International Journal of Industrial Ergonomics 44 (2014) 260–265

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Optimum load for carriage by Indian soldiers on different uphill gradients at specified walking speed

Madhu Sudan Pal, Deepti Majumdar, Anilendu Pramanik, Bodhisattwa Chowdhury, Dhurjati Majumdar*

Defence Institute of Physiology and Allied Sciences, Defence Research & Development Organisation, Min. of Defence, Govt. of India, Lucknow Road, Delhi 110054, India

A R T I C L E I N F O

Article history:
Received 1 June 2012
Received in revised form
11 March 2013
Accepted 13 September 2013
Available online 5 February 2014

Keywords:
Load carriage
Gradient
Maximum permissible load
Oxygen uptake
Physiological cost
Heart rate
Soldier

A B S T R A C T

Physiological responses of soldiers while carrying different loads were studied to suggest maximum weight that can be carried by an Indian infantry soldier comfortably at different gradients at specific walking speed. Ten physically fit infantry soldiers walked at 4.5 km h^{-1} on treadmill (0%, 5%, 10% and 15% gradient) without and with loads of 4.4, 10.7, 17.0 and 21.4 kg. At each gradient, all the loads including without load were experimented for 10 min. Heart rate (HR), oxygen consumption ($\dot{V}O_2$), energy expenditure (EE), respiratory frequency (RF) and minute ventilation ($\dot{V}E$) were determined using $K4b^2$ system. A linear increase in HR, $\dot{V}O_2$, EE, RF and $\dot{V}E$ with increasing gradient and external load was observed. Based on physiological limit of 50%, 60% and 75% of $\dot{V}O_{2max}$ and linear regression equations optimum loads are suggested as permissible for carriage on different gradients by Indian soldiers at above speed. This combination of weight and gradient would improve the combat readiness of soldiers while carrying load.

Relevance to industry: Most of the developing countries do not have load carriage standards, for either Industry or Military personnel and extrapolation of the data from developed countries do not seem feasible. Results of this study may be applicable in developing standards or in recommending optimal loads for similar populations under similar conditions.

1. Introduction

The physiological cost of load carriage at level walking and different gradients has been investigated by many researchers (Sagiv et al., 2000; Pal et al., 2007; Abe et al., 2008; Bastien et al., 2005; Legg et al., 1992; Wu, 2006; Chow et al., 2009, 2011; Cho and Kima, 2012). However, in most of the studies load was placed as single compact unit and carried as backpack or rucksack. In military environment load is carried as multiple units such as combinations of haversack, backpack, web and rifle mainly in the upper torso as per their requirements. These units vary in shape, size and weight and may lead to unequal distribution of load over body and changes in gait pattern of an individual (Attwells et al., 2006; Ryu et al., 2006; Majumdar et al., 2010) which is known to cause increased energy demand and early onset of fatigue. To date, physiological studies of load carriage (as practised by soldiers) in military environment are limited and less reported, especially with varying gradients. Pal et al. (2009) suggested optimum load for carriage by Indian soldiers on level ground at specified walking speeds. No study of load carriage at varying gradients by Indian soldiers is reported. Similarly, load carrying standards, e.g., optimum loads are not available at different gradients. So far, physiological responses of Indian soldiers while carrying load carriage at varying gradients (uphill) have not been reported and no standard for optimum load carriage at different gradients is presently available.

Carrying heavy loads over unpredictable terrain for long distances is a requirement common to military personnel (Liu, 2007). The platoon's combat load varies by mission and includes the supplies physically carried into the fight. Present day soldiers need to carry more equipment, supplies, and ammunition than earlier days to enhance sustenance for longer duration. Manual load carrying by Indian soldiers is often necessary in the remote countryside and mountain areas of India as these areas are mostly inaccessible by vehicle. In these areas soldiers need to carry materials such as arms, ammunitions, rations, clothes and first-aid dressing for survival and at the same time ensuring the maintenance of their work capacity and combat readiness. However, the

* Corresponding author. Tel.: +91 11 23935745; fax: +91 11 23914790.
E-mail address: majum55@yahoo.com (D. Majumdar).

0169-8141/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ergon.2013.09.001

authors are unaware of any reported studies so far that have simultaneously analyzed the effect of both load placement and gradient on cardiorespiratory responses of soldier's while carrying loads on different parts of the body. As load carrying capacity of an individual depends on walking speed and gradient, identification of the optimum load for a specific speed with different gradients is of utmost importance in deciding the combat readiness of soldiers.

Carrying loads by troops is an important aspect of military operations that may prove to be very critical under some circumstances. Overloading of soldiers with ammunition and equipment may lead to discomfort, excessive fatigue, injuries and impair soldier's ability to fight. Therefore, identification of optimum load is important in order to take preventive action to reduce the incidences of common injuries associated with load carriage, excessive fatigue and impairment of the soldier's ability to fight. Scott and Christie (2004) proposed that military marches should be conducted under 'steady state' at an intensity that does not exceed 50% of maximum aerobic capacity ($\dot{V}O_{2max}$), thus ensuring that soldiers are combat efficient. Vogel et al. (1980) recommended that if any task required a work rate of 60% $\dot{V}O_{2max}$, it may be sustained for approximately 2 h, whereas tasks that require work rate of 75% $\dot{V}O_{2max}$ should not exceed approximately 30 min duration. If a soldier is exhausted from carrying a load, he may be unable to perform when he reaches the site of conflict. To ensure the most efficient use of energy, the planning for any load carrying should take into account the elimination of local strain, injuries and fatigue. The greatest concern of military researchers is to establish the conditions at which soldiers can perform prime functions of military exercises, maximally and efficiently, both during and after load carriage. Hence, present study hypothesized that load carriage on a positive gradient would increase cardiorespiratory responses compared to load carriage on a level gradient. The effect of gradient on cardiorespiratory responses of soldiers was assessed while carrying military loads and to estimate the optimum or maximum permissible load (within physiological limit of 50%, 60% and 75% $\dot{V}O_{2max}$) that can be carried comfortably on various gradients at a specific walking speed.

2. Methods

2.1. Participants

Ten physically fit, nonsmoker, experienced (4+ years) male infantry soldiers from the Indian Army volunteered for the study. Mean age was 23.2 (SEM 0.83) years, height 172.6 (SEM 1.20) cm, weight 65.9 (SEM 2.24) kg and maximum aerobic capacity ($\dot{V}O_{2max}$) 47.5 (SEM 1.40) ml min^{-1} kg^{-1}. They had no history of musculoskeletal or cardiovascular pathology. All volunteers provided informed consent to participate in this investigation. The study protocol was approved by the Institutional Ethical Committee on the use of Human as an Experimental subjects and experiment conforms to the principles outlined by the Declaration of Helsinki protocol, 1964.

2.2. Experimental details

On the first day, soldiers were briefed about the purpose of the study. They were then habituated to walking on the motorized treadmill (Taeha, Intertrack 6025, Korea) at various gradients in the laboratory, with and without loads at 4.5 km h^{-1} walking speed. Habituation process continued on the second day also. One day of rest was given on the next day.

Maximum aerobic capacity ($\dot{V}O_{2max}$), of the subjects was measured during treadmill exercise with regular increases in gradient (Harbor Protocol, Wasserman et al., 1994), while keeping the speed constant on fourth day. During measurement of $\dot{V}O_{2max}$, each subject walked on treadmill at 0% gradient for 3 min at self selected comfortable walking speed. After 3 min of walking at comfortable speed chosen by the subjects, every minute the treadmill gradient was increased by 4%, so that the subject reaches $\dot{V}O_{2max}$ approximately in 10 min. A valid $\dot{V}O_{2max}$ was obtained when at least two of these three criterions were met: i) maximum heart rate (HR) > 90% of age predicted maximum HR (220 beats min^{-1} − age), ii) Respiratory Exchange Ratio (RER) of at least 1.10 and iii) plateau in oxygen consumption ($\dot{V}O_2$, <200 ml min^{-1} change) with increasing work rate (You et al., 2004). Mean (SEM) values of RER and HR at maximum $\dot{V}O_{2max}$ were 1.24 (0.018) and 189.9 (1.038) beats min^{-1}, respectively. During the measurement of $\dot{V}O_{2max}$, subjects wore a vest, underwear and physical training (PT) shoes. Subjects took rest on the fifth day.

Table 1
Details of type, combination and placement of load for load carriage experiments.

Load (kg)	Contents	% Body weight (BW)
0	No load (NL)	0
4.4	4.4 kg Haversack on back	6.7
10.7	4.4 kg Haversack on back + 2.1 kg Web in front of waist + 4.2 kg INSAS rifle in right hand	16.2
17.0	10.7 kg Backpack + 2.1 kg Web in front of waist + 4.2 kg INSAS rifle in right hand	25.8
21.4	10.7 kg Backpack + 4.4 kg Haversack on left lateral side of the waist + 2.1 kg Web in front of waist + 4.2 kg INSAS rifle in right hand	32.5

Load carriage experiments were carried out from sixth day onwards. The loads and gradients were assigned randomly to the subjects on different day. On the day of load carriage experiment the subjects reported to the laboratory at 8.00 a.m. after light breakfast and the experimental procedure was initiated after about 90 min of rest. They abstained from smoking or taking any food as long as they were in the laboratory. During the load carriage experiment all subjects wore full Infantry Uniform including combat boots and helmet. Load carriage experiments were carried out on each subject while carrying no load (NL, 0 kg) and loads of 4.4, 10.7, 17.0 and 21.4 kg at 0%, 5%, 10% and 15% gradient, respectively at medium pace (4.5 km h^{-1}) walking speed (Ganguli, 1973) on a treadmill. Details about load items and their placement on the body along with percentage of body weight (BW) are given in Table 1. At each gradient and load including NL, the experiment was carried out for 10 min duration. In this study, load carriage operations were carried out in the laboratory which simulated the operational loads carried under field situations. Carried load corresponded to 6.7% (for 4.4 kg load), 16.3% (for 10.7 kg load), 25.8% (for 17.0 kg load) and 32.5% (for 21.4 kg load) of the average body weight (BW) of the subjects studied. In total, each participant underwent 20 experiments (four gradients and five load conditions including no load), and was required daily to complete two exercise trials (10 min each) from 0930 h to 1300 h, with at least 90 min rest between two exercise trials to eliminate cumulative effect of first exercise trial on second trial.

2.3. Physiological measurements

All load carriage experiments were conducted in a controlled laboratory environment of 22–25 °C, 50–55% relative humidity and at the same hour of the day (between 0930 h and 1300 h) and every day for eliminating the specific dynamic action (SDA) of food for all practical purposes. The load carriage ensembles (LCe) used in this study was regularly used by Indian Infantry soldiers. Each subject used the same LCe and rifle during the experiments.