Ergonomic intervention and optimization for maximum permissible loads to be carried in Sherpa mode based on physiological criteria

Thaneswer Patel[1], P. K. Pranav[2*], Sipe Miso[1]

(1. Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli (Itanagar) – 791109, Arunachal Pradesh, India;

2. College of Agricultural Engineering, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, - 848 125, Bihar, India)

Abstract: The optimum load carrying capacity and maximum allowable work time at various slopes in the existing Sherpa mode of load carriage was determined based on 35% of maximum aerobic capacity. A convenience sample of 30 healthy agricultural who voluntarily signed an informed consent form participated in this study. The maximum loading capacity for a male is 50% of their body weight for a short duration and 17% of their body weight for a long duration. Considering the rate of perceived exertion in the Sherpa mode of load carry, a basket holder was also conceptualized and developed. The silent features of the designed holder are (i) it can accommodate the wide range of existing baskets being used for Sherpa mode, (ii) shoulder straps were provided to transfer part load on the shoulder from forehead with adjustability to suit a wider range of population, (iii) the forehead pressure was distributed by enlarging the strap area on the head and (iv) cushions were also provided in back and straps for comfort. As per the experiment conducted in laboratory conditions, the recommended load carrying capacity and allowable work time for males and females was higher than the existing one. It was observed that maximum enhancement in load carrying for males and females with basket holders was 47% and 23%, at 20% slope for a longer duration of work, respectively. Similarly, a significant improvement in the allowable work time was also observed. The comparative discomfort score indicated enormous pain reduction at the neck and forehead.

Keywords: ergonomics, load carriage, discomfort, product design, physiological

Citation: Patel, T., P. K. Pranav, and S. Miso. 2022. Ergonomic intervention and optimization for maximum permissible loads to be carried in Sherpa mode based on physiological criteria. Agricultural Engineering International: CIGR Journal, 24 (1):175-187.

1 Introduction

The manual load carrying system is still widespread in hilly areas of India due to lack of transportation infrastructure (Patel et al., 2016), and walking with backpack carriage imposes additional loads in the lumbar spine (Goh et al., 1998). Load distribution and walking gradient are important factors in terms of the efficiency of load carriage and should be taken into consideration in both the design and loading of backpacks (Liu, 2007). The awkward postures in carrying load lead to several occupational health concerns i.e. musculoskeletal ailments, postural syndromes, back pain etc. (Waters et al., 1994; Burton et al., 1996, Negrini et al., 1998). The north-eastern region of India is characterized by difficult terrain, wide variations in slopes, altitudes, and indigenous cultivation practices (Patel et al., 2013). These difficulties force the worker to carry goods or agricultural products by human labor. It has been observed that agricultural workers

Received date: 2020-10-05 **Accepted date:** 2021-12-22

[*] **Corresponding author: P. K. Pranav,** Ph.D., Associate Professor, College of Agricultural Engineering, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, - 848 125, Bihar, India. Tel: +91 9436228995; E-mail: pkjha78@ gmail.com.

carry the load mostly in Sherpa mode in these difficult terrains to keep both hands free during operation (Patel et al., 2013). In this mode, the load hangs on the back with strap support from the forehead (Figure 1). This method of load-carrying causes a very frequent accident and creates pain in the spinal cord in the long term.

It is commonly believed that an individual can carry out a task without much difficulty as long as the physiological demands for the particular task do not exceed their maximum aerobic power (Saha et al., 1979). Determining the safe and efficient methods of load carriage has been the subject of interest of many researchers (Robertson et al., 1982; Holewijn, 1990; Hong et al., *2*000; Stuempfle et al., 2004; Bastien et al., 2005; and Liu, 2007) from decades to examine the physiological, postural, gait and subjective responses. Determining the optimum methods of load carriage has been limited mainly to investigations with military personnel and hikers (Keren et al., 1981; Knapik et al., 1996; Simpson et al., 2017; Foster and Lucia, 2007; Lloyd and Cooke, 2000; and Quesada et al., 2000), and the findings of same cannot be applicable for Sherpa mode of load-carrying where the load is distributed mostly on the head and neck. Hence, the present study was undertaken to assess the optimum load carrying capacity (within the physiological limit of 35% of VO_{2max}) and maximum allowable work time (MAWT) for agricultural workers that can be carried by them comfortably on various slopes and loads at specified walking speeds. Further, an ergonomic intervention was also intended to improve the load-carrying capacity in the same mode.

Figure 1 Sherpa mode of load carriage used by female agricultural workers

2 Materials and methods

The methodology of the study includes the design and development of a basket holder as an ergonomic intervention and its evaluation by calculating the optimum load-carrying capacity as well as MAWT. Saha et al. (1979) defined the acceptable workload as the level of physical activity which can be sustained by an individual in 8 hour working day in a physiologically steady state without any fatigue or discomfort.

2.1 Basket holder for Sherpa mode

The design requirement for basket holder was as follows based on the problems reported in the existing Sherpa mode

(1) To maintain the traditional method of load carry with better safety, comfort and work output.

(2) To utilize the wide range of existing baskets being used for Sherpa mode.

(3) To transfer part load on the shoulder from the forehead.

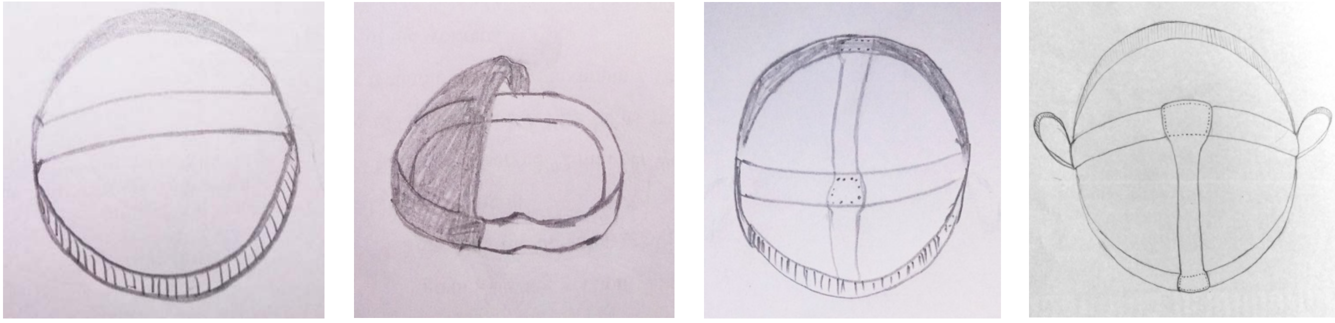
(4)To reduce the forehead pressure by enlarging the strap area on the head.

(5)To provide a cushioning effect in the back and straps for better comfort.

(6)To suit the extensive range of population with gender-friendly.

2.2 Design of basket holder and head strap

Based on the available information and research inputs gathered therefrom, various ideas were hypothesized to explore possible means to design and develop an improved load carrying basket cap and holder. A series of cap sketches were explored/optioned for product outlook and working principle. Some of the competent thoughts for the proposed load carriage cap are shown in Figure 2.



(a) Conceptual head strap model-01 (b) Conceptual head strap model-02 (c) Conceptual head strap model-03 (d) Conceptual head strap model-04

Figure 2 Conceptual head strap design for some feasible solutions

An adjustable basket holder was designed to grip different sizes of baskets based on diameter and length. The basket holder and head strap were designed as per the anthropometric database of male and female agricultural workers of Arunachal Pradesh. Due to the varying shape and size of the basket, the basket holder was provided with an adjustable strap (buckle) at the shoulder, the top circumference of the holder, the holder's vertical length, and at the waist. The basket holder and head strap were made of polyester fabric with expanded polyethylene (EPE) foam sheet for the cushioning effect. Dimensions of the head strap and basket holder were given in Figures 3 and 4.

Figure 3 Isometric view of the improved head strap with dimensions

Figure 4 Isometric view of improved basket holder with dimensions

2.3 Calculation of load capacity and MAWT

2.3.1 Selection of subject

Eighteen male and twelve female agricultural workers served as the participant to conduct 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 written consent was obtained. Their body mass index (BMI) was computed using weight and height parameters by Equation 1 (). Body surface area (BSA) was also calculated by using the Dubois formula.

$$BMI\ (kg\ m^{-2}) = W/H^2 \quad (1)$$

$$BSA\ (m^2) = 71.84\ W^{0.425} \times H^{0.725} \quad (2)$$

where, W = body weight in kg, H = body height in cm

2.3.2 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 of at least five years in agricultural activities. Their ages ranged from 18 to 38 years, bodyweight from 45 to 62 kg, and heights from 1.45 to 1.67 m. Characteristics of participants regarding age, stature, weight, experience, BMI, etc. are given in Table 1. All the selected participants were found within the normal range of BMI (18.5–24.9 kg m^{-2}).

Table 1 Summary of the physical characteristics of the participants

Particulars	Male		Female	
	Mean	SD	Mean	SD
Age, yrs	32.00	4.86	25.33	2.16
Stature, cm	159.40	4.93	149.10	4.25
Weight, kg	55.72	3.91	48.25	3.96
Experience, yrs	9.90	2.88	6.90	1.84
BSA, m^2	1.57	0.08	1.40	0.07
BMI, kg m^{-2}	21.95	0.90	21.70	0.80

2.4 Experimental design

The study was conducted in controlled laboratory conditions to calculate the load-carrying capacity at the various percent body weight (% of BW) and slopes for male and female agricultural workers in Sherpa mode with and without designed basket holder considering the following independent and dependent variables are given in Table 2.

Table 2 Independent and dependent variables of the study

A) Independent variables	level	
Mode of load carrying	2	Sherpa mode, Sherpa mode with basket holder
Load	4	15%, 25%, 35% and 45% BW
Grade	5	0%, 5%, 10%, 15% and 20%
Speed of walking	1	2.5 km h^{-1}
Subjects	30	18 Male and 12 Female
B) Dependent variables		
Volume of oxygen consumption (VO_2)		
Body parts discomfort score		

2.5 Measurement protocols

The study was conducted under the controlled laboratory conditions of 22–28℃ and 60–65% relative humidity at the same hour of the day between 9.00 a.m. and 1.00 p.m. every day for eliminating the specific dynamic action of food for all experiments. All tests were performed on a motor-driven Track master TMX425 treadmill (Figure 5). Before the experiment, all the participants were informed about measurement techniques, and they were familiarized with treadmill walking, wearing a heart rate monitor, and use of the $K4b^2$ system. The subjects preferred to walk on the treadmill barefoot as they generally do on hilly terrain. The maximum heart rate, the maximum aerobic capacity of the subjects was measured in treadmill exercise with pre-decided slopes and loads (harbor protocol) (Wasserman et al., 1987), keeping the speed constant. The step by step procedures for finding load carrying capacity and MAWT were as follow:

The experiments were conducted at 2.5 km h^{-1} speed for 1 hour, starting from 15% BW at 0% slope.

The VO_2 was recorded in $K4b^2$ during the experiment.

The recorded VO_2 was plotted against the time and developed a trend line equation using Microsoft Excel.

The MAWT was estimated from the trend line, corresponding to the 35% of VO_{2max}. A sample curve is shown in Figures 6 and 7. The average VO_{2max} for males and females was taken as 2283 and 1880 mL min^{-1} for the people of the research area, respectively, as reported by AICRP on ESA, 2016.

The VO_2 at 20, 40 and 60 minutes were also noted from the trend line for analyzing the load-carrying capacity.

The same procedure was followed for all % of BW and slopes.

Further, the noted VO_2 was plotted against the percentage of BW, and the trend line was drawn.

From the trend line, the % of BW was calculated against 35% of VO_{2max}.

The final recommendation was made by considering the general thumb rule of load carrying.

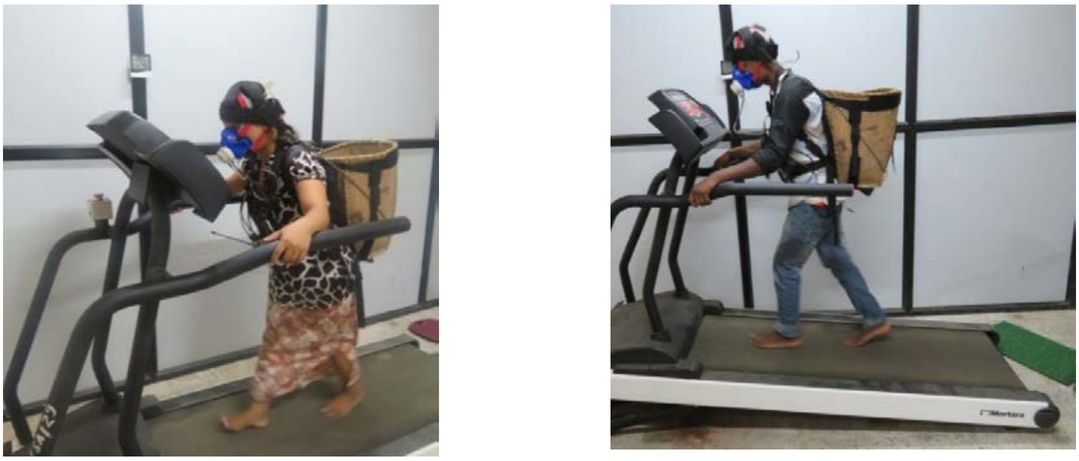


Figure 5 Aerobic capacity test on the treadmill after modification of basket holder

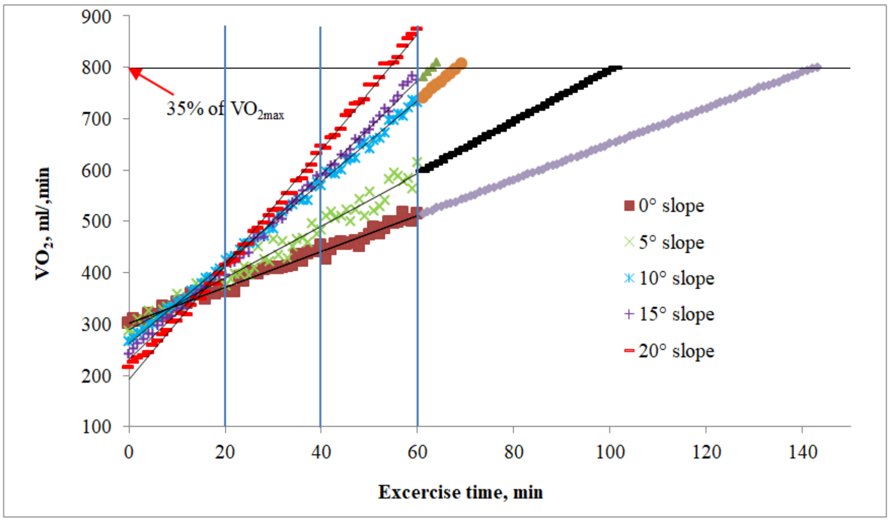


Figure 6 A sample curve for calculating MWAT at 25% body weight for male

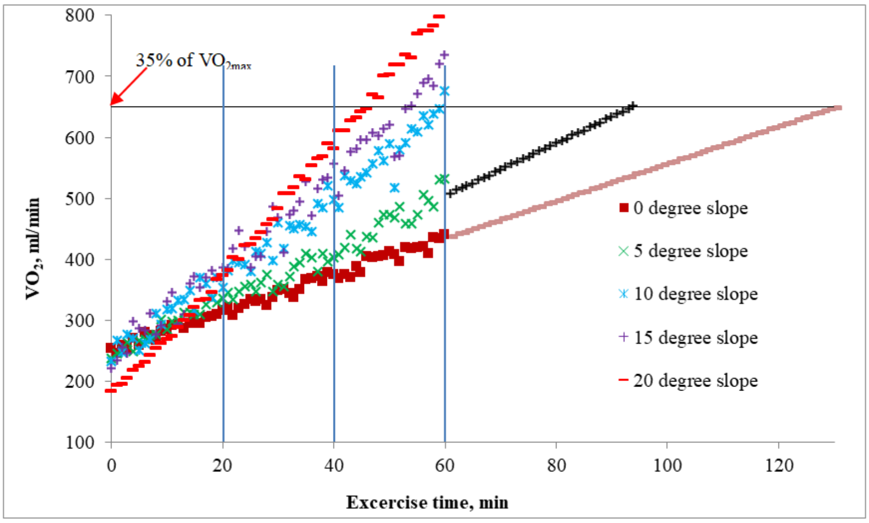


Figure 7 A sample curve for calculating MWAT at 25% body weight for female

3 Results and discussion

3.1 Maximum acceptable work time

Bink (1962) assumed that an acceptable work rate should not exceed 33% of the VO_{2max}. Based on a study of young Indian industrial workers, On the other hand, Saha et al. (1979) suggested that 35% VO_{2max}, as the acceptable work rate. At the same time, Maritz et al. (1961) predicted the corresponding heart rate to be 105 beats min^{-1}, with a range of 95 to 115 beats min^{-1}. In the present study, maximum acceptable work time (MAWT) for load-carrying by a male and female worker in Sherpa mode with and without basket holder was calculated based on 35% of VO_{2max} and is presented in Table 3. The given data in parenthesis represents the value for females. It was observed that the male could carry the load for 33 and 210 minutes in one stretch in the Sherpa model with 45% of BW at 20% slope and 15% of BW at 0% slope, respectively, whereas duration for their female counterpart is 15 and 178 minutes. There is a significant increase in the MAWT using developed basket holders for males and females. At higher load, either in slope or percentage of body weight, developed basket holder is more advantageous up to a maximum of 33% and 53% for males and females, respectively. The increase in MAWT is quite apparent because of the comfort offered using a basket holder.

Table 3 Maximum allowable work time at different slopes for male (female) workers

% BW	Condition	Maximum allowable work time, min				
		0% Slope	5% Slope	10% Slope	15% Slope	20% Slope
15	Sherpa mode	210(178)	133(118)	83(70)	71(56)	54(45)
	Sherpa mode with basket holder	220(192)	140(125)	87(74)	81(63)	70(55)
	Percentage increase	4.8(7.9)	5.3(5.9)	4.8(5.7)	14.1(12.5)	29.6(22.2)
25	Sherpa mode	126(124)	90(84)	60(57)	51(46)	42(39)
	Sherpa mode with basket holder	137(129)	100(90)	68(60)	63(55)	53(46)
	Percentage increase	8.7(4.0)	11.1(7.1)	13.3(5.3)	23.5(19.6)	26.2(17.9)
35	Sherpa mode	120(88)	77(62)	49(44)	42(37)	32(34)
	Sherpa mode with basket holder	133(90)	89(64)	56(49)	51(42)	44(40)
	Percentage increase	10.8(2.3)	15.6(3.2)	14.3(11.4)	21.4(13.5)	37.5(17.6)
45	Sherpa mode	85(59)	59(36)	42(22)	38(19)	33(15)
	Sherpa mode with basket holder	91(64)	68(41)	51(27)	46(25)	44(23)
	Percentage increase	7.1(8.5)	15.3(13.9)	21.4(22.7)	21.1(31.6)	33.3(53.3)

3.2 Optimization of load carrying capacity

The calculated value of VO_2 at 20, 40 and 60 minutes of exercise is tabulated for different slopes and bodyweight presented in Table 4. The VO_2 was further plotted against the percentage of body weight and a trendline was drawn. Sample curves with trend line equations at various slopes for with and without basket holder representing for male and female for medium duration work are shown in Figures 8-11, respectively. From these trend lines, the percentage of body weight was calculated against 35% of VO_{2max} and presented in Table 5. The calculated value was found up to 202% of their body weight, which was based on only their aerobic capacity and may not be suitable physically. Therefore, further criteria i.e. maximum recommended load for short, medium, and long duration, should not exceed 50%, 40%, and 35% of their body weight were imposed. Based on these criteria, the final recommendation for maximum load-carrying capacity is given in Table 6. It was observed that both males and females could carry 50% of their body weight up to 10% slope for a short duration. However, for a medium and long duration, males and females can carry an equal percentage of body weight at 5% and 0% slope, respectively.

Further, a female is not recommended (NR) to carry any load at 20% slope at a stretch of 1-hour duration. However, Soule et al. (1978) recommended that soldiers could carry up to 50.0 kg load (69.5% of body weight) at slow walking speed (3.2 km h^{-1}). Similarly, for Indian porters, Samanta et al. (1987) suggested 41, 23, 21 and 11 kg as the maximum permissible weight at 5 km h^{-1} for the age groups 20-29, 30-39, 40-49 and above 50 years, respectively. Maiti and Ray (2004) recommended that the maximum load limit value for adult Indian women workers be 15.0 kg.

Further, the comparative benefit of basket holders in terms of maximum load-carrying capacity compared to the existing method is presented in Figure 12. It was noted that the maximum benefit of basket holder in terms of workout put was observed for a long duration. The female can take up to 23% of BW at 20 % slope, which was not recommended without a basket holder. Further, the male can increase their carrying capacity from 17% to 25% of BW at 20% slope for a 1-hour duration. For females, the benefit was observed at 15% and 20%, 10%, 15% and 20%, and 5%, 10%, 15%, and 20% slope for a short, medium, and long duration. However, the male benefit was observed at 10%, 15% and 20% for long and 20% for medium only.

Table 4 VO_2 values for male and (female) subjects at different times of experiment for various slope and body weight with and without basket holder

Duration, min	Condition	%BW	VO_2, mL min^{-1} 0% Slope	5% Slope	10% Slope	15% Slope	20% Slope
20	With basket holder	15	325(296)	367(318)	385(331)	374(333)	360(328)
		25	364(315)	375(335)	425(352)	397(386)	416(374)
		35	387(337)	410(353)	452(396)	454(394)	462(414)
		45	393(413)	439(476)	471(550)	473(587)	473(608)
	Without basket holder	15	301(302)	313(334)	367(376)	398(401)	486(437)
		25	383(325)	392(357)	430(405)	471(425)	554(467)
		35	391(351)	416(384)	519(441)	541(466)	600(600)
		45	440(431)	475(480)	520(591)	560(683)	650(779)
40	With basket holder	15	363(339)	425(383)	508(444)	502(472)	533(485)
		25	453(376)	484(403)	572(498)	591(556)	646(582)
		35	439(419)	505(479)	655(581)	671(603)	745(652)
		45	517(524)	596(652)	683(804)	734(1004)	753(1134)
	Without basket holder	15	341(345)	457(399)	558(488)	577(542)	675(599)
		25	412(391)	532(443)	629(547)	680(585)	788(654)
		35	462(428)	562(499)	719(618)	753(658)	897(709)
		45	528(535)	621(694)	751(946)	815(1056)	908(1289)
60	With basket holder	15	406(392)	497(452)	639(561)	654(611)	728(683)
		25	521(514)	618(625)	832(748)	933(806)	1065(904)
		35	514(439)	617(531)	732(676)	775(736)	873(810)
		45	629(626)	736(861)	894(1277)	980(1464)	1049(1718)
	Without basket holder	15	388(396)	534(471)	680(604)	727(671)	836(776)
		25	431(453)	680(537)	895(690)	1003(766)	1197(871)
		35	535(519)	623(631)	787(771)	861(856)	1004(942)
		45	649(659)	775(896)	961(1290)	1054(1500)	1192(1828)

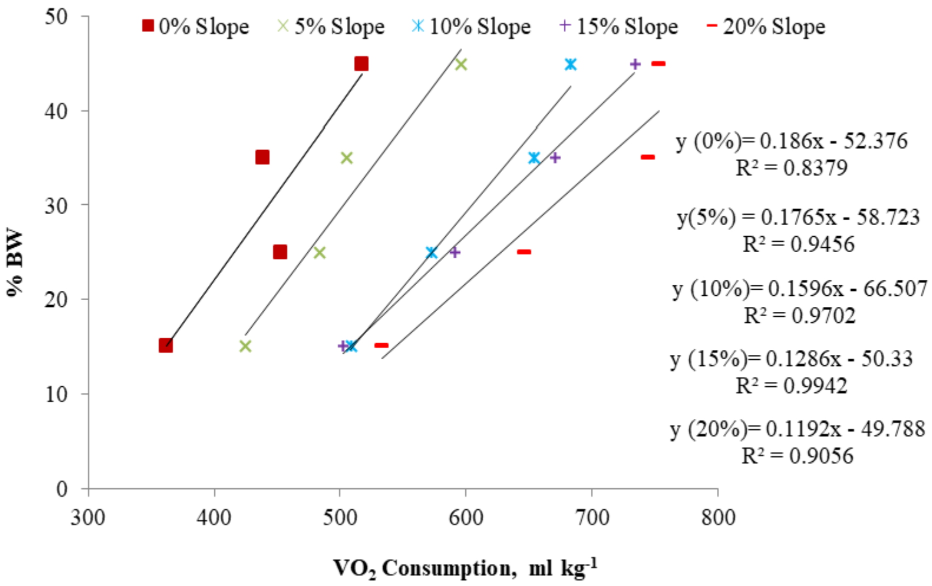


Figure 8 Trend line of VO_2 and % of BW with basket holder for male for medium duration

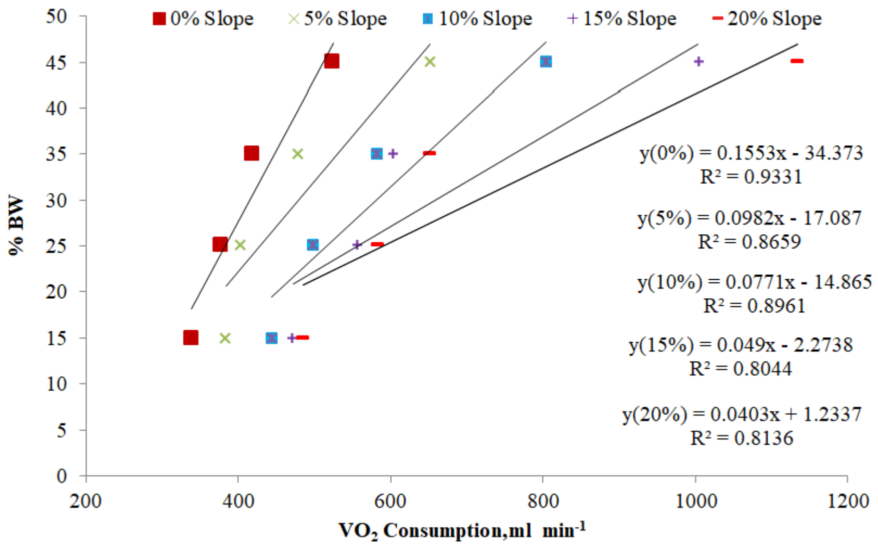


Figure 9 Trend line of VO_2 and % of BW with basket holder for female for medium duration

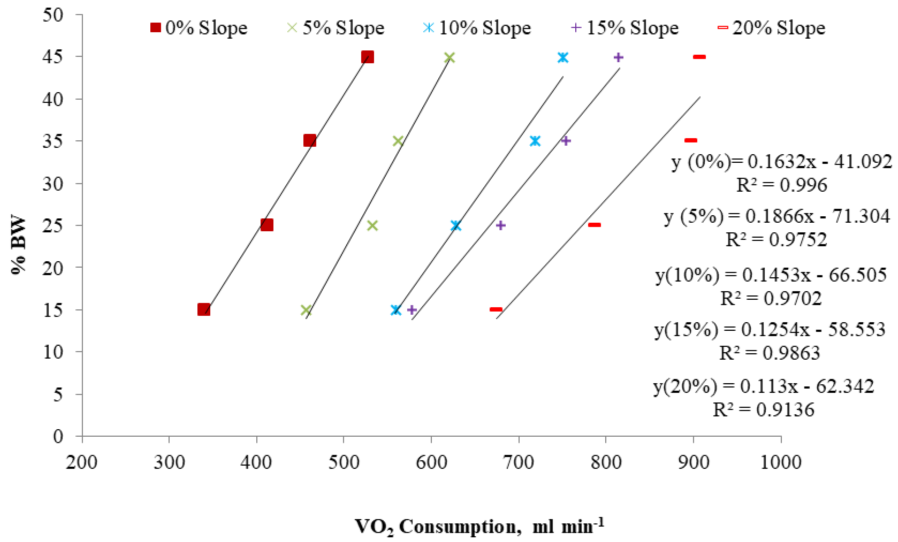


Figure 10 Trend line of VO_2 and % of BW without basket holder for male for medium duration

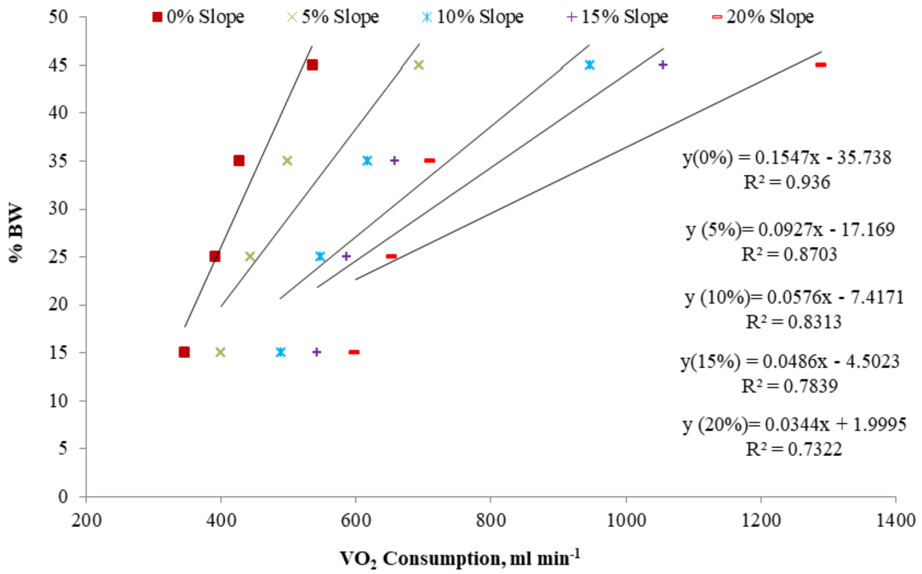


Figure 11 Trend line of VO_2 and % of BW without basket holder for female for medium duration

Table 5 Load-carrying capacity based on 35% of VO_{2max} for male (female)

Working time, min	Condition	Load carrying capacity (%BW) 0% Slope	5% Slope	10% Slope	15% Slope	20% Slope
20	Sherpa mode	119(95)	105(79)	86(54)	82(44)	72(37)
	Sherpa mode with basket holder	202(138)	183(99)	154(77)	132(69)	120(66)
40	Sherpa mode	89(65)	78(43)	48(30)	42(27)	29(24)
	Sherpa mode with basket holder	96(90)	82(61)	61(47)	52(37)	45(33)
60	Sherpa mode	62(46)	46(31)	27(23)	23(21)	17(NR)
	Sherpa mode with basket holder	67(61)	53(41)	32(29)	28(27)	23(25)

Table 6 Recommended load-carrying capacity at different slopes for male (female)

<table>
<tr><th rowspan="2">Time (min)</th><th rowspan="2">Condition</th><th colspan="5">Load carrying capacity, % BW</th></tr>
<tr><th>0% Slope</th><th>5% Slope</th><th>10% Slope</th><th>15% Slope</th><th>20% Slope</th></tr>
<tr><td>20</td><td>Sherpa mode</td><td colspan="3">50(50)</td><td>50(44)</td><td>50(37)</td></tr>
<tr><td></td><td>Sherpa mode with basket holder</td><td colspan="5">50(50)</td></tr>
<tr><td>40</td><td>Sherpa mode</td><td colspan="2">40(40)</td><td>40(30)</td><td>40(27)</td><td>29(24)</td></tr>
<tr><td></td><td>Sherpa mode with basket holder</td><td colspan="3">40(40)</td><td>40(37)</td><td>40(33)</td></tr>
<tr><td>60</td><td>Sherpa mode</td><td>35(35)</td><td>35(31)</td><td>27(23)</td><td>23(21)</td><td>17(NR)</td></tr>
<tr><td></td><td>Sherpa mode with basket holder</td><td colspan="2">35(35)</td><td>32(29)</td><td>28(27)</td><td>25(23)</td></tr>
</table>

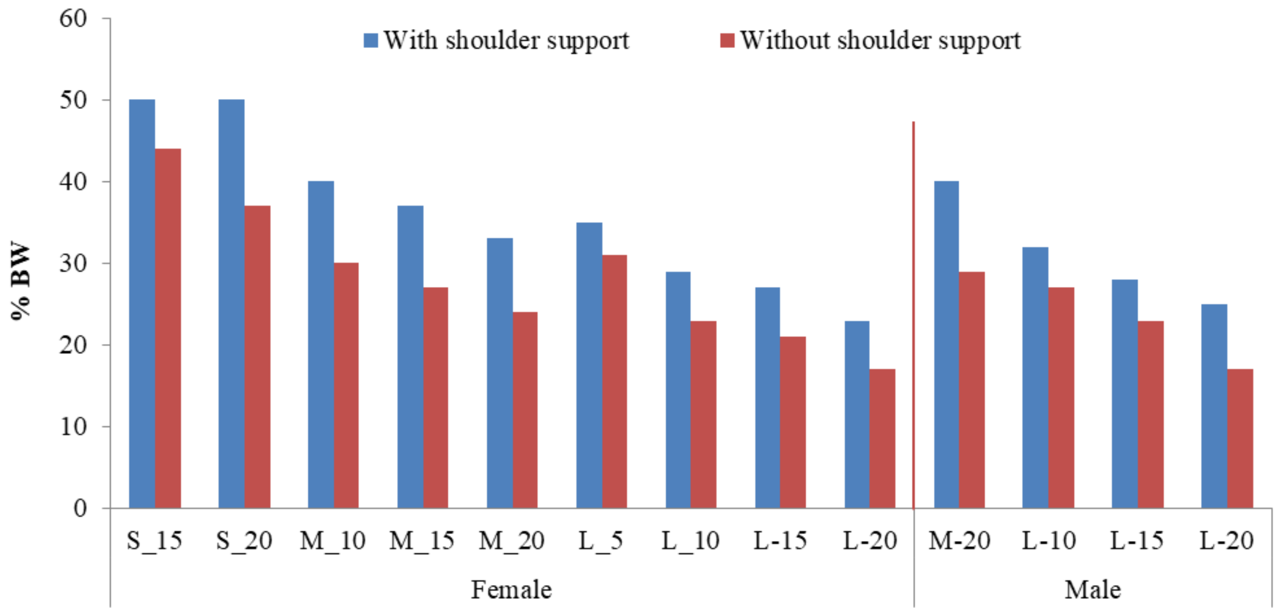


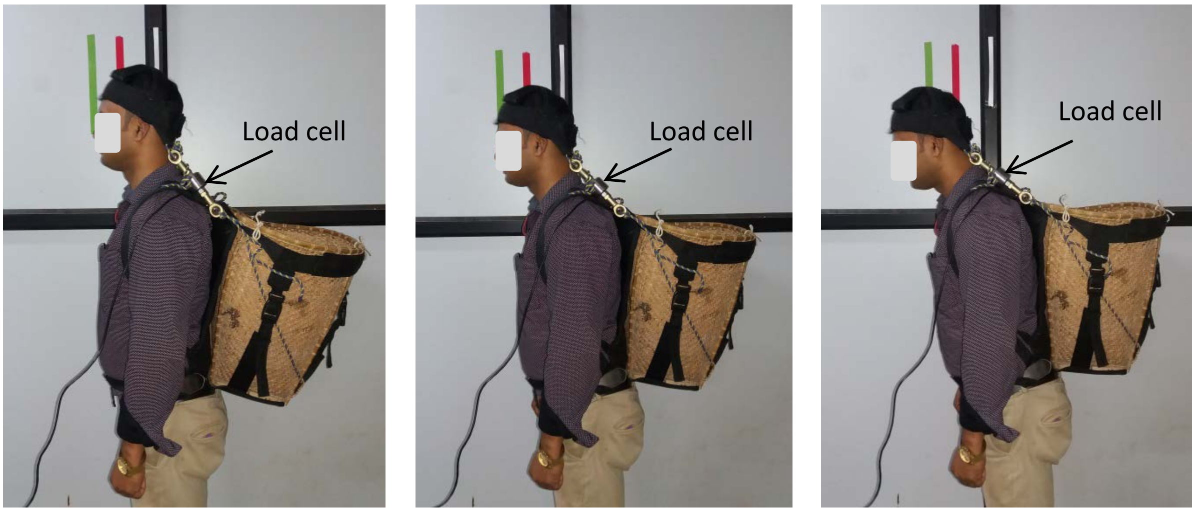
Figure 12 Comparison of basket holder with an existing mode in terms of %BW

Note: S_15: Short duration with 15% BW; M_10: Medium duration with 10% BW; L_5: Long duration with 5% BW; and so on

3.3 Load reduction in forehead

The effect of shoulder strap in reducing the load from the forehead was analyzed at three different postures (i) normal posture (0^o), (ii) slightly bending posture (25^o), and (iii) maximum bending posture (35^o). The measurement view is shown in Figure 13. The forces in the straps for the forehead were measured with load cells with and without shoulder support at four different loads in the basket.

The measured force is presented in Figure 14. It was observed that a significant amount of force is taken by the shoulder in all the postures. Further, it was concluded that an average of 84%, 54% and 48% load was reduced from the forehead in postures 1, 2 and 3, respectively. The force reduced from the forehead is transferred to the shoulder.



P1 P2 P3

Figure 13 Three different postures for experiments

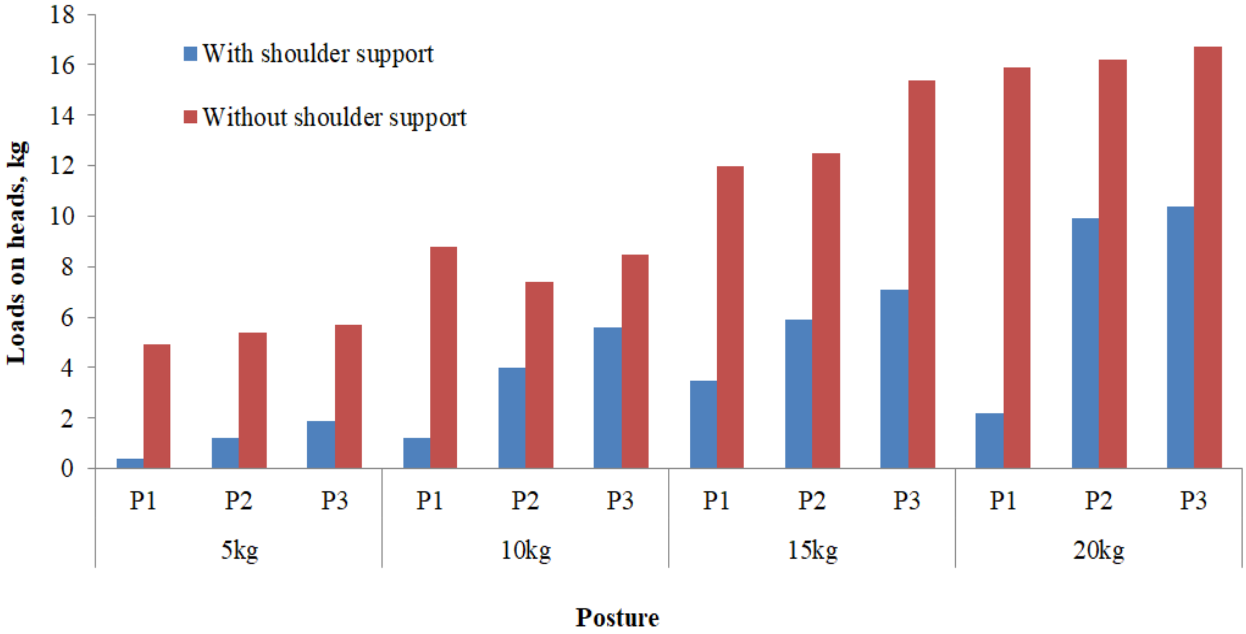


Figure 14 Load distribution on the head with and without backpack during load carrying

3.4 Body part discomfort analysis (BPD)

The assessment of uneasiness is valuable information for determining the physical match between workers and their work. To identify body parts where the pain was experienced during treadmill walking with the Sherpa method, the original body chart of Corlett and Bishop (1976) has been modified and divided body map into various segments, as shown in Figure 15.

Before the experiment, the subjects were acquainted with the measurement of work-related body parts discomfort scores.

The psychophysical measurement system used in the study was a five-point scale of perceived exertion (RPE) rating. Work-related body part discomfort scores used in this experiment are 1: Very light; 2: Light; 3: Moderately heavy; 4: Heavy; and 5: Very heavy.

The regions for evaluating body part discomfort score are shown in Figure 15. In the map, the body diagram was divided into 13 regions numbered for convenient reference and identification.

At the start of the work, the subject was asked about discomfort, if any. At the end of the experiment, the subject was asked to indicate their exertion or discomfort on RPE.

The same procedure was followed for other subjects in the whole experiment. The values obtained for all the subjects were averaged to get mean values.

The mean discomfort score was plotted with the help of the bar diagram, as shown in Figure 16. There were several regions where the participants experienced discomfort in the Sherpa method of load carriage. The regional body pain scores ranged between 0-4, except for the head and neck. The highest rating was given for the forehead and neck. Use of developed head strap and basket holder, musculoskeletal disorder significantly reduced compared to an existing design. In the modified design, discomfort rating was given significantly lower values for forehead and neck.

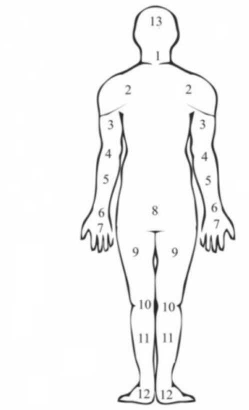
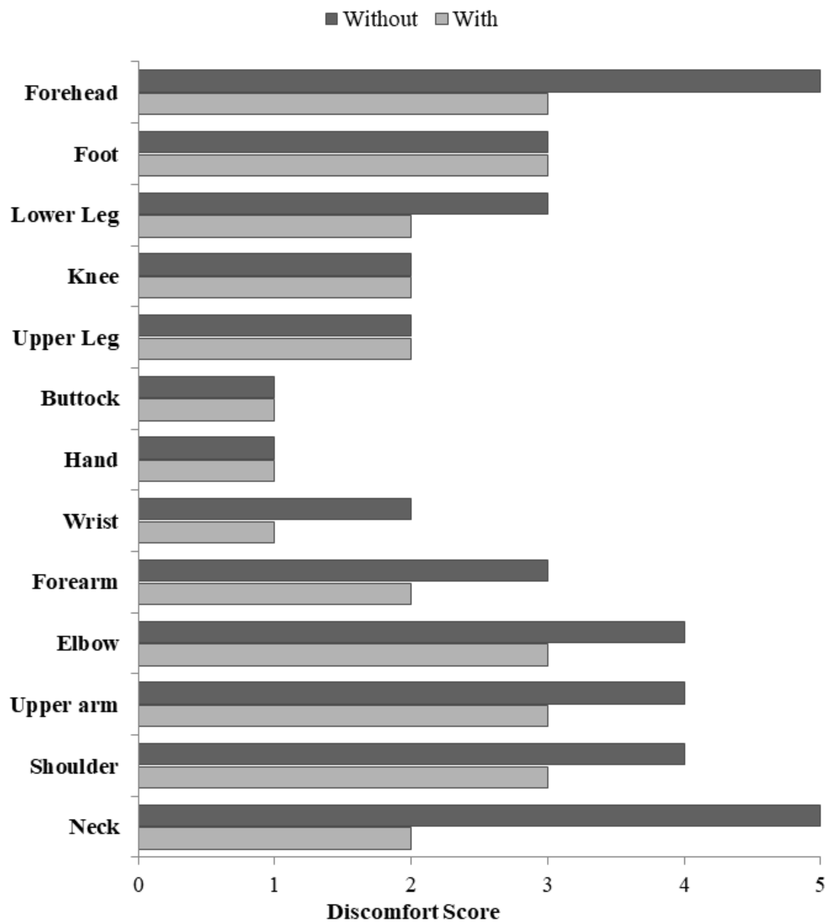


Figure 15 Body map for evaluation of work-related body part discomfort score



1: Very light; 2: Light; 3: Moderately heavy; 4: Heavy; and 5: Very heavy.

Figure 16 Discomfort scores in Sherpa method with and without basket holder

4 Conclusions

The present study is the first of its approach in recommending the optimum load for agricultural workers. The recommendations of permissible load carriage for the male at 50% of their body weight for a short duration and minimum 17% of their body weight at 20% slope for a long duration with the comfortable walking condition as prevailed in the laboratory. Female is not recommended to carry the load at 20% slope for a long duration. However, they can take 24% and 37% of BW at 20% slope for a medium and short duration. The MAWT was also recommended for different slopes. The male can carry the load for 33 and 210 minutes in one stretch in the Sherpa model with 45% of BW at 20% slope and 15% of BW at 0% slope, respectively, whereas the duration for their female counterpart is 15 and 178 minutes.

An adjustable basket holder for the Sherpa mode of load-carrying with shoulder support was developed, accommodating different types of the basket. The shoulder support reduced the forehead load by 48% to 84% at the different postures of workers. It was observed that maximum enhancement in load carrying for males and females with basket holders was 47% and 23%, at 20% slope for a longer duration of work, respectively. A significant reduction in body part discomfort was also observed at the forehead and neck.

References

Bastien, G. J., B. Schepen, P. A. Willems, and N. C. Heglund. 2005. Picking the best speed-load combination in backpack load carrying. *Computer Methods in Biomechanics and Biomedical Engineering*, 8(S1): 19–20.

Bink, B. 1962. The physical working capacity in relation to working time and age. *Ergonomics*, 5(1): 25-28.

Burton, K. A., R. D. Clarke, T. D. McClune, M. K. Tillotson. 1996. The natural history of low back pain in adolescents. *Spine*, 21(20): 2323-2328.

Corlett, E. N., and R. P. Bishop. 1976. A technique for assessing postural discomfort. *Ergonomics*, 19(2): 175-182.

Foster, C., and A. Lucia. 2007. Running Economy: the forgotten factor in elite performance. *Sports Medicine*, 37 (4–5): 316–319.

Goh, J. H., A. Thambyah, and K. Bose. 1998. Effects of varying backpack loads on peak forces in the lumbosacral spine during walking. *Clinical Biomechanics*, 13(1): S26-S31.

Holewijn, M. 1990. Physiological strain due to load carrying. *European Journal of Applied Physiology and Occupational Physiology*, 61(3): 237-245.

Hong, Y., J. Li, A. Wong, and P. Robinson. 2000. Effects of load carriage on heart rate, blood pressure and energy expenditure in children. *Ergonomics*, 43(6): 717-727.

Keren, G., Y. Epstein, A. Magazanik, and E. Sohar. 1981. The energy cost of walking and running with and without a backpack load. *European Journal of Applied Physiology and Occupational Physiology*, 46(3): 317–324.

Knapik, J., E. Harman, and K. Reynolds. 1996. Load carriage using packs: a review of physiological, biomechanical and medical aspects. *Applied Ergonomics*, 27(3): 207–216.

Liu, B. S. 2007. Backpack load positioning and walking surface slope effects on physiological responses in infantry soldiers. *International Journal of Industrial Ergonomics*, 37(9-10): 754–760.

Lloyd, R., and C. B. Cooke. 2000. The oxygen consumption associated with unloaded walking and load carriage using two different backpack designs. *European Journal of Applied Physiology*, 81(6): 486–492.

Maiti, R., and G. G. Ray. 2004. Manual lifting load limit equation for adult Indian women workers based on physiological criteria. *Ergonomics*, 47(1): 59-74.

Maritz, J. S., J. F. Morrison, J. Peter, N. B. Strydom, and C. H. Wyndham. 1961. A practical method of estimating an individual's maximal oxygen intake. *Ergonomics*, 4(2): 97-122.

Negrini, S., R. Carabalona, G. Pinochi, R. Malengo, and P. Sibilla. 1998. Backpack and back pain in school children: is there a direct relationship? *The Journal of Bone and Joint Surgery-British*, 80(3S): 247.

Patel, T., S. Karmakar, J. Sanjog, S. Kumar, and A. Chowdhury. 2013. Socio-economic and environmental changes with transition from shifting to settled cultivation in North-Eastern India: an ergonomics perspective. *International Journal of Agricultural Science and Research*, 3(2): 117-136.

Patel, T., R. L. Moraru, K. P. Vidhu, A. Kumar, and W. A. Singh. 2016. Physiological and perceptual responses in the Sherpa method of carrying loads: Role of hip belt and shoulder strap supports. *CIGR Journal*, 18(4): 157-164.

Quesada, P. M., L. J. Mengelkoch, R. C. Hale, and S. R. Simon. 2000. Biomechanical and metabolic effects of varying backpack loading on simulated marching. *Ergonomics*, 43(3): 293–309.

Robertson, R. J., C. J. Caspersen, T. G. Allison, G. S. Skrinar, R. A. Abbott, and K. F. Metz. 1982. Differentiated perceptions of exertion and energy cost of young women while carrying loads. *European Journal of Applied Physiology and Occupational Physiology*, 49(1): 69-78.

Saha, P. N., S. R. Datta, P. K. Banerjee, and G. G. Narayane. 1979. An acceptable workload for Indian workers. *Ergonomics*, 22(9): 1059-1071.

Samanta, A., S. R. Datta, B. N. Roy, A. Chatterjee, and P. K. Mukherjee. 1987. Estimation of maximum permissible loads to be carried by Indians of different ages. *Ergonomics*, 30(5): 825–831.

Simpson, R. J., S. M. Graham, C. Connaboy, R. Clement, L. Pollonini, G. D. Florida-James. 2017. Blood lactate thresholds and walking/running economy are determinants of backpack-running performance in trained soldiers. *Applied Ergonomics*, 58(January): 566–572.

Soule, R. G., K. B. Pandolf, and R. F. Goldman. 1978. Energy expenditure of heavy load carriage. *Ergonomics*, 21(5): 373–381.

Stuempfle, K. J., D. G. Drury, and A. L. Wilson. 2004.Effect of load position on physiological and perceptual responses during load carriage with an internal frame backpack. *Ergonomics*, 47(7): 784-789.

Wasserman, K., J. E. Hansen, D. Y. Sue, B. J. Whipp, and V. F. Froelicher. 1987. Principles of exercise testing and interpretation. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 7(4): 189.

Waters, T. R., V. Putz-Anderson, and A. Garg. 1994. Applications manual for the revised NIOSH lifting equation, DHHS (NIOSH) No. 94, (US Department of Health and Human Services, Centers for Disease Control and Prevention, NIOSH, Cincinnati, OH).