Physiological and perceptual responses in the Sherpa method of carrying loads: Role of hip belt and shoulder strap supports

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Abstract: The manual load carrying system is still widespread in hilly areas of Northeastern part of India due to lack of transportation infrastructure. It is not uncommon to see workers routinely take head-supported loads like the Sherpa method where a load slung on the back and supported by a strap over the forehead. This type of load carriage has become a concern to significant postural discomforts, mainly on head, neck, and shoulders. Therefore, the purpose of this study was to examine the physiological and perceptual responses to carry the load in Sherpa method with and without hip belt and shoulder strap supports. In this study, hypothesize that the use of a hip belt and shoulder strap in Sherpa style would elicit lower physiological and perceptual responses than without support. A total of 10 agricultural workers participated in this study and carried 20% and 40% of their body weight while walking at 3 km/h on a motor-driven treadmill with the grade alternating at 0%, 5%, and 10% upward slopes. The results showed that the heart rate (HR), oxygen consumption (VO2) and subjective perceptual responses significantly decreased by using the supports of belt and strap in comparison to without supports. This research finding suggests that load transportation without supports is ergonomically inadvisable.

Keywords: Load, strain, heart rate, oxygen consumption, perceptual responses, India.

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1 Introduction

Human beings have been carrying loads supported by the body since their first existence. Rural dwellers typically use traditional means for carrying loads by manual head-loading, either directly or via a forehead strap (Lloyd et al., 2010). Although human aids and advanced technology are commonplace, in many cases, head loading is the only practicable method because of the nature of the paths and the terrain (O'Neill, 2000). This fact is especially relevant to the agricultural workers in hilly regions, who carry heavy loads over long distances, often over uneven and arduous terrain and in adverse environmental conditions.

Manual load transportation is still widespread in developing countries and has important socioeconomic implications because a significant proportion of the population derives their income solely by carrying loads (Datta et al. 1973; Datta et al. 1971; Samanta and Chatterjee, 1981). Load carrying on the head is a typical method in both Asia and Africa (Maloiy et al. 1986). Several researchers of load carriage have concluded that possible determinants of load carrying ability include age, anthropometry, training, gender, muscular strength and body composition (Haisman, 1988; Knapik et al., 1996). Other relevant determinants include placement and dimension of the load, biomechanical factor, climate, terrain, and gradient. The physiological cost of load carriage has been investigated in India (Datta et al., 1975;

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Samanta and Chatterjee, 1981) and elsewhere (Patton et al., 1991; Fredericks et al., 2008; Christie and Scott, 2005; Lyons et al., 2005 and Li et al., 2003). However, none of these studies included the Sherpa method of load carriage.

The Sherpa method is a versatile and shared form of manual load transport in the hilly region of Northeastern India. Mostly, women carry items on their heads, while men usually carry loads on their shoulders. Carrying heavy loads for a long distance is still a regular activity for a variety of reasons (cultural, economical and practical). The head-supported loads are more energy demanding, unstable, and they need well-developed neck muscles to support the spinal loading (Anonymous, 2011). The excessive load carried by an individual can cause spine injury and early onset of fatigue (Parkinson et al., 2009). The long-term effects of this on the body are not well known, but the repetitive stress of carrying the heavy load may contribute to the high prevalence of musculoskeletal symptoms and severe neck pain (Geere et al., 2010). Important risk factors are the weight, terrain and time spent by carrying a load. These effects may be larger in those who traveled in up-slope on foot and took the heavyweight with the help of their head.

Numerous studies have been conducted regarding load carriage for military soldiers (Birrell et al., 2007; Birrell and Haslam, 2010; Knapik et al., 2004; Majumdar et al. 2010). Furthermore, literature has documented some physiological aspects of head load carriage (Heglund et al., 1995; Maloiy et al., 1986) as well as the degenerative changes of the neck vertebrae as a result of this practice (Echarri and Forriol, 2005 and Jager et al., 1997). The numbers of prospective studies undertaken on similar aspects of the Sherpa method are limited and less reported.

The aim of the present study was to evaluate the energy cost of load carriage using with and without shoulder strap and hip belt supports in the Sherpa method of the load carriage system. The shoulder strap and hip belt support incorporations allow the weight distribution between the upper back and lower back of the body trunk. This study examined the Sherpa method of load carriage with combinations of walking grades and loads in a group of agricultural workers.

2 Methods

2.1 Participants

Ten physically fit farm workers served as the participants in this experiment. Initially, participants were screened and excluded from the study if they had reported any past or current musculoskeletal disorder or lower-back pain at the time of the experiment. Each participant has intimated the purpose of this study and a written consent was obtained. Their body mass index (BMI) was computed using weight and height parameters (BMI = body weight/ height^2 (kg/m^2)).

2.2 Experimental design

To compare the physiological and perceptual responses with and without shoulder strap and hip belt supports in the Sherpa method of load carriage, the participants walked on a treadmill for different load and grade combinations. The basket was filled with woods and weights so that they weighed 20% and 40% of each participant’s body weight (BW). Each subject performed treadmill exercise walking in the Sherpa method of load carriage for different combinations of grades and weights for both with and without supports. At the end of the experiment, they were asked to relax and complete the perceptual response assessments like the rate of perceived exertion, body part discomfort diagram, and the subjective questionnaire after every trial. The next session was scheduled two days later to allow participants a recovery period. For the second and third sessions, the treadmill was set to 5% and 10% positive incline respectively for different loads. All the above three trials were carried out for both with and without hip belt and shoulder strap supports. Table 1 summarizes the independent and dependent variables and conditions of the present study.

Table 1 Independent and dependent variables with levels

Variables	Level

Independent variables		
1.	Method of load carrying	2 (With and without hip belt and shoulder strap supports)
2.	Load	0%, 20% and 40% body weight (BW)
3.	Grade	0%, 5% and 10% upslope
4.	Walking speed	1 (3 km/h)
Dependent variables		
1.	Heart rate, HR	
2.	Oxygen consumption rate, OCR	
3.	Discomfort rating, DR	
4.	Rating of perceived exertion, RPE	

2.3 Measurement protocols

The study conducted under the controlled laboratory conditions of 22^0C-28^0C and 60%-65% relative humidity. All exercise tests performed on a motor-driven Trackmaster TMX425 treadmill (Figure 1). At the beginning of the data collection process, all the participants were informed about measurement techniques. The enough time provided to subjects to become accustomed to the use of treadmill walking before starting the experiment. The HR_{max} of each participant was determined using a progressive exercise test on the treadmill. In this process, the speed of the treadmill was gradually increased until they no longer keep up. At this point, their heart rates (HR) in beats/min (bpm) were noted to get the value of HR_{max}. Mean values of HR during first 5 min, before the experiment, were taken as the resting values for each participating subject.

Figure 1 Participant walking on the treadmill during experiment

Participant ratings of perceived exertion (RPE) were taken using the standard scale with the ratings between 6-20-point (Borg, 1998). The estimation of the maximum oxygen consumption rate, based on maximum and resting heart rates, was calculated using the formula given by Uth et al. (2004). The relationship between HR_{max} and RH_{rest} provide a handy tool for evaluating physical workload (VO_2) by directly measuring heart rate data.

2.4 Statistical analysis

Statistical analysis was performed for the interpretation of the results obtained from both subjective and objective analysis. The Shapiro-Wilk's test and quantile-quantile plot (Q-Q plot) were used to verify whether the qualitative variables follow a normal distribution. The dependent variables of this experiment included HR, OCR, DR, and RPE. Analyses of variance were performed to evaluate the effects of the shoulder strap and hip belt supports on the dependent variables. The level of significance was set at $p<0.05$, providing a level of confidence of 95%. The statistical analysis was computed using commercially available statistical software, i.e. *Statistical Package for the Social Sciences* (SPSS) version 20.0.1 (IBM Corporation, USA).

3 Results and discussions

3.1 Participant physical characteristics

Participant body weight was measured to the nearest 0.1 kg and height to the nearest 0.1 cm with wearing minimal clothing and no shoes. Selected participants had work experiences at least five years in agricultural activities. Their ages ranged from 26 to 38 years old, body weight from 51 to 62 kg, and heights from 1.53 to 1.67 m. Characteristics of participants regarding age, stature, weight, experience, BMI etc. are given in Table 2.

Table 2 Summary of the physical characteristics of the participants

Characteristic	Mean	SD
Age, year	32.50	4.86
Stature, cm	159.40	4.93
Weight, kg	55.80	3.91
Experience, year	8.60	2.88
BSA, m^2	1.57	0.08

BMI, kg/m^2	21.95	0.90
HR_{rest}, beats/min	76.90	2.38
HR_{max}, beats/min	187.50	4.86

According to published BMI classifications (WHO, 2014), individuals are considered underweight when their BMI is <18.5; within the normal range when their BMI ranges between 18.5–24.9; overweight when BMI ranges between 25–29.9, moderately obese when BMI ranges between 30–34.9, severely obese when BMI ranges between 35–39.9 and very severely obese when BMI is 40 and above. For this study only selected those participants who had a BMI within the normal range.

3.2 Effect of body weight on heart rate response

The energy requirements to perform the task in uphill walking with carrying the load considerably influenced both the heart rate and the oxygen uptake (Perrey and Fabre, 2008). Graphically, it has shown in Figure 2 by plotting percent body weight versus average HR response with belt supported.

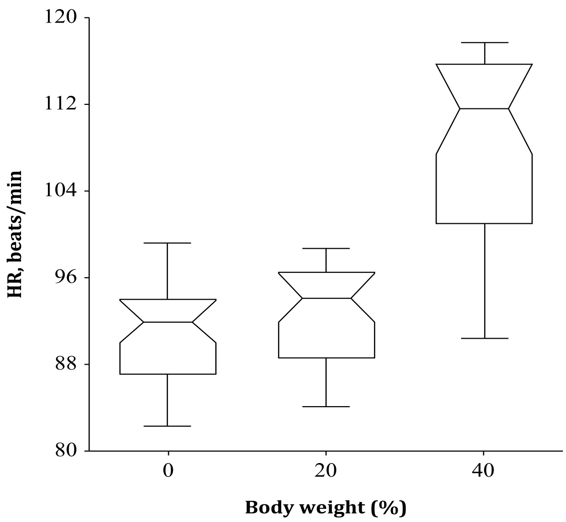
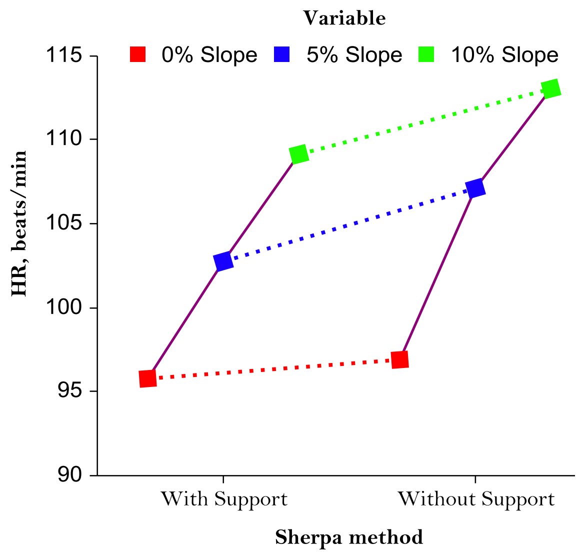


Figure 2 Effect of load on HR response with hip belt and shoulder strap supports

The results showed significant increases in HR with increased load from 0% body weight to 40% body weight. The mean and standard deviation values for the HR in the three load conditions were 91 ±4.69, 93 ±4.60 and 109 ± 8.53 respectively. The repeated measures one-way ANOVA revealed a significant effect on HR ($p<0.001$). Subsequent analysis of LSD (pairwise comparisons) showed that there was an insignificant difference between 0% BW and 20% BW ($p = 0.212$). However, rests of the combinations of 20% BW and 40% BW were highly significant ($p<0.001$).

3.3 Effects of slope on heart rate response

The HR increases with the increase in walking grade levels, such as the maximum HR in the case with supports, and without supports for 20% body is shown in Figure 3. The heart rate mean value at 0%, 5% and 10% slope were found 96 ± 2.92 bpm, 103 ± 6.14 bpm, and 109 ± 10.16 bpm, respectively with support. Similarly, average working HR at 0%, 5% and 10% slope without supports was 97 ± 3.74 bpm, 107 ± 8.56 bpm, and 113 ± 8.05 bpm, respectively. The HR was found higher in the case without subsidies compared to the result with supports for all slopes. This observation was found consistent with the previous studies (Gordon et al., 1983; Quesada et al., 2000) where HR significantly more when the participants carried a load compared to unloaded walk.



(Solid line showing average heart rate response within the group, whereas the dotted line showing the average value of heart rate between groups)

Figure 3 Effect of slope on HR response with and without support of belt and strap

Further, paired t-test was performed to test the equality of the means of each potential predictor between the two groups, i.e. with and without hip belt and shoulder strap supports. Statistical analysis (t-test) of the data indicated that there was a significant difference (paired Student t-test with $p < 0.001$ and $t = 177.91$) in HR between with and without supports at no slope i.e. 0% slope. This tendency was the same when analyzed for 5% ($p < 0.001$ and $t = 105.63$) and 10% ($p < 0.001$ and $t = 91.76$) slopes respectively.

3.4 Effect of grade level on oxygen consumption

A graph has plotted between hip belt and shoulder strap supports (with and without) and maximum oxygen consumption rate for 20% body weight (Figure 4). A significant interaction observed between VO_2 consumption and grade level with and without supports of the hip belt and shoulder strap. A similar finding was noted and stated that significant increase in the oxygen consumption rate with the increase in load, regarding walking grade level (Pal et al., 2009; Lloyd and Cooke, 2000). Since the energy requirement increases as the walking gradient increased, thus more oxygen inhaled to produce the required energy. Therefore, the heart rate also increases.

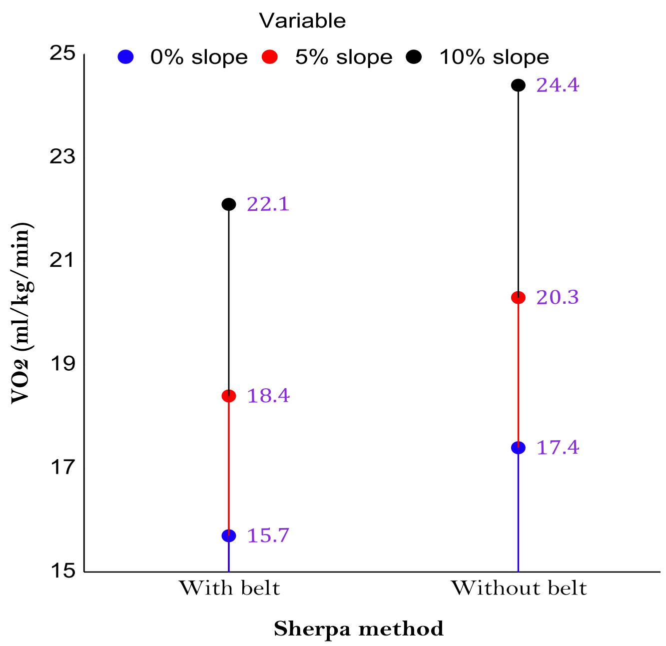
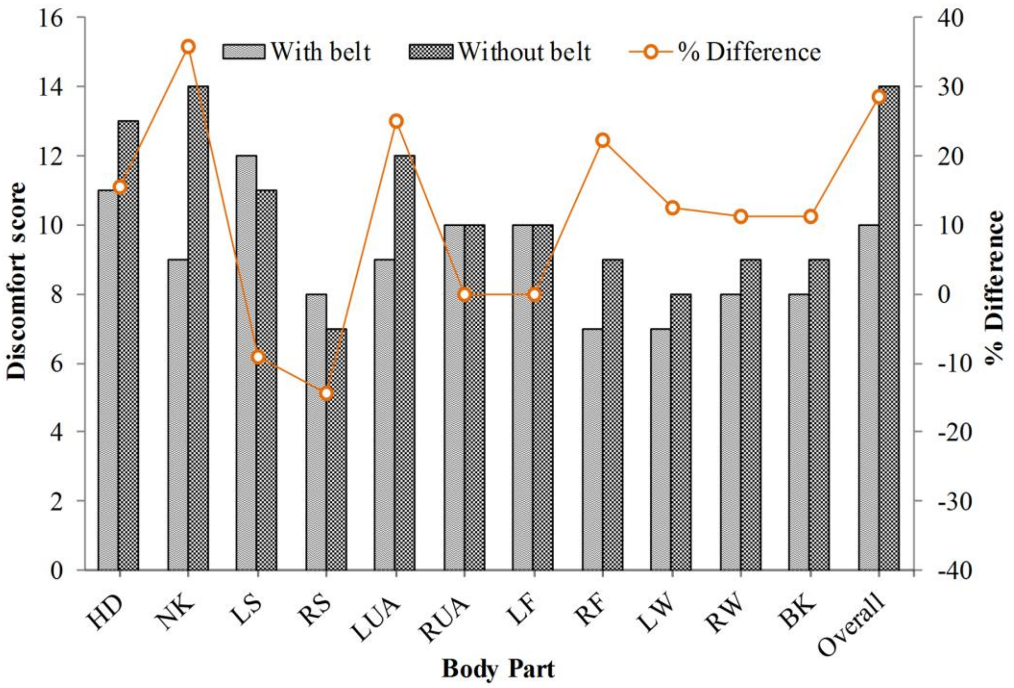


Figure 4 Effect of hip belt and shoulder strap supports (with and without) on oxygen consumption (VO_2) at different upward slopes

From the graph, it was observed that average VO_2 was found lower at 0% grade level and was highest at 10% grade level. In both with and without supports of the hip belt and shoulder strap in Sherpa method, the VO_2 increases. However, the maximum oxygen consumption rate was more in the case without hip belt and shoulder strap supports. The VO_2 increases from 17.4 ml/kg/min to 24.4 ml/kg/min in without hip belt and shoulder strap and from 15.7 ml/kg/min to 22.1 ml/kg/min in case of with the hip belt and shoulder strap supported Sherpa method. The energy cost of walking without the aid increase progressively with increases in load and body mass.

3.5 Assessment of subjective discomfort rating

The assessment of uneasiness is valuable information for determining the physical match between workers and their work. To identify the body parts where the pain experienced during treadmill walking with Sherpa method the original body chart of Corlett and Bishop (1976) has been modified and divided body map into various segments. The data from the regional body discomfort diagrams were first analyzed graphically in Excel. The results consistently showed that pain scores were slightly higher in without the support of hip belt and shoulder strap method than with supporting. There were several regions, where the participants experienced a greater degree of discomfort in both with and without supports Sherpa method of load carriage. The average regional body pain scores ranged between 9-11, except for the head, shoulders, and neck which were higher as shown in Figure 5. The maximum percentage difference in the discomfort scores for support and without support has found in the neck, right forearm, and right wrist.



{HD – Head; NK – Neck; LS – Left shoulder; RS – Right shoulder; LUA – Left upper arm; RUA – Right upper arm; LF – Left forearm; RF – Right forearm; LW – Left wrist; RW – Right wrist; BK – Buttock; Overall – Overall discomfort rating}

Figure 5 Regional body part discomfort scores with and without the supports of hip and shoulder belt strap in Sherpa method

3.6 Assessment of subjective perceived exertion

The level of perceived exertion measured with a category scale like Borg CR-10 scale. The ratings of perceived exertion (RPE) measure feelings of effort, strain, discomfort, and fatigue experienced during any physical task performance. In this investigation, ratings of perceived exertion (RPE) were measured on the Borg CR-10 scale at the end of each experiment and average discomfort scoring of all the subjects was plotted as shown in Figure 6. From the graph, it was observed that with the increase in grade levels, the severity of pain also increases. Hence, the RPE results obtained from the present study indicate that scores ≥5 referred as ‘strong’ on the Borg CR-10 scale, which is due to increase in walking grade level. Overall, the rate of severity was found higher in the case of without hip belt and shoulder strap supports than that of with support.

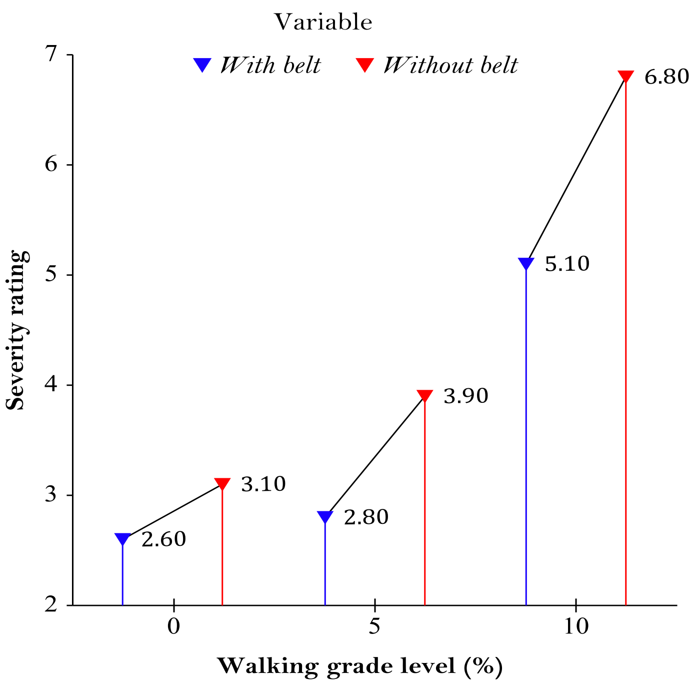


Figure 6 Rating of perceived exertion in conditions with and without belt supports

4 Conclusions

Sherpa method is commonly used in a hilly region to carry loads over long distances, sometimes for many hours a day. Sherpa method of load carriage with hip belt and shoulder strap supports has a considerable influence on physiological and perceptual responses. The lower value of VO_2 associated with the hip belt and shoulder strap revealed that for the same amount of load either a faster rate of walking can be maintained or that the same rate of walking could continue for a longer duration. There were several regions, where the participants experienced a moderate degree of discomfort using and without hip belt and shoulder strap, but the pain and discomfort were unexpectedly higher in head and neck without hip belt and shoulder strap supports. According to the questionnaire responses, participants preferred using supports on the shoulder and hip for carrying the load. This study might be useful for agricultural workers, especially in evaluating physical tolerance and energy consumption while taking the head supported load for day-to-day activities.

Further research is needed to involve more participants to understand fully the influence on physiological and perceptual responses associated with the Sherpa method of load carrying technique. In addition to that, field exploration should be performed to compare the findings of laboratory outcomes with the real situation.

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