratory conditions. They used in their field experiments eight different subjects who carried three different weights, 15·3 kilos (drill order), 20·5 kilos (fighting order), or 25·0 kilos (marching order). The maximum load 25·0 kilos varied as a percentage of the body weight of the subjects tested from 32·0 per cent to 54·3 per cent, and for the average 135 pounds man would have formed about 41 per cent.

In the determination of the cost of the load the rate of marching selected was 100 yards per minute on a good level road. It was found that the average cost in gramme calories per horizontal kilogrammetre for the three loads was 0·543 for the lightest, 0·638 for the medium, and 0·672 for the heaviest load.

The second series of observations were carried out in a laboratory on a single subject weighing 62·6 kilos. The loads carried were 11, 16, 21 and 26 kilos, forming respectively 17·5, 25·5, 33·5 and 41·5 per cent of the body weight. In addition to varying the load the influence of variation in the velocity of marching was also investigated. The results are summarized in the following table:—

Velocity in metres per hour	Load in kilos.											
	11		16				21				26	
	A	B	A	B			A	B			A	B
3428	0·52	44	0·45	41			0·49	47			0·48	49
4388	0·56	41	0·51	40			0·57	48			0·55	49
5486	0·60	44	0·61	47			0·60	50			0·63	55
6039	0·66	48	0·65	51			0·65	54			0·70	62
6583	0·69	51	0·71	55			0·71	59			0·72	63
8778	—	—	0·84	67			0·89	75			—	—
10,972	0·85	63	0·81	64			0·83	69			—	—

A = cost in gramme calories per horizontal kilogrammetre.
B = ,, ,, ,, metre.

In a further short series of laboratory experiments with three subjects carrying loads of nine and twenty-six kilos, the lighter load being about fourteen per cent of the body weight, and the heavier about forty-one per cent at 55, 82 and 110 metres per minute, the cost in gramme calories per horizontal kilogrammetre for the nine kilo load was for the three speeds 0·48, 0·51 and 0·65, and for the twenty-six kilo load 0·53, 0·54 and 0·70 gramme calorie.

Benedict, Miles, Roth and Smith (1919) in the course of their valuable inquiry into the effects of a restricted diet on the cost of performance of work, compared the energy expenditure of a group of twelve young men under normal conditions of feeding with that of the same group after they had been on a restricted diet for twenty days. They found that the average cost in gramme calories per horizontal kilogrammetre for the men on the normal diet was 0·597, and after twenty days on a restricted diet it

was 0·592 gramme calorie. They also made a number of observations on a group of eleven men who had been kept on a restricted diet for 120 days and who were much below their normal weight, and found that the cost per horizontal kilogrammetre had fallen slightly, to 0·522 gramme calorie. The rate of marching, which was done on a treadmill in a closed chamber, was about seventy metres per minute.

Liljestrand and Stenström (1920) using the Douglas bag method, experimented on men walking on a good track. The influence of velocity of movement was alone tested. They found with their two subjects, who differed markedly in weight, the following figures :—

(I) The cost in gramme calories, and (II) oxygen intake in cubic centimetres per horizontal kilogrammetre.

	I		II	
Velocity per minute	A 80 kilos	B 60 kilos	A	B
50—75 metres ..	0·517	0·491 ..	0·107	0·101
75—100 ,, ..	0·613	0·574 ..	0·127	0·118
100 ,, ..	0·830	0·710 ..	0·172	0·146

They suggested that the oxygen intake was a better guide than the heat output, as the calculated calorie value depends on the respiratory quotient which is readily altered by variations in the carbon dioxide output.

Cathcart, Lothian and Greenwood (1920) criticized the formula put forward by Brezina and Reichel on the grounds that the data on which it was founded did not justify the conclusions. They showed that the relation between the energy cost per unit of time and speed may be equally well represented by another type of formula. They did not believe that either the formula of Brezina and Reichel or their own was the expression of any physiological law. They applied their formula to a collection of experimental data, obtained for the most part from one trained subject marching at approximately 55, 82 and 110 metres per minute, and found that their optimum rate, about eighty-two metres per minute, agreed very closely with the maximal economic velocity of Durig.

Finally, Smith (1922) has just published from Benedict's laboratory a large monograph on metabolism during level and grade walking. He found for horizontal walking that the average value of eight men, at speeds mostly below eighty metres per minute, was 0·538 gramme calorie per horizontal kilogrammetre. He also considered the influence of velocity on the cost per horizontal kilogrammetre, and found, like many other observers, that with speeds below eighty metres per minute the influence of the velocity was not at all marked. It may be noted, however, that at the lowest speeds tested, thirty-five to forty-five metres per minute, there was a tendency, although Smith did not commit himself to this as a definite conclusion, for the cost to be a little higher than at faster rates. The suggestion, however, in view of Frentzel and Reach's (1901) statement that

very slow speeds are somewhat more costly than moderate speeds, a conclusion questioned however by Durig (1909), is decidedly interesting. Smith has also an excellent discussion of the percentage cost of the total energy expenditure in walking due to step lift. He found that step lift accounted for about nine per cent of the energy expended in horizontal walking at a rate of 43 to 48 metres per minute, about 11 per cent at 52 to 58 metres per minute, 15 per cent at 60 to 68 metres per minute, over 16 per cent at 71 to 73 metres per minute, and 18 per cent at 76 to 78 metres per minute. These results would be of prime importance if the question arose of altering the nature of the gait with a view to reducing the cost of marching. The "pas de Raoul" or "marche en flexion" is a case in point—see also Cathcart and Orr (1919).

(*To be continued.*)