Cardio-Respiratory and Metabolic Changes during Continuous Uphill-Downhill Load Carriage Task

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ABSTRACT

Indian Army soldiers are deployed in hilly and mountainous regions of eastern and western part of the Himalayas to guard the borders. In this context they are required to march uphill and downhill with moderate to heavy load continuously for long duration. The physiological cost of such activities has been of specific interest for maintenance of optimum soldier performance. Studies on physiological changes during continuous uphill and downhill climbing are rare. A study was therefore undertaken to find the effect of uphill and downhill walk with load on the physiological parameters in laboratory conditions. Twelve soldiers with mean (± SD) age- 26.8 (± 3.9) yrs, height- 170.6 (± 3.2) cm and weight 66.2 (± 6.8) kg participated in the study as volunteers to measure the energy cost and physiological changes of continuous uphill and downhill load carriage task. The soldiers were subjected to treadmill walking at a speed of 3 km/h. They had to undergo continuous uphill walking at 0, 5, 10, 15 and 20% gradients and downhill walking in the opposite manner. Participants walked 6 mins in each gradient. Total duration of walk was 60 min. The volunteers carried 10.7 and 21.4 kg load beside without load. Oxygen consumption (VO_2), Heart rate (HR), and energy expenditure (EE), were measured breath by breath using Metamax 3B system throughout the test. Relative work load (RWL, $\%VO_2max$) was calculated as percentage of VO_2max. Repeated measure ANOVAs were used to predict level of significance across the experimental conditions. The mean (± SD) VO_2max of the participants was found to be 52.6 (± 3.8) ml/min/kg. All the physiological parameters increased significantly with the increase in uphill gradient irrespective of the loads. VO_2, EE and $\%VO_2max$ decreased till 5% downhill gradient, but slight increase was observed at the level walking. HR continued to decrease till the downhill walking reached 0% gradient with and without load. Relative work load reached above the recommended limit (35% of VO_2max) at 10% and above uphill gradients in both the load conditions. This information will be helpful in making strategy for designing uphill and downhill load march in mountains for Army personnel and hitch hikers.

Key words : Load carriage, uphill walking, downhill walking, $\%VO_2max$.

INTRODUCTION

There has been a long history of military concern relative to load-carrying. The problem is not trivial because manual load carriage is a universal activity and an inevitable part of the daily schedule of a soldier. Indian Infantry soldiers carry loads on the waist, back, shoulders and in the hands for a marching order [1]. The soldiers have to operate with this load in different terrains. The complexity of terrain such as climbing up and walking down a hill or mountain with load is a part of the soldier's routine activity. The energy expenditure measured by oxygen consumption of such a load march has drawn attention of scientists as the soldier has to be ready for the battle after that. Anything that could further deplete their energy levels or increase the onset of fatigue must be carefully characterized. These negative impacts on soldiers' performance have to be sorted and physiological cost of this kind of activity has to be quantified [2].

Continuous fluctuations in walking surface properties are often in natural surroundings, which include modifications to surface slope, navigation of stairs, alterations in stiffness and changes in direction. Margaria [3] pioneered the physiological study of sloped walking. He found that during uphill (UH) walking at a constant speed, metabolic rate increases linearly with slope. During downhill (DH) walking, the metabolic rate decreases until about -6° and then inflects and is actually greater for -9° and steeper slopes. More recently, Minetti and colleagues have further explored both the mechanical work output and metabolic cost during DH and UH walking at a variety of speeds [4]. They reported that during DH walking at -9°, positive work was less than 5% of the total external work, whereas during UH walking at +9°, positive work was almost 100% of the total external work. At UH angles above +9°, the trajectory of the center of mass increased steadily and external mechanical work was entirely positive [4]. Subsequently, Minetti and colleagues reported that mechanical energy exchange is less effective during both DH and UH walking [5].

Studies on physiological changes during continuous uphill (UH) and downhill (DH) walking with load are rare and less cited in the literature. The primary objective of the present study was to find out the cardiorespiratory and metabolic changes during continuous UH and DH walking in treadmill in simulated laboratory conditions. A guideline for load carriage in mountainous terrain is also aimed. The findings of the study will be helpful in developing strategy for designing UH and DH load march in mountains for Army personnel and recreational hikers.

EXPERIMENTAL PROTOCOL

Twelve Indian Army soldiers [Age- 26.8 (± 3.9) yrs, height- 170.6 (± 3.2) cm and weight 66.2 (± 6.8) kg] participated in a simulated treadmill continuous uphill and downhill walking while carrying multiple loads at 3 km/h walking speed.

Load carriage Experiments

The participants were subjected to treadmill (TM) walking (h/p/cosmos treadmill, Cortex Biophyzik Ltd, Leipzig, Germany) for load carriage experiment without load (No load, NL) and with two magnitudes of load such as 10.7 kg [Haversack (HS), Web (Wb) and Rifle; L1]; and 21.4 kg [Backpack (BP), HS, Wb and Rifle; L2] at a constant walking speed of 3 km.hr-1. Loads were selected as per existing load carriage system of Indian Army [Fig. 1]. The experiments were carried out inside the laboratory with a controlled environment. Room air temperature and relative humidity (RH) were monitored by a digital thermometer hygrometer and were maintained within a comfortable range- 25-30 °C and 30-50% respectively. The UH walking was performed in an incremental gradient of TM starting from 0-20% with a 5% increase after each 6 mins of exercise followed by DH walking in a reverse decremental gradient (20-0%) without load as well as two other magnitudes of loads. Each participants thus undergone 30 mins UH and 30 mins DH walking continuously totaling 60 mins of full exercise. During the interchange of the rotation of the treadmill belt to the reverse direction, the volunteers walked on a different treadmill at 20%. At least two days gap was allowed between load carriage sessions of each participant. Physiological parameters such as VO_2, HR, EE and VE were recorded breath by breath by using Metamax 3B system (MMX 3B, Cortex, Germany). The Relative work load (RWL, $\%VO_2max$) was calculated as percentage of VO_2max. The average value of last 2 mins of the 6 mins of exercise at each gradient for each of the parameters recorded was considered for statistical treatment. Maximal aerobic capacity (VO_2max) was measured during treadmill exercise with regular increase in the gradient, keeping the speed constant (Harbor protocol).

Fig 1: Existing load carriage ensembles of Indian Army (ElCe)

Statistical Analysis

A repeated measure ANOVA was applied for the physiological parameters as the same group of subjects was exposed to all ten gradients (0, 5, 10, 15, 20%, -20, -15 , -10, -5, 0%), and three loads to see over all significance across the conditions. Subsequent to the observed significance level for the various cardiorespiratory and metabolic parameters Bonferroni Post-Hoc test was applied to compare between the conditions pair wise. For all the tests statistical significance were verified at $p \leq 0.05$ level.

RESULTS

Mean VO_2max of the participants was 52.6 (± 3.8) $ml.min^{-1}.kg^{-1}$. All the cardio respiratory and metabolic variables increased with the increase in magnitude of load along with increment in the gradient. Also the measured variables decreased with the decrement in the gradient. Changes in VO_2 with different loads and grades are presented in fig 2. VO_2 increased linearly with increase in load and UH gradient. It increased from 12.7 $ml.min^{-1}.kg^{-1}$ at 0% NL to 38.5 $ml.min^{-1}.kg^{-1}$ at 20% UH gradient walk while carrying 21.4 kg load. During DH walking VO_2 decreased from 11.8 $ml.min^{-1}.kg^{-1}$ at NL -20% to 11.7 $ml.min^{-1}.kg^{-1}$ with NL 0% and 16.7 $ml.min^{-1}.kg^{-1}$ in 21.4 kg load carrying to 16.4 $ml.min^{-1}.kg^{-1}$ in 0% gradient in same load. However, these values are much lower in -10% and -5% than final 0% gradient walk. The result of the repeated measured ANOVA revealed significant change in VO_2 with various gradient- $F_{(2.6, 29.7)}$ = 1.320E3, load- $F_{(2, 22)}$ = 136.7 and in a combination of gradient and load- $F_{(18, 198)}$ = 20.8; $p< 0.05$. Significant difference was observed between three loaded conditions after pair-wise comparison. Interaction between load and grade was also significant.

Changes in HR with different loads and grades are shown in fig 3. HR increased linearly with increase in load and UH gradient. It increased maximally 164.2 $b.min^{-1}$ at 20% gradient with 21.4 k load compared to 85.7 $b.min^{-1}$ at 0% gradient in NL. HR decreased with decrease in load and gradient. This was lower at -5% than 0% gradient walk. HR was significant in the following conditions - gradient- $F_{(2.4, 26.7)}$ = 276.4, load- $F_{(2, 22)}$ = 42.1, and interaction between gradient and load $F_{(18, 198)}$ = 28.1; $p< 0.05$. Bonferroni Post Hoc test revealed all three loaded conditions were significant in the study. Interaction between gradient and load was found to be significant.

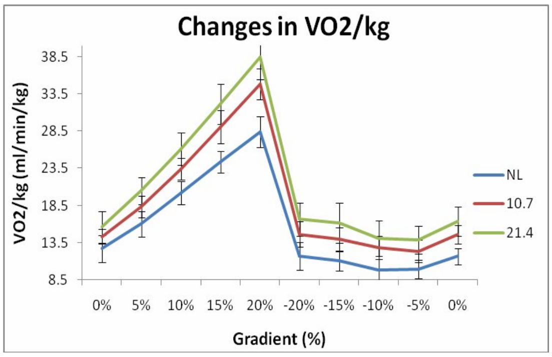

Fig 2: Changes in VO_2 and with different gradients and load

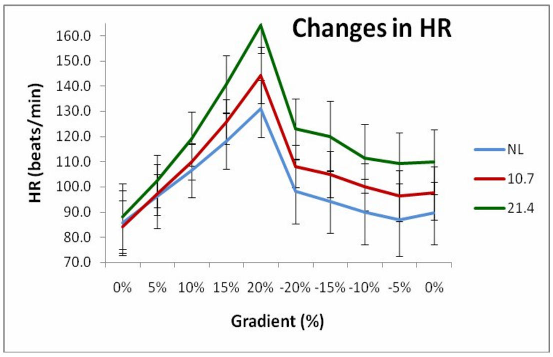

Fig 3: Changes HR in with different gradients and loads

Changes in EE with different loads and grades are shown in fig 4. EE increased for 4.0 $kcal.min^{-1}$ at 0% in NL to 12.5 $kcal.min^{-1}$ at 20% gradient in 21.4 kg load. The EE values of DH walking at -15, -10 and -5% gradients were lower than the final 0% gradient walk in NL and all of the load conditions. Overall significance was observed for EE in the following condition - gradient- $F_{(1.9, 21.6)} = 791.1$, load- $F_{(2, 22)} = 158.1$, and interactions of gradient and load $F_{(18, 198)} = 24.2$; $p < 0.05$. After Bonferroni Post Hoc analysis all three loaded conditions were found to be significant in the study. Significant difference was observed in the interaction between gradient and load.

Changes in VE with different loads and grades are presented in fig 5. VE increased linearly with increase in load and UH grade. The pattern of increase and decrease of VE was same as other parameters. VE was significant in the following conditions - gradient- $F_{(1.6, 17.9)} = 277.3$, load- $F_{(2, 22)} = 97.1$, and interactions of gradient and load $F_{(18, 198)} = 31.1$; $p < 0.05$. Bonferroni Post Hoc analysis revealed all three loaded conditions were significant in the study. Significant difference was observed in the interaction between gradient and load.

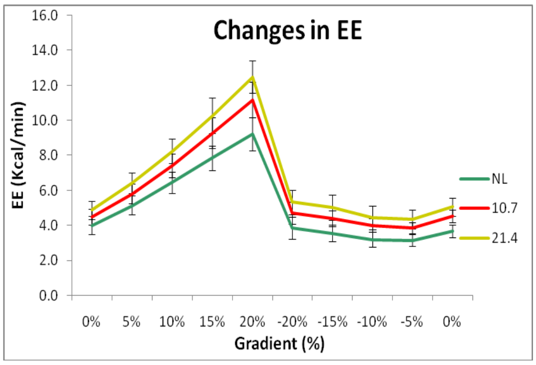

Fig 4: Changes in EE with different gradients and loads

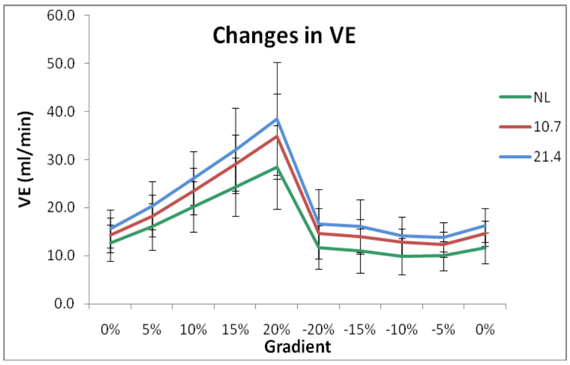

Fig 5: Changes in VE with different gradients and loads

Changes in RWL with different loads and grades are presented in table 1. RWL increased linearly with increase in load and UH gradient. It increased from 24.5% at NL in 0% to 74.2% at 20% gradient in 21.4 kg load carriage. Here also during DH walking the RWL response was lower in -15, -10 and -5% gradient than final 0% gradient walk in NL and other loaded conditions. RWL was significant in the following conditions - gradient- $F_{(2.5, 28.1)} = 1.149E3$, load- $F_{(2, 22)} = 144.1$, and interaction of gradient and load $F_{(18, 198)} = 20.6$; $p < 0.05$. After pair-wise comparison using Bonferroni Post Hoc test all three loaded conditions were found to be significant in the study. Significant difference was observed in the interaction between gradient and load.

Table 1: changes in the relative work load throughout the gradients and loads

Gradients	Relative workload (%VO_{2max})		
	NL	10.7 kg	21.4 kg
0%	24.5	27.7	30.1
5%	30.9	35.4	39.5
10%	39.1	45.3	50.4
15%	47.1	56.2	62.1
20%	54.8	67.3	74.1
-20%	22.7	28.4	32.2
-15%	21.3	27.0	31.2
-10%	19.1	24.8	27.3
-5%	19.2	23.9	26.8
0%	22.5	28.2	31.6

DISCUSSION

Physiological and mechanical factors affecting walking and running extreme UH and DH gradients were studied by Minetti et al [6]. They found that energy cost of walking and running increased with increment in gradient and vice versa. Findings of the present study completely corroborate with this study. Crouter et al [7] and Padulo et al [8] compared physiological outcome of incremental exercise with other forms of exercise having similar intensity. Both groups of scientists found incremental exercise as more physiologically demanding. Physiological response of DH walking was studied by Navalta et al [9]. They found a curvilinear response of HR, VO_2, VE and blood pressure were found at steeper DH gradients. Minimum physiological response was observed in -5 and -10% gradients. Beneficial effects of DH walking were cited, and recommended for sedentary individuals. Similar result is reported in the present study. Such studies are helpful in understanding the physical requirement of UH and DH exercise as well as pointing the need of biomechanical, electromyographycal exploration of load carriage in a complex terrain. Twenty one hrs long duration load march in a hilly terrain was studied by [10]. Based on the pre and post trials of kinetic, kinematic changes, energetics and muscular activity of lower limb muscles the authors suggested exploiting each min of sleep / resting periods to limit fatigue. Oxygen consumption of post operation treadmill exercise drives the occurrence of perceived fatigue instead of the central one in such exercise. Therefore importance of rest / pause in case of long duration load march in a complex terrain, which is simulated in the present study, may be applicable for reduction of central or perceived exertion. The recommendations might be taken as an important criterion for improving UH and DH load marching strategies.

In this study soldiers were subjected to a continuous treadmill walking with load, first incremental then subsequently decremental gradients to simulate a mountainous terrain. Physiological cost of this simulated load carriage operation was measured. All the physiological parameters increased significantly with the increase in UH gradient with gradual increment in loads. Significant decreases from the maximum UH and maximum DH gradient were also visible with all physiological variables. The measured variables continued to decrease with decrease in gradient. Based on widely followed predictions of permissible work load (using RWL), the optimal load for uphill and downhill task was recommended [11]. According to their recommendations 35% of the RWL should be considered as AWL. Corresponding HR and EE of around 110 beats/min and 18 KJ. min^{-1} i.e. 4.3 kcal.min^{-1} respectively may also be considered as criteria for classification of workload. The changes in the RWL in the loaded and unloaded walking at different gradients are mentioned in table 4. As per the recommendations, uphill walking 21.4 kg cannot be permitted for carriage at a gradient beyond 10%. Any load above 10.7 kg can be dangerous at a gradient of 15% for continuous carriage for 8 hrs. However considering the AWL prediction by Vogel et al [12] (50% of VO_2max), 21.4 kg i.e. 32% of body weight can be allowed for carriage for shorter duration (2 hrs). Adequate rest/ pause during load carriage at steeper gradients and full utilization of the rest are suggested. Downhill walking with load does not look difficult in terms of physiological and relative work load. -5 to -10% gradients are suggested as the most economical range for DH load carriage. Findings of this study can be utilized in designing strenuous military operation apart from adventurous activities like those of trekkers, backpackers and mountaineers.

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