LOAD CARRIAGE BY INFANTRY SOLDIER—CRITERIA FOR ASSESSMENT OF PHYSIOLOGICAL AND PSYCHOLOGICAL FATIGUE

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Load Carriage by Infantry Soldiers is an important problem concerning the Army. This study attempts to evolve suitable criteria for assessing the physiological and psychological fatigue at the end of a given task in field studies pertaining to load carriage. Fifteen tests, physiological and performance which included assessment of Blood Pressure, Respiration Rate, Pulse Rate, Erythrocyte Sedimentation Rate, Eosinophil Count, Harvard Step Test, Energy expenditure during work, Motor Reaction, Cancellation Test, Target Hitting, and Weight Discrimination were tried. Among the various tests studied, there was a consistently progressive fall in eosinophil count with increasing levels of fatigue. The 'pulse recovery index' which was a measure of the rate of pulse recovery after exercise, was lower with higher levels of fatigue. All the other tests in their present form were found unsuitable as tests of fatigue.

One of the important problems facing our army is load carriage by infantry soldier, a reasonable solution of which would help the soldier to remain fighting fit after marching across a long and difficult route in the operational areas. Two things are essential for success in war : (*i*) power of undertaking rapid load marches without loss of number and energy[1], and (*ii*) ability of the infantry to reach its destination in the best possible condition for engaging in hand-to-hand combat. The above factors depend ultimately on the successful solution of the problem of load carriage. Although carrying zero load is the optimum condition for movement, the soldier has to carry a certain amount of load in the form of ammunition, fuel, clothing, etc which is dictated by tactical needs of an operation, terrain and climate.

Earlier studies in this laboratory have revealed that the most economic speed of marching with a load of 34 lbs where energy expenditure is taken into consideration is 3·15 mph on hard level ground and 2·29 mph on dune sand. Ramaswamy[2] had reported that with a given load, the optimum speed of march comes down with increase of gradient. It was further reported by him that in the same gradiant the optimum speed comes down with increase in load. While the load to be carried by a soldier is fixed, the best that can be done is to find out the most economical mode of carrying it so as to leave the soldier quite fit for action at the end of the march. The problem thus reduces to finding the optimal conditions of carrying load on the body of the soldier taking into consideration the speed of march, the distance and the terrain over which the load is to be carried so as to cause the least physiological stress.

When undertaking such studies, it is essential to ensure that there are suitable sensitive indices to measure the degree of fatigue which results from such load march. For this purpose, a study was planned to evolve suitable criteria for assessing physiological and psychological fatigue at the end of a given task. The results of this study are presented in this paper.

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MATERIAL AND METHOD

8 ORs (age : 20–30 years, height : $66\frac{1}{2}$–$69\frac{7}{8}$ in. and weight : 113–145 lbs; all clinically normal), were used as test subjects. Everyone of these was subjected to two degrees of fatigue (*i*) relatively less severe, and (*ii*) more severe. The less severe fatigue was induced by making the subject walk on the treadmill (fixed load : 50 lbs inclusive of clothing, boots etc; speed : $3\pm0\cdot1$ mph) for a period ranging from 45 minutes to 1 hour. The more severe fatigue was induced by subjecting the individual to walk for a further period ranging from 45 minutes to 1 hour. The two periods of walking were not continuous—there being an interval of 15–20 minutes between them during which the tests were performed.

The experiments were performed in 3 Series : Series I—The treadmill was set at a gradient of 5° to the horizontal. The fatigue at the end of the second walking session was considered severe but appreciably below the point of exhaustion. Series II—The treadmill was set at a gradient of 8°. The degree of fatigue at the end of the second walking session was quite severe and was considered to be approaching the point of exhaustion. However, the second walking session being left to the discretion of the subject, its duration varied from 30–60 minutes with the majority of the subjects stopping the exercise before the expiry of 45 minutes. Series III—The treadmill was set at a gradient of 8° and the duration of each walking session was 1 hour. Many of the subjects needed much persuation to complete the second session of 1 hour duration.

The experimental conditions including the environmental temperature during these three series of physiological and psychological tests were almost identical.

The following tests were carried out before and after each walking session :

Blood pressure and respiration rate were determined 1 minute after the end of each walking session with subject in sitting posture. Pulse rate was counted 30 seconds after the end of each walking session in series I, and 45 seconds after in series II and III. Oral temperature was recorded with the help of clinical thermometer kept under the tongue for about 3–4 minutes towards the end of each walking session. Erythrocyte sedimentation rate was determined by Westergreen method on blood drawn about 4 minutes after the end of the walking sessions. Total eosinophils were counted in Neubauer counting chamber on blood drawn about 8 minutes after the end of the walking sessions in series I, and about 4 minutes after, in series II.

Energy expenditure during exercise was determined by indirect calorimetry by collecting expired air samples in Douglas bag towards the end of the walking sessions. The samples were analysed in a Haldane gas analysis apparatus. Resting values were taken in the standing position before beginning the exercise.

Immediately at the end of the treadmill exercise in series III, the subjects were made to rest in a setting position and their recovery pulse was counted during the periods 1–$1\frac{1}{2}$, 2–$2\frac{1}{2}$, 3–$3\frac{1}{2}$ and 4–$4\frac{1}{2}$ minutes while the subjects were resting in the sitting position. The difference between the half-minute recovery pulse counts obtained during the periods 1–$1\frac{1}{2}$ and 4–$4\frac{1}{2}$ minutes was calculated. This difference could be taken to be a measure of the rates of pulse recovery and was termed the *pulse recovery index.*

A modified form of the Harvard Step Test was administered in order to assess the physical fitness status of the subjects. In series I and in the first part of series II (shown as

II(a) in Table 1), the subject stepped up and down a 16 inches high stool for 5 minutes at the rate of 30 cycles per minute, after which the recovery pulse during the periods $1\text{–}1\frac{1}{2}$, $2\text{–}2\frac{1}{2}$ and $4\text{–}4\frac{1}{2}$ minutes were counted. In the second part of series II (shown as II(b) in Table 1) and in series III, the subject walked for 5 minutes at 4 mph on the treadmill set at a gradient of 8°, after which the recovery pulse was counted as before. The fitness index(S) was calculated thus :

$$S = \frac{50 \times \text{stepping or running time in seconds}}{\text{sum of the three } \frac{1}{2} \text{ minute pulse counts}}$$

The test was carried out exactly 1 minute after the end of the walking sessions in series I, 10–11 minutes after the exercise in series II and 6 minutes after in series III.

PERFORMANCE TESTS

The performance tests consisted of a battery of six tests :

Dial test—In this test, the apparatus consisted of a stool and four electric switches fixed at approximately floor level at suitable distances from the stool. The first switch was on the right side of the subject towards the front, the second on his right side towards the back, the third on his left side towards the back and the fourth on his left side towards the front. The distances of the switches were so fixed that the subject had to bend and extend his arms to the maximum in order to operate the switches. The subject sat on the stool and starting with the right side front, he applied the switches one after another, going round in the clock-wise direction. The time required to complete 40 rounds was noted. The test was performed about 10 minutes after the end of walking sessions in series I and about 6 minutes after, in series II.

Magazine test—This test consisted in alternately filling and emptying out 19 dummy rounds in the Brengun magazine. The time taken for 20 cycles of filling and emptying was recorded. The test was carried out about 10 minutes after the end of walking sessions.

Motor reaction time test—The motor reaction time was estimated in the performance of a task of a vigilant nature. The subject was asked to remain alert and keep a strict watch on the glowing of a lamp kept a few feet away. He was instructed to press a switch immediately after the glow was seen. The intervals between the consecutive presentations of stimulus were varied at random. Duration of the test was about 15 minutes. Data were recorded, using a graphic method, after a warming-up period. Sample for analysis was collected from the graphic record, at random. In series I and II, the test was conducted after the subject had completed the treadmill walking and started on the recovery stage. In series III, the test was conducted towards the end of the treadmill walking, while the subject continued with the exercise.

Geometrical figures test—Cancellation of geometrical figures was a task which required concerted attention, clear perception and quick action. The apex of an isosceles triangle was oriented 30° and twelve different positions were identified. A chart from a random

TABLE 1

MEAN VALUES OF SCORES IN DIFFERENT TESTS

(Speed of walking : 3 ± 0·1 mph; Load : 50 lb)

Test Subjects : Mean body wt = 128 lbs; mean ht 5 ft. 5 in ; mean body surface area = 1·65 m²

Series	Mean ambients	Stages of observations	Blood pressure (mm of Hg)	Respiration rate/min	ESR	Dial test (sec)	Magazine test (sec)	Oral temp (°F)	Eosinophil count (cu. mm)	Pulse/min	Physical fitness (a)*	Physical fitness (b)**	Energy expenditure (Cal/m²)	Pulse recovery index
I	D.B. Temp †92°F	Initial	123/78	17	3	262	143	99·1	250	80	60·3		58	
Gradient	(90°—95°F)	Intermediate	142/92	27	3	265	139	99·6	200	121	51·2		280·	
5°	W.B. Temp†† 76°F (73°—78°F)	Final	143/75	29	3	261	135	99·3	150	135	47·7		282	
II	D.B. Temp 84°F (82°—87°F)	Initial	118/75	19		248		98·4	250	75	(a) 63·5	(b) 94·0	58	
Gradient	W.B. Temp 65°F	Intermediate	162/88	32	Not done	254	Not done	98·5	190	121	52·6	90·7	282	
8°	(64°—76°)	Final	164/89	33		257		98·6	70	122	50·4	90·5	255	
III	D.B. Temp 80°F (76°—82°)	Initial							146	74		90·8	60·5	
Gradient	W.B. Temp 64°F	Intermediate	Not done	Not done	Not done	Not done	Not done	Not done	105	127		82·5	324·1	13
8°	(62°—67°)	Final							61	125		80·6	301·7	7

†Dry bulb temperature.

†† Wet bulb temperature.

*Arbitrary physical fitness score assessed from the modified Harvard Step Test.

**Arbitrary physical fitness score assessed from the Treadmill Running Test.

sample of those positions was drawn up. The subject was directed to cancel the figures with specified degrees of inclination. The task was for a duration of about five minutes and the record of last three minutes were taken into consideration for analysis. The scores were calculated on the basis of correct or wrong response and speed of cancellation.

Target hitting test—Target hitting task required eye-hand coordination. The subject was instructed to hit the bull's eye charted out on a paper by a pencil from equal distances once every second as guided by a metronome. Each target comprised five circles and different scores were given to it. Ten such targets were designed on each chart. Three repetitions on one chart were taken to be one set of reading.

Weight discrimination test—Weight discrimination was a task which required sustained attention and sharp tactile sensitivity. Objects of identical shape, size and colour, were weighed and twelve such objects were selected for discrimination. A set of six weighed 9 gm and the other set weighed 13 gm. The subject was instructed to discriminate 10 out of the assorted 12, leaving two untouched. The objects were presented for a number of times but records of only five presentations were noted at random for measurements of distraction and incorrect perception.

RESULTS AND DISCUSSION

The results have been summarised in Table 1. Series I, II and III give the mean of 8, 22 and 6 readings respectively. The values for each test were taken at three stages: (*i*) initial—just before the start of exercise, (*ii*) intermediate—at the end of the first walking session, and (*iii*) final—at the end of the second walking session.

Blood pressure—In series I and II blood pressure, both systolic and diastolic, showed a rise over the initial value as a result of exercise. The diastolic pressure showed less pronounced rise, resulting in an increase of pulse pressure. The mean post-exercise systolic pressure in series I and II was 140 and 160 mm respectively. The lower value in series I was probably due to the fact that the work load was lower than that in series II. However, very low differences were seen between intermediate and final values. The output of the heart may increase manyfold with the increase in pulse rate and one would expect a parallel rise in blood pressure in the same proportion as the cardiac output; but the rise in BP from intermediate to final values was relatively small showing that the pheripheral resistance in exercise was decreased[3]. This indicated that the test did not reflect the degree of fatigue.

Respiration rate—A rise in respiration rate as a result of increased work load was observed but there were negligible differences between the intermediate and final values indicating that the test did not reflect the degree of fatigue.

Pulse rate—Pulse rate showed a rise due to work load in all the series from the initial to the intermediate value. In series I the final pulse rate was higher than the intermediate value but this was not true in series II and III where the intermediate and final pulse rates were almost equal. It was also observed that the intermediate pulse rates in series I and II were the same on the average in spite of the fact that the work load in series II was higher. This might have been due to the fact that in series II the pulse count was taken 45 seconds after the end of exercise whereas in series I it was taken after 30 seconds. These results indicate that pulse rate (though related to work load) does not reflect the degree of fatigue, *Erythrocyte sedimentation rate (ESR)*—Significant lowering of ESR as a result of load march during a field trial has been reported[4]. However, in the present study, there was no change in ESR either due to work stress (initial to intermediate value) or due to different levels of fatigue (intermediate to final value).

Eosinophil count—Eosinophil count has been reported to drop as a result of physical stress[3,5-8]. One of the reasons for its decrease is the liberation of corticosteroids from the adrenal glands. The depth of eosinophenia may be taken as proportional to the severity of stress. For exercises of different durations, the decrease in the total eosinophil count was found to be somewhat related to the duration of the exercise. In all the series in the present study, there was a decrease in eosinophil count (from initial to intermediate values) as a result of exercise. It was further observed that in all the three series the final value was appreciably lower than the intermediate value; also, the final values in series II and III were lower than the final value in series I, thus indicating that the test could differentiate between levels of fatigue. The test may, therefore, be used as an index for assessing the degree of fatigue.

Energy expenditure—In series I, the intermediate and final values of energy expenditure were about the same. This was considered reasonable as the limit of exhaustion was not reached and both tasks were performed as on 'steady state level'. The intermediate value in series II was nearly the same as intermediate value in series I. The work load in series II was higher than in series I and was expected to yield a higher value for energy expenditure. However, actually this was not so. An unexpected finding was the fall in energy expenditure from intermediate to final value in series II and III. It was observed that, particularly during series II and III, where gradient was higher than in series I, the subjects tended to support themselves on the treadmill railings towards the end of the exercise. This factor could not be controlled properly. The unexpected values for energy expenditure observed in series II and III might have been partly due to this.

Physical fitness score—Harvard Step Test or its modification is widely used as a test of physical fitness in terms of cardiovascular efficiency[5]. In all the three series there was a fall in the fitness index from initial to intermediate. From intermediate to final, the fall was either much less or nil. This would indicate that the test could differentiate the fatigued from the unfatigued state but could not assess the actual degree of fatigue.

Pulse recovery index—Pulse recovery index was used only in series III. There was a decrease in the value of the index from intermediate to final indicating that pulse recovery was delayed as the degree of fatigue was increased. It has been reported that in untrained subjects the recovery pulse is more delayed than in trained individuals[9]. This test may prove useful in assessing the degree of fatigue.

Oral temperature—In the two series tested, the oral temperature observed did not seem to have any relation with the degree of fatigue.

Dial test—Little change in the value of Dial test was shown in either of the two series tested. It was hoped that this test might indicate an impairment in performance due to fatigue particularly of the muscles of the trunk and the upper extremities.

Magazine test—The performance of magazine test showed a slight progressive fall from initial to final. However, the magnitude of the change was very low.

Motor reaction time—In series I and II the test was done in the sitting position after the subjects had completed the treadmill task. The initial, intermediate and final values of reaction time in series I (mean of 280 readings) were 412, 413 and 426 milliseconds respectively with 45, 44 and 45 as their standard deviations. These values in series II (mean of 600 readings) were 367, 379 and 383 milliseconds respectively with 41, 47 and 50 as their standard deviations. In series III the test was done during the exercise on the treadmill towards the end of each walking session. The three values (mean of 600 readings) were 430, 433 and 430 milliseconds respectively with standard deviations of 43, 44 and 38. In none of the series were the three values of reaction time significantly different from one another. The results of this test, therefore, did not differentiate between levels of fatigue.

Cancellation of geometrical figures—The mean values of cancellation scores of 15 readings taken before and after the induction of the two levels of fatigue showed an improvement of 15 and 17·5 points respectively from the initial. The improvement was relatively more from initial to intermediate than from intermediate to final.

Target hitting task—The initial, intermediate and final values (mean of 45 readings) of target hitting were 107, 105 and 103 out of 150 marks. The fact that the test called for a very short resistance to tension, and brief bursts of power kept up motor coordination, may explain why no differences were observed as a result of physical fatigue.

Weight discrimination—The results of weight discrimination test did not also show any change in the degree of physical fatigue. The mean scores of 15 sets of readings were 78, 78 and 76 out of 100.

CONCLUSION

From the results it is seen that there was a consistently progressive fall in total eosinophil count with increasing levels of fatigue. The pulse recovery index which is a measure of the rate of recovery of pulse after exercise, showed a tendency to be lower with higher level of fatigue. Hence these two tests would appear to be useful in assessing the degree of fatigue. All the other physiological, psychological and performance tests in the present form were found to be unsuitable for this purpose.

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