Indian J Physiol Pharmacol 2012; 56(2) : 130–136

CARDIORESPIRATORY CHANGES WITH COMPACT BACKPACK SYSTEM AND DISTRIBUTED MODE OF LOAD CARRIAGE

TIRTHANKAR CHATTERJEE, DEBOJYOTI BHATTACHARYYA, MADHUSUDAN PAL AND DHURJATI MAJUMDAR*

Ergonomics Division,
Defence Institute of Physiology and Allied Sciences,
Defence R & D Organization,
Lucknow Road, Timarpur, Delhi – 110 054

(Received on June 30, 2011)

Abstract : In Indian Army, soldiers normally carry 21.4 kg in backpack (BP), haversack, and web distributed in different parts of the body and rifle in hand. This load distribution is unequal, may involve excess energy expenditure, mostly uncomfortable, and restricts the normal movement of the hand carrying rifle. A new BP has been developed which accommodates the rifle on sides leaving the hands free. Physiological evaluation of load carriage [21.4 kg in the existing Load Carriage ensembles (LCe) and in the new BP] and without load was carried out on a group of Indian Army soldiers (n= 8) to understand the efficacy of the new BP vis-á-vis the existing one at 4.5 km/h speed at level ground and at 5% gradient on a treadmill in controlled laboratory environment. Heart rate, oxygen consumption, relative work load and energy expenditure were determined and one-way repeated measure ANOVA was applied to compare the results. All the physiological parameters showed higher responses in distributed mode in comparison to compact mode. However, the differences were not significant. The study may be carried out on a larger sample size to find out the better efficacy of compact mode of load carriage over the distributed mode.

Key words : load carriage compact mode distributed mode

INTRODUCTION

Carrying moderate to heavy load is a common phenomenon in military operations and many industrial setups. In Indian Army, soldiers have to carry loads ranging from 20 to 30 kg in different terrains and extreme environmental conditions. The composite load in existing Load Carriage ensembles (LCe) amounts to be 21.4 kg and consists of backpack (BP, 10.7 kg), haversack (HS, 4.4 kg) and web (2.1 kg) distributed in different parts of body and INSAS rifle (4.2 kg) in hand. This load distribution is unequal and may cause problems in the body of the user. The LCe contains specific items as per the requirement of soldier for different operations. BP is placed at the back while

*Corresponding Author : Dr. Dhurjati Majumdar Sc 'F' & Additional Director, Ergonomics Division, Defence Institute of Physiology and Allied Sciences, Defence R & D Organization, Lucknow Road, Timarpur, Delhi – 110 054, Ph. No. : 01123883014, 01123935745, Email : majum55@yahoo.com

web is tied in front of the body. Weight distribution in this combination of frontpack (FP) and backpack (BP) is unequal. According to previous researchers the FP – BP combination becomes most economical in terms of energy cost when equal load is given in both sides of the body (1). Placement of HS on the body is not fixed. Sometimes it is placed on the either side of the body or attached in the lower portion of the back with the belt at the bottom of the BP. These arrangements are mostly uncomfortable to the user. Carrying rifle in right hand restricts normal swinging motion of the said arm. Birrel and Haslam (2) showed that restricted arm movement caused body's centre of mass to deviate from its normal path which might lead to excess energy expenditure.

Different modes of load carriage have been thoroughly investigated by several researchers in the past (3-13). Considerable research has been carried out to determine best method of load carriage that minimized the physical stress on the body (1, 7, 14-17). But the studies on physiological effects of distribution of load in different parts of the body are very few (18-20).

In most of the earlier studies load was placed as single unit (CM) such as BP. Pal et al (21) compared the effect of carrying 10.7 kg load in compact BP and distributed mode (DM) and found that physiological cost was more in DM than in CM during level walking. The present study was designed to evaluate the cardiorespiratory responses of carrying standard 21.4 kg military load in two different modes (CM and DM) at 4.5 km/h walking speed in two different gradients by Indian soldiers.

METHODS

Eight physically fit male soldiers of Indian army without any history of musculoskeletal disorders or cardiovascular pathology and with a service experience of atleast four years volunteered for this study. Their mean (SD) age, height, weight and maximum aerobic capacity (VO_{2max}) were 29.83 (2.86) yrs, 165.5 (3.15) cm, 63.5 (5.47) kg and 31.88 (4.13) ml/min/kg. respectively. They signed informed consent before participating in the experimental procedure.

Experimental details

A clearance from the Ethical Committee was obtained for the study. Thereafter, soldiers were briefed about the purpose and the risk of the study. Initially, they were allowed to walk on treadmill (Taeha, Intertrack 6025, Korea) for habituation at various speeds without and with loads at different gradient in the laboratory. After that maximum oxygen consumption (VO_{2max}) of the subjects was measured during treadmill exercise with regular increase in the gradient (Harbor protocol, 22), keeping the speed constant. During the measurement of VO_{2max} subjects wore vest, underwear, shorts and physical training shoes. On the day of experiment all the subjects reported to the laboratory at 0800 hrs after light breakfast. They were allowed to take rest for one hour before the commencement of experiment. Subjects were debarred from smoking and taking any food till they were in the laboratory. During the experiment subjects wore full Indian Army combat uniform including combat boot (weighing 2.5 kg). Load carriage experiments were carried out on each subject with 21.4 kg load

(33.5% of body weight) in two different modes (CM and DM) and without load (NL) at 4.5 km/h walking speed and at two gradients (0 and 5%) on treadmill for 10 min duration. Distributed mode (Fig. 1) of load comprised of BP (10.7 kg) on the back, HS (4.4 kg) in the waist region, web (2.1 kg) tied in front at abdomen and INSAS rifle (4.2 kg) in hand. Compact mode involved carrying 21.4 kg load with all belongings of the DM including rifle fitted into newly designed larger BP (CM) (Fig. 2a, b). The mode, magnitude and placement of the loads are given in Table I. A total of 48 experiments (3 Loads × 2 Grades × 8 subjects) were performed. Each subject was required to complete two conditions per day (between 0930 hrs to 1300 hrs), with atleast 60 min rest between two experiments.

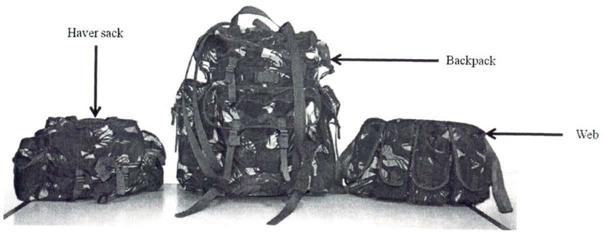

Fig. 1: Existing Load Carriage Ensembles.

Fig. 2a: Newly designed backpack (Front view).

Fig. 2b: Newly designed backpack (Back view).

Cardiorespiratory measurements

All load carriage experiments were conducted in controlled laboratory environment at 22°–25°C, 50–55% relative humidity, at same hours of the day between 0930 hrs and 1330 hrs for eliminating specific dynamic actions of food for all practical purposes. During the experiments, heart rate (HR), oxygen uptake (VO_2), relative work load ($\%VO_{2max}$) and energy expenditure (EE) of each of the individuals were determined by the process of breath by breath gas analysis using $K4b^2$ system ($K4b^2$, Cosmed, S.r.l, Italy). Average of the last 3 minutes HR, VO_2, $\%VO_{2max}$ and EE data of 10 min walking trial were considered as individual value and subjected to statistical treatment.

Statistical analysis

A descriptive statistics in the form of

TABLE I : The mode, magnitude and placement of load during load carriage experiment.

Condition	*Weight (kg)*	*Placement of load*	*Mode*	*% of body (kg) weight*
NL	0.0	No load	–	–
DM	21.4	10.7 kg BP on the back, 4.4 kg HS in the waist, 2.1 kg web in front near abdomen and 4.2 kg Rifle in hand.	Distributed mode	33.5%
CM	21.4	Modified larger BP	Compact mode	33.5%

mean and standard deviation is presented in table II for various cardiorespiratory parameters e.g HR, VO_2, $\%VO_{2max}$ and EE.

An one-way repeated measure ANOVA was applied as the same subjects were used for NL, DM and CM conditions at 0% and 5% gradient to see overall significance across the conditions. Followed by the significance observed for the various cardiorespiratory parameters across the conditions mentioned above a Bonferroni Post-Hoc. test was applied to compare between the conditions pair wise. For all the tests statistical significance were verified at P<0.05 level.

RESULTS

The results revealed that the significant changes in HR [$F_{(1.14, 8.04)}$ = 19.61, P<0.05 at 0% gradient; $F_{(2, 14)}$ = 226.41, P<0.05, at 5% gradient], VO_2 [$F_{(1.06, 7.43)}$ = 17.10, P<0.05 at 0% gradient; $F_{(1.08, 40.01)}$ = 28.61, P<0.05 at 5% gradient], $\%VO_{2max}$ [$F_{(1.04, 7.33)}$ = 13.76, P<0.05 at 0% gradient; $F_{(1.09,7.67)}$ = 28.90, P<0.05 at 5% gradient] and EE [$F_{(1.15, 8.11)}$ = 37.30, P<0.05 at 0% gradient; $F_{(1.05, 7.41)}$ = 65.27, P<0.05, at 5% gradient] across NL, DM and CM conditions at 0% and 5% gradient (Table II).

After performing Bonferroni Post-Hoc, test significant increase in HR was observed for DM (21.07% at 0% and 30.92% at 5% gradient, P<0.05) and CM (18.15% at 0% and 27.06 % at 5%, P<0.05) in comparison to NL at 0% and 5% gradients. However, the increase in HR was found to be insignificant when DM and CM were compared at 0% (2.46%) and 5% (3.10%) gradient.

TABLE II : Mean±SD of different physiological parameters in three modes and two gradients of load carriage at constant speed (4.5 kmph).

Parameters	*Gradients (%)*	*Load*			*% Increase*		
		NL	*DM*	*CM*	*NL vs DM*	*NL vs CM*	*DM vs CM*
HR	0	92.8±7.05	112.3±13.97	109.5±12.69	21.07*	18.15*	2.46^{NS}
(Beats/mm)	5	105.7±10.24	137.9±9.06	133.8±9.90	30.92*	27.06*	3.10^{NS}
VO_2	0	11.63±2.35	16.07±4.01	15.54±4.29	38.67*	33.18*	4.23^{NS}
(ml/min/kg)	5	16.20±2.80	22.03±5.16	21.38±4.87	35.26*	31.37*	2.96^{NS}
$\%VO_{2max}$	0	35.47±6.26	49.44±14.17	47.84±14.97	38.67*	33.18*	4.23^{NS}
	5	49.62±8.87	67.40±16.21	65.56±15.53	35.26*	31.37*	2.96^{NS}
EE	0	3.98±0.65	5.28±0.80	5.11±0.89	33.72*	28.98*	3.81^{NS}
(Kcal/min)	5	5.47±0.65	7.36±0.95	7.12±1.02	34.73*	30.11*	3.65*

*P<0.05, NS = Not significant.

The increase in VO_2 was found to be significant for DM (38.67% at 0% gradient and 35.26% at 5% gradient, $P<0.05$) and CM (35.26% at 0% gradient and 31.37% at 5% gradient, $P<0.05$) in comparison to NL at 0% and 5% gradient. However, the increase in VO_2 was found to be insignificant when DM and CM were compared at 0% (4.23%) and 5% (2.75%) gradient.

The increase in $\%VO_{2max}$ was found to be significant for DM (38.67% at 0% gradient and 35.26% at 5% gradient, $P<0.05$) and CM (33.18% at 0% gradient and 31.63% at 5% gradient, $P<0.05$) in comparison to NL at 0% and 5% gradient. However, the increase in $\%VO_{2max}$ was found to be insignificant when DM and CM were compared at 0% (4.23%) and 5% (2.96%) gradient.

There was a significant increase in EE for DM (33.72% at 0% gradient and 34.73% at 5% gradient, $P<0.05$) and CM (28.98% at 0% gradient and 30.11% at 5% gradient, $P<0.05$) in comparison to NL at 0% and 5% gradient. At 5% gradient the increase in EE was found to be significant (3.65%, $P<0.05$) when DM and CM were compared. However, the increase was found to be insignificant (3.81%, $P<0.05$) at 0% gradient for the same comparison.

DISCUSSION

The present study was conducted to explore whether any differences exist in physiological responses while carrying the same magnitude of the load in the DM and CM. Results showed overall significant changes in all four physiological parameters recorded across NL, DM and CM. Similar finding was observed by Soule et al (23) who found that the demands of energy cost during load carriage probably depend on the pattern of load distribution. If the load is well distributed, balanced and placed close to the centre of the body it demands less energy cost than load in unbalanced positions. Results of their study revealed a lower energy cost when carrying the load in the CM. Malhotra and Sengupta (5) conducted load carriage experiment on school children (carrying school bags weighing 6.0 lb in four different position, i.e. rucksack, low back, across the shoulders and hands) to identify the most economical way of carrying school bags by them. They concluded that rucksack was the most economical and efficient, whereas the hand carriage was the most inefficient method in terms of energy expenditure for Indian children. Bonferroni Post-Hoc. test revealed that there were significant increase in all the physiological parameters from condition NL to conditions DM and CM, but the increases were not significant when conditions DM and CM compared, except the EE at 5% gradient which showed a significant increase for condition DM than condition CM (Table II). In previous studies (6, 7) the principle of keeping the load close to the trunk was followed by placing it in a CM (e.g. double pack). In the present study the CM is a single unit which utilizes the large muscle mass of back and trunk. At the same time arms are left free to swing normally to maintain the centre of mass of the body in its utmost position for minimum energy expenditure. This arrangement allowed the body to move in a more balanced way compared to the DM.

Rifle carriage in hand may be considered as an isometric work. Jackson et al (24) showed that when an isometric exercise component was added to a dynamic exercise task, cardiovascular responses were elevated above levels noted for the dynamic exercise alone. In the existing DM, INSAS rifle is carried in hand that disturbs the balance and normal swing of arm during load carriage. Graves (25) compared between hand weight, wrist weight and ankle loads and found 1.36 kg increase in hand or wrist weight increases the energy cost more than ankle weight and provided additional exhaustion to the upper body. Other researchers have also found that load carriage in hand is among the worst when compared between modes of load carriage (6, 7). Birrel et al (26) studied the effect of military load carriage on ground reaction force. They found rifle carriage and restriction of natural swing changed vertical and horizontal position of the body's centre of mass. Birrel and Haslam (2) showed restricted arm movement due to rifle carriage in one hand causes increased range of motion of body's centre of mass. Extra energy may be required to normalize centre of mass in this situation. Greater muscular activity of the arm and shoulder carrying rifle may be the key factor behind excess physiological cost with distributed mode in our study. This observation is in line with the present study where there was a significant increase in EE at 5% gradient with DM compared to the CM.

In the existing load carriage system (DM), BP is attached to an outside metallic frame to hold it properly. This frame has fixed dimensions, thus less compatible to major population group of the Indian Army. In the newly designed CM, the BP is provided with a telescopic frame inside. This arrangement allows the user to adjust the frame according to the length of their back. Compact mode has other features like additional waist strap which holds the bag close to the body so that the centre of mass does not move away. The changes in all physiological parameters were less in CM compared to DM. The result of the study indicates that CM as the better mode of load carriage than DM. The study may be carried out on a large number of subjects for further verification of the efficacy of CM over DM.

The knowledge of this study will help in design and development of new load carriage ensembles to reduce the cardiorespiratory burden during load carriage.

ACKNOWLEDGEMENTS

The authors wish to thank all the volunteers who participated whole heartedly in the study. The authors are grateful to all the staff of Ergonomics laboratory who have contributed and cooperated in the study.

REFERENCES

1. Legg SJ. Comparison of different methods of load carriage. *Ergonomics* 1985; 28: 197–212.
2. Birrel SA, Haslam RA. The influence of rifle carriage on the kinetics of human gait. *Ergonomics* 2008; 51: 816–826.
3. Bedale M. Comparison of the energy expenditures of a woman carrying loads in eight different positions. Industrial Hygiene Research Board Report No. 29, Medical Research Council, London. 1924.
4. Das SK, Saha H. Climbing efficiency with different modes of load carriage. *Indian J Med Res* 1964; 54: 866–871.

5. Malhotra MS, SenGupta J. Carrying school bags by children. *Ergonomics* 1965; 8: 55–60.

6. Datta SR, Ramanathan NL. Ergonomic comparison of seven modes of carrying load on horizontal plane. *Ergonomics* 1971; 14: 269–278.

7. Datta SR, Ramanathan NL. A preliminary investigation of ergonomics of load carrying. *Indian J Physiol Allied Sci* 1967; 21: 134–142.

8. Datta SR, Chatterjee BB, Roy BN. The relationship between energy expenditure and pulse rates with body weight and load carried during load carrying on level ground. *Ergonomics* 1973; 16: 507–513.

9. Cathcart EP, Richardson DT, Campbell W. Army hygiene advisory committee report No. 3- on the maximum load to be carried by the soldier. *J Royal Army Med Corps* 1923; 40: 435–443; ibid., 41: 12–24, 87–98: 161–178.

10. Lind AR, McNichols GW. Cardiovascular responses to holding and carrying weights by hand and by shoulder harness. *J Appl Physiol* 1968; 25: 261–267.

11. Renbourne ET. The knapsack and pack. A historical and physiological survey with particular reference to the British Soldier. Part II. *J Royal Army Med Corps* 1954; 100: 77–88.

12. Samanta A, Chatterjee BB. A physiological study of manual lifting of loads in Indians. *Ergonomics* 1981; 24: 557–564.

13. Soule RG, Goldman RF. Energy cost of loads carried on the head, hands or feet. *J Appl Physiol* 1969; 27: 687–690.

14. Legg SJ, Mahanty A. Comparison of five modes of carrying a load close to the trunk. *Ergonomics* 1985; 28: 1653–1660.

15. Kirk J, Schneider D. Physiological and Perceptual responses to load-carrying in female subjects using internal and external frame backpacks. *Ergonomics* 1992; 35: 445–455.

16. Jacobson B, Jones K. Comparison of selected perceptual variables for backpacks with internal and external frames. *Percept Mot Skills* 2000; 90: 605–608.

17. Lloyd R, Cook CB. The oxygen consumption associated with unloaded walking and load carriage using two different backpack design. *Eur J Appl Physiol* 2000; 81: 486–492.

18. Johnson DH, Knapik JJ, Merullo DJ. Symptoms during load carrying: effects of mass and load distribution during a 20 km road march. *Percept Mot Skills* 1995; 81: 331–338.

19. Legg SJ, Ramsey T, Knowles DJ. The metabolic cost of backpack and shoulder load carriage. *Ergonomics* 1992; 35: 1063–1068.

20. Abe D, Yanagawa K, Niihata S. Effects of load carriage, load position and walking speedon energy cost of walking. *Appl Ergon* 2004; 35: 329–335.

21. Pal MS, Majumdar Deepti, Dhara PC, Majumdar D. Cardiorespiratory responses of military load carriage with varying walking speeds and Gradients. *Indian J Biol Sci* 2007; 13: 1–9.

22. Wasserman K, Hansen JE, Sne DY, et al. Principles of Exercise Testing and Interpretation. 2nd ed. Philadelphia. Lea and Febiger. 1994; 112–131.

23. Soule RG, Pandolf KB, Goldman RF. Energy expenditure of heavy load carriage. *Ergonomics* 1978; 21: 373–381.

24. Jackson DH, Reevs TJ, Sheffield LT, Burdeshaw J. Isometric effects of treadmill exercise response in healthy young men. *Am J Cardiol* 1973; 31: 344–350.

25. Graves JE, Martin D, Miltenberger LA, Pollock ML. Physiological responses to walking with hand weights, wrist weights, and ankle weights. *Med Sci Sports Exerc* 1988; 20: 265–271.

26. Birrel SA, Hooper RH, Haslam RA. The effect of military load carriage on ground reaction forces. *Gait and Postures* 2007; 26: 611–614.