LOAD CARRIAGE BY INFANTRY SOLDIERS

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ABSTRACT

At constant speed of marching, oxygen consumption has been found to increase linearly with the amount of load carried, indicating that there is no optimum load. However, an optimum speed of marching has been found, depending on the terrain condition. A different line of approach, involving a study of the relationship between stride-length, frequency of stepping and speed in normal walking and the effect of muscular fatigue on this relationship has also yielded similar results. Desirability of further studies on the effect of load on optimum speed of marching, effective reduction of weight of equipment and optimum distribution of load on the body has been stressed.

Introduction

The need for a satisfactory solution of the ever important problem of load carriage by infantry soldiers in relation to different climates and terrain conditions has been widely felt in our country as well. A soldier at the end of a marching spell must maintain his fighting efficiency and as such it is important to know, not only the amount of load he can safely carry, but also the proper marching speed with reference to his load, the terrain conditions and the specific task ahead of him.

It is also necessary to know the most economic way of distributing the load on the body to ensure minimum energy expenditure and fatigue. The environmental heat load as an additional liability should also receive due consideration.

The object of the present paper is to indicate briefly the progress made so far in this laboratory regarding some aspects of the problem.

Energy Expenditure as a Criterion

The various items and their weights, in the equipment normally carried by an infantry soldier are shown in table I.

According to the present service standard, the load to be carried by a soldier should not exceed one-third of his body weight. This is based on Cathcart et al's[1] work, in which they have reported that, under laboratory conditions at constant speed, the mechanical efficiency is maximum for a load of 40 per cent of body weight, beyond which the energy cost shows a rapid rise with load. Our critical analysis[2] of their original data indicates that their conclusions are not justified by the data. Our observations show that oxygen consumption cannot be taken as a criterion for the determination of optimum load, because it gives a more or less linear relationship with the load carried, within the observed range of about 50 per cent of body weight, although near the upper limit, symptoms of severe fatigue have been noticed.

TABLE I

Load carried by Infantry Soldier.

The Infantry School, Mhow, April, 1957

	Weight lb.	oz.
A. *Battle Order—*		
1. Personal Clothing, eqpt., arms & ammunition	36	7
2. Haversack & Contents	13	0
Total	49	7
B. *Field Service Marching Order—*		
Pack & Contents	16	0
Total (A+B)	65	7
In addition, Pick or Shovel may have to be carried	5	0
Rifle	9	7
Light Machine Gun	19	0

Usual marching speed—3 m.p.h., with 10 minutes rest after every 50 minutes marching, covering 5 miles in 2 hours.

During these studies, we have found it convenient to introduce the concept of "Effective body weight" as an important factor determining the efficiency of load carriage. This has been defined as that weight which when carried as an extra load, causes the same extra energy expenditure as in carrying the body weight alone. It is estimated by dividing the extra oxygen cost while marching without load by the oxygen cost per pound of extra load carried, at the same constant speed.

It has been found[3] that the oxygen consumption is linearly related with pulmonary ventilation rate, the slope being characteristic of the individual. It, therefore, seems possible to avoid tedious and time consuming measurements of oxygen consumption, especially during field trials.

Optimum Marching Speed

It has been theoretically established by Hill[4] that for any type of muscular work of a periodic nature, there exists an optimum rate, characteristic of the nature of work, requiring a minimum energy expenditure for a given amount of total work. We have studied the optimum rates for three different forms of muscular exercise, baithaks[5], stepping up and down a stool and cycling. Results of our study[6] show that Hill's theoretical equation can be replaced by another simple equation fitting the data with reasonable accuracy. It is of the form $O-O_0=m\,(\log R/R_0)^2$, where O is the oxygen requirement for a fixed amount of work at the rate R, O_0 and R_0 being the corresponding values at the optimum.

The constant 'm' should obviously depend on the amount and nature of work as well as on the unit in which O is expressed.

The energy cost of marching without load at different speeds, has been studied by us[7] for two different types of ground. Results indicate an optimum speed of about 3·5 m.p.h. on hard level ground and about 2·5 m.p.h. on loose, dry, sandy soil. The critical speeds beyond which oxygen consumption shows an abrupt rise with speed, are about 3·9 m.p.h. and 2·8 m.p.h. respectively for the two types of ground. An interesting finding is that the oxygen consumption at the corresponding critical speed is practically same for both types of ground. The effect of varying load on the optimum speed has yet to be studied.

Stride Length, Frequency of Stepping and Speed

A different approach to the problem was made by studying the quantitative relationship between stride length, frequency of stepping and the marching speed[8]. Since speed is controlled by both stride length and frequency of strides, it was assumed that both take an equal part in normal walking. This led to the deduction that each factor should vary directly as the square root of speed, the constant of proportionality depending on the leg length and hence height of the individual. Observations taken on 13 normal male adults in the height range of 60″ to 72″ have confirmed our findings within the range of normal walking speeds. Beyond a certain critical speed, the balance is upset resulting in a disproportionately large increase in stride length compared to frequency for a given increase in speed, so that the $\sqrt{V}$ law is no longer obeyed. The same is true at very low speeds, suggesting that there is a radical change in the pattern of walking beyond the normal range. The critical speed beyond which the $\sqrt{V}$ law fails has been found to agree with that based on oxygen-consumption, as discussed earlier. With the onset of muscular fatigue, a similar change in the relationship is observed leading to a failure of the $\sqrt{V}$ law[9]. It is, however, interesting to note that at a certain speed within the normal range, practically same as the individual's natural speed, the effect of fatigue is not reflected in the values of stride length and frequency of strides. It has also been noted that this natural speed is very close to the optimum speed as determined from energy cost. At any given speed other than the natural, the percentage change in stride length due to fatigue can be taken as a rough measure of the degree of fatigue. It also seems to be related to the physical efficiency of the individual as determined by other methods [5,10]. It is yet to be seen whether the results can be generalised for different types of muscular work.

Oxygen-extraction During Work

In a series of observations[11] taken on four subjects engaged in progressively increasing grades of activity, the relation between oxygen extraction and pulmonary ventilation was studied for different types of exercise. The oxygen extraction was found to increase with increasing pulmonary ventilation, touch a peak value and then gradually decline with further increase in pulmonary ventilation. It appears that there is an optimum grade of work depending on the individual and the nature of work, for which oxygen extraction is maximum.

Conclusions

It has been established that oxygen consumption cannot be taken as a criterion for the determination of optimum load. But some suitable criterion should be found, because with heavy loads symptoms of severe fatigue have been noticed. Further studies on oxygen extraction during work seem desirable in this connection.

Different methods of approach lead to a fairly accurate estimate of optimum speed of marching without load which is about 3·5 m.p.h. for hard level ground and about 2·5 m.p.h. for loose, dry, sandy soil. The critical speeds for these two types of ground above which oxygen consumption shows a rapid rise, are about 3·9 m.p.h. and 2·8 m.p.h. respectively, the oxygen consumption being practically same at these limits. Effect of load on the optimum and critical speeds should also be studied.

The results can be interpreted in terms of the balanced relationship between stride length and frequency of strides in normal walking. Beyond the critical speed, the balance is upset changing the very nature of walking. Muscular fatigue is also found to have a similar effect.

While the desirability of reducing the total weight of the equipment carried by a soldier cannot be ignored, substantial reduction is not possible within the limitations of operational requirements. Hence efforts should be concentrated on the design of the load carrying equipment, for which studies should be undertaken on the optimum distribution of load on the body which might result in a minimum energy expenditure, delayed on set of fatigue, and maximum comfort and operational efficiency. Preliminary observations[12] undertaken in this laboratory indicate that in terms of energy expenditure, one pound of load carried on the legs is equivalent to 5 to 7 lbs. carried on the back, individual variation being considerable.

In all future studies on load carriage, the speed and terrain conditions should be kept in view. Uphill marching with load should also receive special consideration.

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