1. Introduction

Throughout recorded history, mankind has transported loads from place to place manually using different carrying devices, however primitive, such as yokes, rucksacks and backpacks (BP). Carrying load has always been an integral part of many occupational, recreational and household tasks. Today, despite technological advances and automation, this basic form of man-powered transportation remains an indispensable resource for many occupational tasks and several daily life activities. Manual handling of loads and load carriage forms an integral part of a soldier's daily schedule, whether he is posted in plains or in high altitude. The physical movements and associated demands involved in load carriage operations vary according to nature of duty. The possible determinants of an individual's load carriage ability may include age, anthropometric attributes, anaerobic and aerobic power, muscle strength, body composition and gender. Other relevant factors may be dimensions and placement of loads, biomechanical factors, nature of terrain and gradient, effect of climate and protective clothing. The energy cost of walking with loads have been found to primarily depend on walking speed, body weight and load weight together with terrain factors, e.g., surface type and gradients. The prediction of energy expenditure influenced by these variables may provide valuable information for assessing severity of proposed task of load carriage. It is well established that the anthropometric dimensions of a population (e.g., stature, limb lengths and breadths, body weight and body composition, etc.) serve as important determinants of load carriage ability of that population (Haisman 1988, Knapik et al. 1996, 1997). Body dimensions related to height (e.g. stature, sitting height, etc.) and hip breadth are most critical in describing international variations (Sangdon and Ramus 2008). Sizing surveys by different countries (SizeUK, SizeUSA, SizeMexico, SizeThailand, etc.) indicate that ethnic variability of body size and body dimensions cannot be overlooked while evaluating the load carriage capacity of a particular population. The variations in physical characteristics between Indians and Westerners are known and it is expected that these variations may also affect the biomechanical responses of gait during load carriage operations in Indian population with respect to Westerners. This makes extrapolation of load carriage standards formulated for Westerners not feasible for deciding maximum or optimum load to be carried by Indian soldiers, either for maritime or for war time activities

The ability of soldiers to carry heavy load has been a subject of interest for many years. An infantry soldier carries minimum 40 kg load in addition to his body weight for marching order. The load includes his ration, water, ammunition, clothing, etc. In addition, he carries radio sets and/or other electronic equipment weighing 10-15 kg or more for long duration. Similar loads are required to be carried by soldiers of Artillery Units, Engineering Corps., etc. Carrying heavy and unequally distributed load for long duration causes physiological and biomechanical stresses and produces body soreness, aches, back pain, tiredness, exhaustion, burning out, injury, march fracture and an overall loss of physical performance of the soldier. The soldiers suffer from these associated ailments which are similar to that suffered by unskilled labourers lifting and carrying heavy loads to earn their livelihood (Datta and Ramanathan, 1971). Snook (1978) reported that load lifting and carrying represent principal sources of compensable work injuries in the United States.

It is therefore important to distinguish between the maximum load carrying capacity and optimal load or load carrying ability of an individual which enables him to retain the capacity to perform other tasks, e.g., observation, navigation and combat operation. Physiological studies remain inconclusive about definition of a maximum load, but suggested that one-third body weight or relative workload equivalent to one-third of VO_2max for a working day as optimal load. These studies however cautioned about the proper distribution of load around the human body and minimization of biomechanical stress for optimum performance.

In order to ensure a minimum expenditure of energy for load carriage and design of such equipment certain biomechanical factors are most essential: a) Maintenance of normal posture and centre of gravity of the body b) Maintenance of normal and free gait c) Elimination of local strain and d) Chest freedom. Studies in developed countries have indicated that carriage of heavy load and improper and inadequate distribution of load for long duration leads to severe biomechanical stress and increasing shearing forces in various joints and muscular system of the body with decrease in stride length, stride frequency, and trunk angular motion but increase in double support, stance period, trunk forward lean motion, etc. These changes are presumed to increase energy expenditure and injury risk and decrease in safety and efficiency of the individual for load carriage operation. In case of soldiers, they may further hamper in the navigational, skilled performance, maneuverability, marksmanship and combat performance.

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Scientific evaluation and quantification of biomechanical stress due to load carriage in Indian population has not been reported so far, either for civilian or for military population. Therefore, presently no guidelines exists on how the load should be distributed on various parts of the body and how the LCe should be designed to suite the anthropometry and biomechanics of the soldiers with diverse ethnic variability existing in Indian Army. Under field situations, the modes of load carriage and load magnitudes for carriage remained same for all ethnic groups including both extremes of physical structures, like the shortest Gorkha population and tallest Sikh-Punjabi soldiers for all conditions of environments and terrains in Indian Army. Their LCe also remained same in size for the whole population. However, it is now well known from studies undertaken in other parts of the globe that ignoring the anthropological attributes and kinematic and kinetic responses of the soldiers (Kinoshita 1985, Lloyd and Cooke 2000b, Attwells et al. 2006, Birrell et al. 2007, Birrell and Haslam 2008) may cause serious compromises in terms of mobility, agility, cognitive and physical performance and result into early fatigue and considerable decrease in combat fitness. As gait is a balanced operation, any variation in gait parameters may lead to excess metabolic demand and early fatigue. Military load carriage involves carrying loads of different shapes and sizes on different parts of the body e.g., back, waist**,** hand and shoulder. Presently there is no reported study on the biomechanical aspect of load carriage on Indian population. No guidelines exists on how the load should be distributed in various parts of the body and how the load carriage ensembles should be designed to suite the anthropometry and biomechanics of the soldiers of Indian Army. It is need of the modern warfare scenario that the soldier must be properly loaded with maximum freedom of mobility.

Present study was therefore designed to investigate the biomechanical responses of load carriage operation with response to different load carriage ensembles presently used by Indian Infantry soldiers. The study also attempted to optimize the load carriage operations for the same group of population.

2. OBJECTIVES

(i) Evaluation of kinematic changes during load carriage operations at two speeds on level ground

(ii) Evaluation of kinetic changes during load carriage operations on level ground

(iii) Suggest possible modifications in the load carriage operations including load and load carriage ensembles used in Indian Army

2.1 Scope

1. The study will generate database on kinematic and kinetic aspects of gait during load carriage in Indian soldier population.
2. Quantification of changes in certain biomechanical parameters on unequal distribution of load over body will facilitate the evaluation of the stresses involved in load carriage operations in Indian Armed Forces.
3. Understanding the design deficits of existing LCe being used in Indian Armed Forces and suggestion of possible design modification for better performance of the soldiers.
4. Suggestion of proper distribution of load around the body in order to reduce physical strain and fatigue and enhance performance in terms of changes in kinematic and kinetic parameters.

3. METHODOLOGY

In this study changes in kinematic and kinetic parameters of gait in soldiers of Indian Armed Forces during load carriage operations were studied. For this, first loads, load carriage ensembles and mode of load carriage were identified. Subjects were selected randomly based on age range, years of service and physical fitness. Both kinematic and kinetic studies were carried out on same set of subjects on same load carriage conditions but on different days. The laboratory set up was carried out and instruments used for kinematic and kinetic data collection were standardized prior to the study using standard procedure. The complete description of procedure for kinematic and kinetic data collection along with hardware and software setup follows.

3.1 Load

Weight of the subject while wearing vests, shorts and military boots was designated as no load (NL) condition where external load was 0% of the body weight. Soldiers in Indian Army, while on load marches carry their essentials, equipment and ammunitions in specific ensembles. The final weight of these ensembles along with the items that it would contain is fixed. Commonly carried ensembles are backpack (BP, 10.7kg) and haversack (HS, 4.4kg). They are carried on different parts of the body and in different combinations, as per requirement. Indian small arms system (INSAS) Rifle (4.2kg) and light machine gun (LMG, 6.8 kg) are carried in hand (RH) or on shoulder. Details of the load carriage operations carried out are given in Table 1.

Table 1. Different load magnitude (kg) and modes of load carriage operations for kinematic and kinetic studies and the load as % of mean body weight (n=10)

S. No.	Load Carriage Operations	Load (kg)	% of Mean Body Wt.
1.	No Load, with vests, shorts and military boots (NL)	0.0	-
2. & 3.	INSAS Rifle (loaded) in hand (RifleH) & on shoulder	4.2	6.5
4.	Haversack containing tiffin box with ration, water bottle and personal accessories (HS)	4.4	6.8
5. & 6.	LMG (loaded) in hand (LMGH) and on shoulder	6.8	10.6
7. & 8.	HS, INSAS Rifle (loaded) in hand (HSRifleH) and on shoulder	8.6	13.4
9.	Backpack containing P.T. shoes, blanket, mosquito net, rug, rain coat, etc. (BP)	10.7	16.6
10. & 11.	HS, LMG (loaded) in hand (HSLMGH) and on shoulder	11.2	17.4
12. & 13.	BP, INSAS Rifle (loaded) in hand (BPRifleH) and on shoulder	14.9	23.2
14. & 15.	BP, LMG (loaded) in hand (BPLMGH) and on shoulder	17.5	27.2

Figure 1. Loads and Load Carriage Ensembles (LCe) used in Indian Armed Forces.
A : Front view of BP; B: Side view of BP; C: Scaffolding Structure of BP;
D : Haversack (HS); E : Indian Small Arms System (INSAS) Rifle
F: Light Machine Gun (LMG)

Soldiers carry Rifle or LMG ammunition as magazine in the Web attached to the waist region in front of the body. The same could not be applied due to obscuration of the markers while collecting data. Following load maneuvers could be administered without causing any loss of data due to obscuration of markers during data collection : No load (NL, 0kg, 0% BW), INSAS Rifle (Rifle, 4.2kg, 6.5% BW) in hand (RH) and on shoulder, Haversack (HS, 4.4kg, 6.8% BW), Light Machine Gun (LMG, 6.8kg, 10.6% BW) in hand (LMGH) and on shoulder, Backpack (BP, 10.7kg, 16.6% BW), Haversack and INSAS Rifle (HSRifle, 8.6kg, 13.4% BW) in hand (HSRifleH) and on shoulder, Haversack and LMG (HSLMG, 11.2kg, 17.4% BW) in hand (HSLMGH) and on shoulder, Backpack and Rifle (BPRifle, 14.9kg, 23.2% BW) in hand (BPRifleH) and on shoulder, Backpack and LMG (BPLMG, 17.5kg, 27.2% BW) in hand (BPLMGH) and on shoulder. These combinations were designed to simulate the actual load carriage activities frequently carried out by Infantry soldiers in field situation.

Table 1 gives detail account of the items contained in these ensembles and it also represents loads as % of mean body weight (BW).

3.2 Subjects

A requisition for ten subjects was made to the Indian Armed Forces administration body. The inclusion criteria for selection of the subjects were that subjects should be within age range of 20-30 years, having comparable height and weight and be physically fit and that they should be from Infantry division. They required to be familiar with load carriage operations carried in Indian Armed Forces for at least 3-5 yrs. The exclusion criteria included any pre-existing musculoskeletal disorders, e.g., back ache, neck pain, etc., history of injury, fracture or any other physical indisposition.

Ten randomly selected healthy male infantry soldiers volunteered for the study. They were sent to the laboratory in two batches of five each. After the kinematic and kinetic data collection on one batch was completed, next batch followed. When subjects arrived at the laboratory for the first time, they were familiarized with the scientific equipment to be used by fitting them with markers and collection of demo trials, so as to assure them of the non-invasive nature of the study and were given necessary information regarding the experimental procedure. They signed informed consent before commencement of the study. The mean (SD) age, height and weight of ten subjects were 23.3(2.6)yrs, 172.0(3.8)cm and 64.3(7.4)kg, respectively. Table 2 gives their physical characteristics.

Table 2. Physical characteristics of the subjects for kinematic and kinetic studies

		Mean(SD)
1.	No. of Subjects	10
2	Age(yrs)	23.3(2.6)
3.	Height(cm)	172.0(3.8)
4.	Weight (kg)	64.3(7.4)
5.	Right Foot Length(cm)	26.5(0.92)
6.	Right Foot Width (cm)	10.1(0.67)
7.	Left Foot Length(cm)	26.6(0.97)
8.	Left Foot Width (cm)	10.1(0.68)

3.3 Walking Speed

Kinematic data was collected at level ground while walking with two speeds. Each subject was first asked to walk at his own comfortable normal pace before starting the experiment and the speed was noted using metronome and millisecond timer. The subject was asked to try and maintain that particular pace throughout the experiment. The speed at which the subjects walked comfortably ranged from 3.5 to 4.0 $km.h^{-1}$ (0.97 to 1.11 $m.s^{-1}$). And this speed was taken as normal pace or slow speed. Kinematic data for 15 experimental conditions for each subject at this speed was collected on the same day.

On a different day, same procedure of subject preparation and video data collection was carried out for data collection at faster speed. Subjects were asked to walk at about double the pace they had walked earlier and this speed was found to be 6.0-6.5 $km.h^{-1}$ (1.79 to 1.87 $m.s^{-1}$). The subjects were asked to maintain this speed throughout the video data collection on that particular day.

3.4 Experimental Design

The Ethics Committee of the Institute approved the experimental protocol. Accordingly, subjects were first accustomed to gait laboratory and gait data collection procedure prior to starting the experiment. Then anthropometric data of each subject was recorded which included body weight (while wearing only vests, shorts and military boots), height, foot length and width. Kinematic and kinetic studies were carried out on same set of ten subjects on the same load conditions but on different days.

Each of the Infantry soldiers were subjected 15 load carriage operations including NL at two different walking speeds, i.e., 3.5 to 4.0 $km.h^{-1}$ (0.97 to 1.11 $m.s^{-1}$) and 6.0-6.5 $km.h^{-1}$ (1.79 to 1.87 $m.s^{-1}$) on level ground in the controlled condition of gait laboratory on different days for kinematic study. Thus each subject performed 15 loads x 2 walking speeds = 30 experimental trials.

The video data for kinematic parameters during walking with load at two different speeds were collected on same set of ten subjects on different days. For each subject the left and right static trials and walk trials with no load and load carriage maneuvers at one walking speed were collected on the same day. For each load condition they needed to walk for about 10-15 minutes in the 12 m walkway. About 20 minutes' interval was allowed between two experimental conditions to overcome the fatigue effect. On the day of data collection, concerned subject reported at the laboratory at 0900h in the morning. He was asked to rest for about 30 minutes and the study commenced at 0930h. At 1330h he was given lunch break for one hour. At 1430h second session of the study commenced and continued till 1830h. Each subject was subjected to NL condition at the beginning but application of other load conditions was randomized to avoid any bias effect in the whole experimental protocol. First the batch of five subjects completed kinematic study at slow speed during the initial five days. Then they completed the kinematic study at fast speed one by one in the next five days. In between two sets of walking speed trials, each subject got a minimum of four days' rest. Care was taken not to use same subject on successive days. The kinematic study for one batch of five subjects was completed in about 10-15 days. Subject's trials were repeated on other days if the trial data showed any discrepancy.

Kinetic parameters were collected at comfortable normal pace of walk of the soldiers, which ranged between 3.5 to 4.0 $km.h^{-1}$ (0.97 to 1.11 $m.s^{-1}$). The study was completed in about 10 days for the first batch of five subjects. Same experimental design as in kinematic study, such as same load conditions but applied in random fashion, comfortable normal walking speed, about 10-15 minutes walking, 20 minutes rest between two experimental conditions, etc., was followed in this study.

Second batch of five subjects reported the laboratory after a gap of 15 days and was subjected to kinematic and kinetic studies in the same manner as done on subjects in earlier occasion.

The six CCD cameras based 3D Motion Analysis System (Model HiRes ExpertVision, Motion Analysis Corp., USA) was used for video data collection which was given a minimum of 20 minutes warm up time everyday in the morning before starting the system calibration. After cube and wand calibration the right and left static trials were collected for the subject. In order to get full body dynamic trials (without head) a set of 25 Cleveland Clinic retro-reflective surface markers (Cleveland, OH, USA) was used. Each subject was first asked to walk in the laboratory at his own comfortable pace before starting the experiment on a 10m walkway and the speed was noted. The subject was required to try and maintain that particular pace throughout the experimental session that day. The walking speed of the subject in the beginning, middle and end of the Capture Volume, which was about 3m (common area of view for 6 cameras for recording gait data), was monitored by three pairs of infra-red photoelectric cells placed at 1.5m apart from each other (Birrell et al. 2007). The speed at which the subjects walked comfortably (slow speed) for different load carriage operations ranged from 0.97 to 1.11 $m.s^{-1}$. The fast speed for the subjects ranged between 1.79 to 1.87 $m.s^{-1}$. They were instructed to keep on walking up and down the 10m walkway under controlled laboratory condition on level ground for about 0-15 minutes in each experimental condition. During this period atleast 10 walk trials were collected for each condition only when the subject was walking up the walkway. Threshold monitor gave an exact picture of each of the camera view and marker tracking during walk trials. The subject kept on walking on the walkway and video data was collected without the subject’s being aware when the data was collected. Walk trials at slow speed were collected for 3.5 seconds duration at 120Hz and at fast speed the time duration was increased to 5 seconds so that one each of right and left gait cycle could be obtained. The collected trials were tracked and edited as per the standard procedure prescribed according to manuals and tutorials of Eva7.0 and trials were saved as binary files with extension *.trb.

The load carriage combinations, as given in Table 1 were designed to simulate the actual load carriage activities frequently carried out by infantry soldiers. They carried LMG or INSAS rifle in right hand or on right shoulder as commonly practised by them in their normal work environment.

Collected trials were then tracked and edited using Eva7.0 software. The trials showing any distortion due to marker drop-out, obscuring or equipment failure were rejected even though such occurrences were rare. Subsequently, these trials were exported to clinical gait analysis software Orthotrak 6.26 for final processing as track binary file format with an extension *.trb. After processing the exported trials in Single Trial Module (STM) in OT6.26, 4 - 5 good tracks were selected for each subject in each condition at each speed and processed in Multiple Trial Module (MTM) where they were normalized for subsequent statistical analysis. Right and left side gait cycles were analyzed separately.

Two piezoelectric based force platforms (Model 9286AA, Kistler Instrumente AG, Switzerland) were used to measure kinetic parameters on level ground. The instrument was standardized for optimum and precise data collection prior to the experiment. The subjects were asked to walk with and without load at their comfortable normal pace which ranged from 0.97 to 1.11 $m.s^{-1}$. Data collection was carried out at 200 Hz and each trial was of 7 seconds duration. Subjects were given prior training on walking on force plates with and without load in such a way that their left foot made contact with Forceplate 1 and right foot made contact with Forceplate 2. The loads were applied randomly and subject was asked to keep on walking over the forceplates up and down the walkway. The data was collected only when the subjects moved up the walkway. Five trials were collected at each condition, out of which three good trials were selected for further processing and analysis in each condition for each subject. Matlab 7.0.0.19920 (R14; The Mathworks Inc., USA) was used to interpolate the data within 100% of stance phase for each trial.

3.6 Parameters Studied

Kinematic study : Mean (SD) values for spatial and temporal parameters and angular displacements were computed. Spatial parameters recorded were step length (cm), stride length (cm) and cadence ($steps.min^{-1}$). Temporal parameters, recorded as % of gait cycle were total support time (TST), initial double support time (IDST), single support time (SST), midstance (MST), terminal stance (TS) and swing phase. In sagittal plane, angular changes for ankle, knee, hip, pelvis and trunk at different events of gait cycle (initial foot strike, midstance, terminal stance and toe-off) were recorded. Maximum angle in swing phase was reported and the ranges of motion (ROM) in sagittal plane for ankle, knee, hip, pelvis and trunk joints in normalized gait cycle for each load condition was calculated.

Kinetic study : The vector components of ground reaction forces (GRF) were recorded. These components were mediolateral GRF (x-axis), anteroposterior GRF (y – axis) and vertical GRF (z – axis). The unit of measurement was Newton. To allow comparison, all GRF components were normalized for body weight and represented as $N.kgBW^{-1}$. All time scales were represented as percentage of contact time. The % support time of associated temporal variables for the vertical, anteroposterior and mediolateral components were also reported.

3.7 Statistical Treatment of Data

3.7.1 Kinematic Study at Slow and Fast Speed of Walking

Mean (SD) values for spatial and temporal parameters and angular displacements were computed for two speeds of walking. Spatial parameters were step length (cm), stride length (cm) and cadence ($steps.min^{-1}$); temporal parameters were total support time (TST), initial double support time (IDST), single support time (SST), midstance (MST), terminal stance (TS) and swing phase. In sagittal plane, angular changes for ankle, knee, hip, pelvis and trunk at four events of gait cycle, i.e., initial foot strike (FS1), midstance (MST), terminal stance (TS) and toe-off (TO) were reported. Ranges of motion (ROM) in sagittal plane for ankle, knee, hip, pelvis and trunk joints in normalized gait cycle for each load condition was calculated and reported. The data were reported for both slow and fast speeds. Load carriage operations studied were NL, RifleH, HS, LMGH, HSRifle, BP, HSLMGH, BPRifle and BPLMGH for comparing NL against load conditions, left kinematics with right kinematics and for comparing fast speed data with slow speed data. For comparing responses of load carried on shoulder with that in hand, loads administered were Rifle, LMG, HSRifle, HSLMG, BPRifle, BPLMG.

The data was analyzed using Statistical Package for Social Sciences (SPSS) for Windows (Release 10.0.1; SPSS Inc., Chicago, IL, USA). Normality was established using Shapiro-Wilk test and Lilliefors significance correction. Analysis of homogeneity of variances was applied to see whether the null hypothesis of equality of variance had been violated or not using Levene's test at $\alpha = 0.05$. Most of the parameters failed to reject null hypothesis. Whenever any parameter rejected the null hypothesis, the “transformed Levene’s test” selecting “natural log” under “Spread vs level with Levene’s test” was applied for correction.

Load conditions were compared with NL in right and left side separately using One-way ANOVA to find out conditions where overall significant changes occurred. After ANOVA rejected the hypothesis of equality of the means for different load conditions, Dunnett post hoc test for pair wise comparison of the significant main effect against "Reference" group (NL) was applied for each speed and changes at $p<0.05$ were considered significant. One way ANOVA was applied for comparing left side data with right side data and load on right shoulder with that in right hand for each load condition at each speed. The right side gait data for fast speed was compared with right side slow speed data using One way ANOVA. However, post hoc tests were not performed for those analyses where there were less than three groups to be compared.

3.7.2 Kinetic Study

In this study, components of ground reaction forces were recorded while the subjects walked over forceplates at normal comfortable pace. Three components of ground reaction forces(GRF) : lateral (x-axis), anteroposterior (y – axis) and vertical (z – axis) were recorded in Newton. To allow comparison, all ground reaction forces were normalized for body weight and represented as N.kg BW^{-1} . All time scales were represented as percentage of contact time. The % support time of associated temporal variables for the vertical, anteroposterior and mediolateral components were also reported.

The GRF and associated temporal components in both sides of the body were recorded separately and analysed to find out overall significant changes in the data. Data was analysed for three GRF components (vertical, anteroposterior and mediolateral) and % support time of associated temporal variables using Statistical Package for Social Sciences (SPSS) for Windows (Release 10.0.1; SPSS Inc., Chicago, IL, USA). Normality was established using Shapiro-Wilk test and Lilliefors significance correction. Analysis of homogeneity of variances was applied to see whether the null hypothesis of equality of variance had been violated or not using Levene’s test at α =0.05. Most of the parameters failed to reject null hypothesis. Whenever any parameter rejected the null hypothesis, the “transformed Levene’s test” selecting “natural log” under “Spread vs level with Levene’s test” was applied for correction.

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4. RESULTS & DISCUSSION

Load carriage is an integral part of the military operations any where in the world. Infantry soldiers all over the globe, are subjected to carrying loads of different magnitudes, sizes and shapes for different duration in peace and field situation as a part of the routine activities, training or mock drills. Indian Infantry soldiers carry loads mostly in haversack (HS), web and backpack (BP). Rifle or light machine gun (LMG) is carried by them either in the right hand or placed on the shoulder and held by the right hand. Unequal distribution of these loads may affect the kinematics and kinetics of gait and cause associated postural adjustments in these soldiers which may ultimately affect their performance, level of combat fitness and fatigue. The resultant injury potential of some of these load carriage maneuvers need to be ascertained for future design modification of heavy BP and other load carriage ensembles.

The present study aimed to evaluate the spatiotemporal parameters and kinematic changes of gait at two different speeds and kinetic changes of gait during load carriage operations at normal cadence carried out by Indian infantry soldiers on level ground. This study further attempted to suggest possible modifications in the load carriage operations including load and load carriage ensembles used in Indian Army.

4.1 Kinematic Study

4.1.1 Slow Walking Speed (0.97-1.11 m.s^{-1})

4.1.1.1 Right Side Kinematics

Main objective of this study was to investigate the effects of carrying military load carriage ensembles, e.g., HS, BP and arms, e.g., Rifle and LMG, singly or in combination on kinematic parameters of gait. Results indicated that there were small variations in temporal and spatial parameters between NL and the load carriage conditions studied on the right side of the body. This corroborated well with previous studies on load carriage (Pierrynowski et al. 1981, Charteris 1998, Hong and Cheung 2003).

Similar to Hong and Cheung (2003), this study did not find any change in temporal and spatial parameters with the maximum load administered was 27.2% of subjects' body weight except for BP and BPLMGH. Also present study showed an increase in stride length when loaded conditions were compared to NL, though the increase was not statistically significant and inconsistent with increase in load magnitude.

Winter (1991) observed that temporal parameters were directly dependent on walking velocity. However a few studies stated that when velocity remained constant, an increase in load should cause decrease in stride length with an increase in total double support time, giving greater stability to the individual (Fiolkowski et al. 2006, Kinoshita 1985). For military load carriage, Attwells et al. (2006) observed that stride length and cadence increased in webbing (16 kg) condition but decreased with higher load (40 and 50 kg) in comparison to control condition where walking speed was self paced. The changes in spatial parameters in webbing condition compared to other conditions were explained as due to an increase of walking speed in this condition. In the present study step length, stride length and cadence increased with addition of load irrespective of their mode of carriage. Maximum increases in step length, stride length and cadence were 5.1 cm, 9.4 cm and 5.0 steps.min^{-1}, observed during BPLMGH (17.5kg), HS(4.4kg) and HSLMGH (11.2 kg) conditions, respectively, compared to NL.

In the present study, subjects were asked to walk at self selected comfortable speed. However, inspite of repeated instructions, they could not maintain the desired constant speed while walking with load. Their average slow and comfortable walking speed in this study increased with addition of each load and ranged between

0.97 m.sec^{-1} at NL and 1.11 m.s^{-1} at BPLMGH. It was observed that over imposition and strictness on the maintenance of speed caused abnormal gait pattern of the soldiers. Maximum load, BPLMGH (17.5 kg) in the present study was comparable to the webbing load of Attwells et al. (2006) and the observed changes in spatial parameters with addition of load may be explained due to an increase in speed similar to Attwells et al. (2006). Consistency in stride called for larger steps, for which angular motions at ankle, knee and hip increased (Winter 1987) as observed in the present study. As the joints got closer from their full flexion/extension position, antagonist muscles became more and more stretched and passive resistance built up which along with limited range of the joints could reduce irregularities in gait. Thus the small but distinct changes in spatial parameters in the present study may be the result of subjects' attempt to maintain consistency in gait as natural response to the gait variability during loaded walking (Danion et al. 2003).

The loads in question in previous studies were quite heavier than the present study. The present study stands apart from previous studies in the aspect that the differences in magnitudes of loads between experimental conditions were smaller. It is possible that the magnitude of applied load, 6.5% - 27.2% of BW might be insufficient to cause substantial significant change in spatial parameters when compared to NL condition.

A significant delay in occurrence of midstance as compared to NL was observed in this study with BP and when LMG was carried in hand along with BP, although these changes were small (3.1% – 8.3%) and unrelated to load magnitude. It is suggested that the delay in midstance in our study could have resulted from increase in the ranges of motion of body's CoM, restricted arm swing and placement of load below waist level. Major weight of Rifle and LMG is located at rear (butt) of these weapons which possibly added in delaying the transfer of the whole body load from one leg to another during midstance. Possible role of this phenomenon as injury potential is not known.

Majumdar et al. (2010) reported increases in step length, stride length, cadence and midstance with addition of load compared to NL. Ankle and hip ROM were significant. Ankle was more dorsiflexed; knee and hip were more flexed during initial foot strike and helped in absorption of load. Trunk showed more forward leaning with addition of load to adjust the CoM of the body and BP system back to NL condition. This adaptive phenomenon has been earlier explained as compensatory reflex adaptations in response to the load. In this adaptation process, load information is used to modify the reflex responses, including proprioreception signaling, so that a desirable and stable posture during walking is attained (Fouad et al. 2001).

In the present study, ankle dorsiflexion was found to increase significantly at FS1 in all load conditions at 10.7kg and above in comparison to NL. This ankle ROM increase in turn influenced the knee ROM by increasing flexion and extension of knee which is required for transporting greater mass and the supplementation of the associated increase in energy requirement (Attwells et al. 2006). In present study significant increased knee extension at initial foot strike was observed, similar to Attwells et al. (2006), who had earlier suggested this increase in knee ROM to be a protective measure used by the body to absorb impact forces. Significant increase in hip ROM along with increase in knee extension with increase in load in comparison with NL may be another factor in contributing the absorption of impact forces (Attwells et al. 2006).

The smaller load magnitude in the present study caused significant change in ankle ROM throughout the gait cycle. This increase in ankle ROM in the stance phase due to increase in dorsiflexion further helping in the load absorption and gait process. This rapid transit of ankle from dorsiflexion to plantarflexion during TO at the initial swing may be explained as due to an increase in load, gravity and inertia (Rose and Gamble 2006). With the addition of load, significant increase in knee flexion at FS1 and increase in knee extension at TO compared to NL were seen in the present study, resulting in an increase in knee ROM. Knee ROM increased maximally (3.7°) at HSLMGH but the trend of increase was not linear to the increase in load magnitude. Similar but greater increase in knee ROM were observed for heavier load conditions (Attwells et al. 2006, Kinoshita 1985). It was suggested that the increased knee flexion at FS1 is a protective measure which helped to absorb impact forces, As expected, smaller load magnitude used in the present study caused lesser changes in knee ROM. (Attwells et al. 2006).

Hip ROM in the present study increased almost linearly and significantly during higher load conditions with maximum increase at BPLMGH (17.5) by 7.8° compared to NL. At TO hip extension angle increased linearly and significantly with addition of load. Harman et al. (2000b) explained that an increase in load increased the degree of hip motion. The degree of increase in hip extension angle at BPLMGH (9.4°) compared to NL (4.5°) was quite notable. Maximum applied load (17.5 kg) however was quite less compared to heavier load carriage in the previous studies (Attwells et al. 2006, Martin and Nelson 1986, Kinoshita 1985) in terms of the changes observed.

Forward lean of the trunk while carrying heavier loads has been reported by several researchers earlier (Attwells et al. 2006, Kinoshita 1985). It is notable that the present study elicited similar results at much lower loads. Increase in load induced forward lean of trunk is always necessary to counterbalance the hip moments and to stabilize body's CoM. An upright posture was considered more efficient when carrying load but it could inhibit forward advancement of the body with load on the back (Kinoshita 1985, Martin and Nelson 1986, Pascoe et al. 1997). Significant increase in trunk forward inclination in the present study was associated with BP, BPRifleH and BPLMGH conditions, mainly involving a load carriage of 10.7 kg (16.6% of BW) and above. Grimmer et al. (2002) stated that even very light loads (3-10% of BW) could cause an increase in forward lean. It was observed from the present study that when a soldier carried BP, BPRifleH or BPLMGH, he would try to adjust the CoM of the body and BP system back to that of NL condition. This was achieved by forward inclination, helping the body to minimize the energy expenditure of load carriage and increase the efficiency of walking process. The resultant forward inclination of about 5-7° or more of the soldiers in this study during carrying BP, BPRifleH or BPLMGH, which were lighter load compared to heavier loads studied earlier, were significant. Hence the injury potential of the BP needs to be further verified specially in consideration of the large soldier population. Martin and Nelson (1986) observed that there was no significant change in forward lean even with rucksack load as high as 34 kg. Therefore, it might be possible that BP used in the present study was not properly designed, load was not aptly distributed within the BP and was not snuggly fitted to the body, causing forward over leaning of the back of our soldiers. Though smaller in magnitude, a significant delay in occurrence of MST was observed in this study at BP and BPLMGH. At that point of time, trunk also became significantly flexed and the degree of flexion increased with addition of load. At MST when the body was transferring load from one leg to the other, significant increase in trunk forward lean indicated that in order to counterbalance the load on back, the subjects were moving their trunk more anteriorly (Attwells et al. 2006, Hong and Cheung 2003).

4.1.1.2 Left Side Kinematics

This study is unique in it's approach of revealing the kinematic changes of left side while most of the previous studies dealt with right side kinematics only. Similar to right side kinematics, the spatial parameters increased with increase in load magnitude in each load conditions while subjects walked with slow speed but these changes were neither consistent nor significant in relation to the changes in load magnitude. None of the temporal parameters showed an overall significant interaction with increase in load. No trend in the changes of these parameters could be identified as in right side. These observations corroborated well with previous studies (Pierrynowski et al. 1981, Charteris 1998, Hong and Cheung 2003).

In contrast to right side data the MST as % of gait cycle decreased in loaded conditions for left side. It may be considered as a response of contralateral side compensatory adjustment to the load carried. It would be interesting to further study this phenomenon by placing load in the left side and comparing the response when this side became ipsilateral. Significant increases for all load conditions as compared to NL in ankle plantarflexion at FS1 and TO were observed for left side while walking at slow speed. Ankle plantarflexion ranged from 5.8(1.1)° at NL to 3.8(0.4)° at BPLMGH for FS1. For TO maximum plantarflexion was observed at HSRifleH (9.4(1.3)°) as compared to NL (12.0(2.1)°). At both these events, the increases were almost linear across load conditions. The reasons for the rapid transit of ankle from dorsiflexion to plantarflexion during TO at the initial swing, as observed in the present study, has been explained in detail for right side. However the resultant changes in ankle ROM for complete gait cycles were not significant when loads were compared to NL. Ankle ROM increased maximally in the range of 2.0° - 2.2° with BP, BPRH, and BPLMGH and for others remained almost unchanged.

In the present study an increase in only ankle plantarflexion was seen for FS1 and TO for left side of the body. These increases in ankle plantarflexion and knee extension with load could not bring about the desired changes in knee ROM in the left side and might be responsible for not absorbing the impact forces completely. A linear increase in hip ROM, though not significant, was seen through the load conditions, the increase being maximum by 6.4° at BPLMGH. This was a desirable change and could contribute to absorbing impact forces during walking with load (Attwells et al. 2006). Both pelvis and trunk showed a general trend of increase in flexion with increase in load as compared to NL. Increase in load induced forward lean of trunk and pelvic joints are necessary to counterbalance the hip moments and to stabilize body's CoM. An upright posture was considered more efficient when carrying load but it could inhibit forward advancement of the body with load on the back (Kinoshita 1985, Martin and Nelson 1986, Pascoe et al. 1997). For left side of the body, significant increase in trunk forward inclination was associated with BP, BPRifleH and BPLMGH conditions, mainly involving a load carriage of 10.7 kg (16.6% of BW) and above, in the present study at FS1, MST, TS and TO when load conditions were compared to NL similar to right side. The resultant forward inclination of about 7.5° in this study in the soldiers during carrying BP, BPRifleH or BPLMGH, which were lighter loads compared to heavier loads studied earlier, were significant.

Pelvic ROM showed significant increase only for BPLMGH when compared with NL. Trunk ROM did not show significant change for any load condition. Though significant changes in ankle, knee, hip, pelvis and trunk at different events of stance phase and beginning of swing phase were observed, the effective ROM for these joints did not show any significant change in comparison to NL. This was possibly caused due to the extent of change in minimum and maximum angles in these joints remained almost similar to NL condition.

4.1.1.3 Left Side Kinematics versus Right Side Kinematics

Previous literature shows that gait symmetry has been frequently assumed to simplify data collection and analysis. Present study attempted to look into whether or not the lower limbs behaved symmetrically during gait while carrying light military loads. In the present study, though differences were not significant, step length of right side was longer than the corresponding left side in each condition and in contrast left side stride length was longer than the corresponding right side in each load conditions. Among temporal parameters, significant differences were observed at midstance for HSRifleH and BPLMGH when left side data was compared with corresponding right side data. Right side midstance values were higher than corresponding left side by 1.3% for HSRifleH and 1.7% for BPLMGH. Similar asymetry was reported by Gunderson et al. (1989) and Wheelwright et al. (1993). In the current study, at FS1, left ankle remained more dorsiflexed (5.8(1.1)°) in comparison to right side (4.9(0.5)°) for NL.

With load, left side became significantly more plantarflexed in comparison to right side for HS, HSRifleH, BP, HSLMGH, BPRifleH and BPLMGH. Ankle plantarflexion was maximum for BPLMGH, i.e., from 7.1(1.4)° in the right side to 3.8(0.4)° in the left side. Knee also exhibited increase in extension in the left side in comparison to right side with significant increases for NL, RifleH and HS. Maximum increase in knee extension for left side (1.2(0.2)°) in comparison to right side (5.5(1.1)°) was for RifleH.

At TS, load involving LMG caused knee angles to be symmetrical in right and left side gait data whereas, other conditions elicited significant increases in flexion for NL, RifleH, HS, HSRifleH, BP and BPRifleH in the right side. At TS, for NL significant increase in hip extension was seen (by 2.9°). Ankle, hip, pelvis and trunk in right and left side gait cycles at TS were quite similar, corroborating firmly with the international convention of reporting only the right side data. At TO, left ankle remained significantly more plantarflexed for RifleH, HS, HSRifleH, HSLMGH and BPLMGH. Knee extension increased in left side in comparison to right side for NL, BP, BPRifleH and BPLMGH; for NL left knee was extended by 4.7° and for BPLMGH by 7.3°. Hip showed an equal increase in extension (by 3.3°) for NL and BPLMGH. Pelvis showed significant increase in flexion for HSRifleH and BP in the left side in comparison to the right side. Trunk forward inclination was more in the left side than right side and significant changes were observed for LMGH and HSLMGH. There was no change in ROM of any joint for NL or any load condition. These results were similar to the results obtained by studies on asymmetry of gait in able bodied population (Sadeghi et al. 2000).

4.1.1.4 Shoulder Load Carriage versus Hand Load Carriage

Previous studies have regarded carrying load by hands mode being worst but none reported the effects of load carried on shoulder as practised in the carriage of Rifle or LMG in military operations.

Present study attempted to quantify whether there was any difference in kinematic responses between load carried in hand and the same load being carried on shoulder while it is held by hand as a support at slow walking speed. Spatial parameters did not show any significant changes and among temporal parameters only MST was found to be significantly different for HSRifle and BPLMG when shoulder carriage was compared against hand load carriage operations. These results were in agreement with previous studies (Attwells et al. 2006, Hong and Cheung 2003, Pascoe et al. 1997).

At initial foot strike ankle became significantly more plantarflexed for HSLMG and BPLMG by 1.6° and 2.4°, respectively when load on shoulder was compared to that in hand. Knee was significantly extended for Rifle, HSLMG and BPRifle and degree of increase in extension were 2.9° during Rifle and 1.7° during HSLMG. For BPLMG knee became significantly flexed though the degree of change between hand and shoulder load carriage was minimal. Pelvic angle flexed significantly at HSRifle (by 1.9°) and BPLMG (by 1.7°) but became extended for BPRifle (by 2.3°) when load carried on shoulder and held by hand were compared with the corresponding hand held load carriage. At FS1, on shoulder carriage trunk became significantly upright with increase in extension for Rifle, LMG, HSRifle, BPRifle and BPLMG. Similar changes in joint angles at MST, TS and TO were observed when load carriage on shoulder were compared with that of load carried in hand at slow speed. Ankle, knee and hip angles did not show any significant differences between hand and shoulder load carriage. From pelvic and trunk angle differences it is apparent that carrying Rifle and LMG on shoulder require different postural adaptations resulting in different responses to above loads. The responses of all the joints showed that for load carriage on shoulder some intrinsic adaptation in the individual comes into play and causes all the joints become more extended in comparison to the responses during load carried in hand. The increased extension in different joints indicated an upright posture and biomechanically greater stability in the subjects while they carried load on shoulder while walking at slow speed. For loads carried on shoulder the midstance occurred earlier than the corresponding load in hand and this in addition to the increased trunk extension may be a better mode of load carriage as the trunk can remain upright while carrying the load. This process can eliminate low back pain to a great extent. Soldier in field situation is found to prefer to keep the Rifle or LMG on right shoulder by holding it in right hand. The degree of occurrence of right arm or shoulder fatigue is yet to be ascertained.

4.1.2 Fast Walking Speed (1.79-1.87 $m.s^{-1}$)

4.1.2.1 Right Side Kinematics

In the present study, in all load conditions, during fast walking speed step length and stride length decreased in comparison to NL, though this decrease was not consistent in relation to the changes in load magnitude and was not significant. In comparison to NL, changes in cadence did not show any specific pattern with addition of load and the changes were not significant.

Results for spatial parameters with fast walking speed were not similar to that observed for slow speed walking. At initial foot strike, with fast speed overall significant changes in ankle, knee, pelvic and trunk angles were observed. For ankle increase in plantarflexion with increase in load was observed. Ankle plantarflexion may lead to knee extension and would not help in the absorption of impact load which was very much required during higher speed of walking. Significant increase in trunk forward lean was observed for all conditions while walking at fast speed. At midstance, overall significances were observed for hip and pelvis angles. At midstance and TO, pelvis flexed significantly at HSLMGH but extended significantly for BPLMGH. Trunk flexion increased significantly at almost all conditions for MST, TS and TO. At TS, overall significance was observed for knee, hip, pelvis and trunk angles while walking at fast speed. Knee was significantly extended for HSLMGH, BPRifleH and BPLMGH. Hip extended significantly at all conditions when compared with NL. At TO overall significances were observed for ankle, knee, hip, pelvic and trunk. No significant changes were observed in any joint ROM and the changes they showed were inconsistent when compared to NL. This corroborated with Smith et al. (2006), who studied the pelvic responses of thirty female college students while they carried backpack with 15% of their mean body weight, observed that carrying loaded backpack bilaterally displaced subject’s centre of gravity towards posterior side. They concluded that the increase in pelvic tilt or forward lean was to keep the subject in an upright, vertical position.

4.1.2.2 Left Side Kinematics

Similar to right side gait data for fast walking speed, overall significance was observed for stride length which decreased significantly for BPRifleH and BPLMGH in comparison to NL. Changes in cadence did not show any specific pattern and the changes were not significant. Among temporal parameters TST and SP showed overall significance but no significant change was observed when compared with NL. The possible explanation given for the changes in the right side kinematics in previous pages is valid for left side also. The fast walking speed in our study matched with the walking speed applied by Martin and Nelson (1986), i.e., 1.78ms^{-1} and results obtained were also similar for temporal and kinematic characteristics. Some of the earlier studies had shown that a decrease in stride length and an increase in cadence were observed with larger increments in load while walking at fixed speed (Kinoshita 1985, Martin and Nelson 1986, Pascoe et al. 1997). However present study elicited similar results at a much lower load magnitude (6.5% - 27.2% of BW) and faster walking speed.

At FS1 overall significances were observed for ankle, knee, pelvic and trunk angles. Ankle plantarflexion increased significantly for HS, HSRifleH, BP, HSLMGH, BPRifleH and BPLMGH. Knee flexion significantly increased for RifleH, BP and BPLMGH. Pelvic flexion increased for HSRifleH and HSLMGH. Trunk flexion increased significantly for HS, LMGH, HSRifle, BP, HSLMGH, BPRifleH and BPLMGH. Maximum increase in trunk flexion was 6.4° for BPLMGH. At midstance overall significances were observed for hip, pelvis and trunk. In comparison to NL pelvic flexion increased significantly for HSRifleH and became significantly extended for BPLMGH. Trunk flexion increased significantly at all conditions as compared to NL. At TS overall significances were observed for knee, hip, pelvis and trunk. Knee became significantly extended for BP and BPLMGH. Hip became significantly extended (maximum extension by 6.1°) for RifleH, HS, BP, BPRifleH and BPLMGH. Pelvis became significantly extended for HS and BPLMGH. Trunk flexion increased significantly and consistently with load, maximally by 6.5° BPLMGH. At TO overall significances were observed for ankle, knee, hip, pelvic and trunk. Ankle dorsiflexion increased significantly for BP and HSLMGH. Knee was significantly extended for BP and hip showed significant extension for BPLMGH. Pelvis showed significant increase in extension for HS and BPLMGH. Trunk significantly flexed at all conditions, maximally by 6.5° at BPLMGH. Changes in ROM for any joint were not significant when compared with NL and load conditions did not show any trend in the change.

In the present study an increase in only plantarflexion was seen for all gait events for left side of the body. According to Attwells et al. (2006) it was desirable to have an increase in ankle ROM which would further influence the knee ROM to increase as a result of increased knee flexion and extension. This increase in knee ROM was an important criteria required for transporting greater mass and the supplementation of the associated increase in energy requirement and served as a protective measure used by the body to absorb impact forces. In the present study knee flexion increased at initial foot strike for left side while walking with fast speed.

Significant increase in knee extension were observed for TS and TO for left side at fast walking speed. However, these increases in ankle plantarflexion and knee flexion/extension with load could not bring about the desired changes in knee ROM in the left side and might be responsible for not absorbing the impact forces completely which may increase the injury risk for the contralateral side. A linear increase in hip ROM, though not significant, was seen through the load conditions, the increase being maximum by 6.4° at BPLMGH. This was a desirable change and could contribute to absorbing impact forces during walking with load (Attwells et al. 2006). Harman et al. (2000b) explained that an increase in load increased the degree of hip motion. Hip extension increased maximally by 4.9° at BPLMGH in comparison to NL at TO. Maximum applied load (17.5 kg) in present study was quite lesser compared to heavier load carriage in the previous studies (Attwells et al. 2006, Harman et al. 2000a, 2000b, Martin and Nelson 1986, Kinoshita 1985) and therefore lesser extent of hip motion could be expected. Both pelvis and trunk showed a general trend of increase in flexion with increase in load as compared to NL. Increase in load induced forward lean of trunk and pelvic joints are necessary to counterbalance the hip moments and to stabilize body's CoM.

4.1.2.3 Left Side Kinematics versus Right Side Kinematics

Symmetry in gait patterns, with and without load, has been frequently assumed to simplify data collection and analysis. In the present study for fast walking speed, left side data was compared with right side gait data with respect to spatiotemporal and kinematic parameters. With regards to spatiotemporal parameters, in the present study, both side of the body exhibited symmetry while walking with load at a fast speed. Therefore, in the present study, gait evaluation could give incorrect interpretation if lower limb symmetry had been assumed without investigation. Present study attempted to look into the important aspect related to gait, 'whether or not the lower limbs behaved symmetrically during gait while carrying light military loads at a fast speed of walking?' The aspects of symmetry / asymmetry of lower limbs during walking and possible effects of laterality on gait were important issues that needed to be looked into while an attempt to standardize gait and load carriage operations for military activities that were undertaken.

Among temporal parameters, significant differences were observed at midstance for HSRifleH and BPLMGH when left side data was compared with corresponding right side data. Right side midstance values were higher than corresponding left side by 1.3% for HSRifleH and 1.7% for BPLMGH.

In the current study, at FS1, left ankle remained more dorsiflexed 5.8(1.1)° in comparison to right side 4.9(0.5)° for NL. With load, transition of left side from dorsiflexion to significant plantarflexion in comparison to right side was observed for HS, HSRifleH, BP, HSLMGH, BPRifleH and BPLMGH. Ankle plantarflexion was maximum for BPLMGH, i.e., from 7.1(1.4)° in the right side to 3.8(0.4)° in the left side. Knee also exhibited increase in extension in the left side in comparison to right side with significant increases for NL, RifleH and HS. Maximum increase in knee extension for left side (1.2(0.2)°) in comparison to right side (5.5(1.1)°) was for RifleH.

Similar to slow walk data, the present study reported discrepancy in gait pattern between right and left side of the body at fast speed also. Carrying BP and BPLMGH might have caused an asymmetry in gait, as there was a delay in occurrence of the event MST in the subjects in the right side of the body in load conditions as compared to NL. On the other hand, it caused the event MST to occur earlier than that of NL in load conditions for the left side. Present study showed that, at MST, ankle angle differences between right and left side were minimal and not significant. At midstance left knee remained extended in comparison to right side for all conditions, showing significant difference for LMGH (by 3.4°) and BP (by 4.5°). But hip angle showed significant increases in extension in the left side in comparison to right side for HSLMGH and BPLMGH. In other words, hip remained more flexed on the ipsilateral load bearing side. Pelvis showed significant increased flexion at HSRifleH and trunk remained significantly extended at LMGH while no other joint in any condition showed any significant change at MST when left side was compared with right side. The changes observed in pelvis and trunk angles seemed to be independent of either load effect or side effect and may be attributed to subjective differences. When load was carried in one hand, body was supposed to be in a state of asymmetry. And in order to counteract this state of asymmetry, the adjustments done in the body may manifest as the significant changes shown in the MST, an event which was important for the transfer of weight from one leg to the other. This phenomenon has been explained in the section comparing left kinematics with right kinematics with slow walking speed.

The significant delay in occurrence of MST in the right side along with simultaneous early occurrence of MST for left side in load conditions as compared to NL in the present study was accompanied by significant increases in trunk forward inclination at MST at all conditions in comparison to NL for both sides. The magnitude of increase was more with BP and other load conditions in combination with BP. At MST when the body was transferring load from one leg to the other, the significant increase in trunk forward lean indicated that, in order to counter balance the load on back the subjects were shifting their trunk forward (Whittle 2000, Attwells et al. 2006, Hong and Cheung 2003). Carrying a BP induced deviation from natural postures and may increase stress on low back. At TS, load involving LMG caused knee angles to be symmetrical in right and left side gait data whereas, other conditions elicited significant increases in flexion for NL, RifleH, HS, HSRifleH, BP and BPRifleH in the right side. At TS, for NL significant increase in hip extension was seen (by 2.9°). Ankle, hip, pelvis and trunk in right and left side gait cycles at TS were quite similar, corroborating firmly with the international convention of reporting only the right side data. At TO, left ankle remained significantly more plantarflexed for RifleH, HS, HSRifleH, HSLMGH and BPLMGH. Knee extension increased in left side in comparison to right side for NL, BP, BPRifleH and BPLMGH; for NL left knee was extended by 4.7° and for BPLMGH by 7.3°. Hip showed an equal increase in extension (by 3.3°) for NL and BPLMGH. Pelvis showed significant increase in flexion for HSRifleH and BP in the left side in comparison to the right side. Trunk forward inclination was more in the left side than right side and significant changes were observed for LMGH and HSLMGH. There was no change in ROM of any joint for NL or any load condition.

4.1.2.4 Shoulder Load Carriage versus Hand Load Carriage

In the present study when load carried on shoulder was compared to that in hand while walking with fast speed, none of spatial parameters showed any significant difference. Among temporal parameters TST and SP showed significant difference for LMG and TS showed significant difference for HSRifle when shoulder load carriage was compared to hand load carriage. These observations are similar to the observations discussed for slow speed walking in previous sections. These observations can also be explained similar manner.

There were significant changes in ankle ROM (Rifle, LMG and HSLMG), knee ROM (BPLMG), pelvic ROM (HSRifle) and trunk ROM (BPRifle) when the results of load carried on shoulder were compared with that in hand. Effects of shoulder load carriage in comparison to hand load carriage on the ROM of different joints were found to be scattered and not related to load magnitude. With increased speed in the present study, for bringing about consistency in stride required larger steps which resulted in ROM at ankle and knee to increase.

4.1.3 Fast Speed Walking versus Slow Speed Walking

All spatial and temporal parameters increased significantly at NL and load conditions when fast speed data was compared with corresponding slow speed data. Percentage increments in step length, stride length and cadence at NL for fast walking speed with respect to slow walking speed were 23.4%, 22.4% and 26.0%, respectively. For BPLMGH, the percentage increments in above parameters were 10.0%, 10.7% and 24.4%, respectively. This shows that at higher speed and higher load step length and stride length were affected more and but cadence remains least affected.

At FS1, at fast speed of walking, ankle angle changed significantly for NL, RifleH, LMGH, HSRifleH and BPLMGH in comparison to slow speed.. Till the load magnitude of 11.2kg (HSLMGH) ankle remained dorsiflexed but for higher load the ankle became plantarflexed and at MST ankle dorsiflexion increased for all conditions. This increased dorsiflexion of ankle caused greater knee flexion at FS1, ultimately absorbing the impact forces (Kinoshita 1985). However, at TS and TO, there were significant increases in plantarflexion of ankle for all load conditions when fast speed data were compared with slow speed data. A rapid transit of ankle from dorsiflexion to plantarflexion during TO at the initial swing as a passive phenomenon was expected, as ankle angle transit from dorsiflexion to plantarflexion at fast speed compared to slow speed could be explained as due to an increase in load, gravity, speed and decrease in inertia.

Significant increases in knee flexion were observed at FS1 (all load conditions including NL) and MST(significant in HS, LMGH, HSLMGH and BPLMGH) when fast walk data were compared with slow speed data. At FS1, knee flexion increased in the NL condition by 115% and in the BPLMGH it increased by 347.6%. Increased knee flexion at FS1 is said to be a protective measure which aids in absorption of impact forces (Attwells et al. 2006). Knee extension increased significantly for fast speed data at TS and TO. Although there were significant increases in knee flexion at FS1 and knee extension at TO.

Pelvic flexion increased significantly at fast speed in comparison to slow speed in some conditions at FS1 and in all conditions at MST, TS and TO. At MST, pelvic flexion increased by 60.8% in NL, maximum increase was seen with HSRifleH (100.0%) but in BPLMGH the increase was minimum (12.2%). At TS, pelvic flexion increased by 46.4% in NL and increased maximally by 92.1% in HSRifleH. At TO pelvic flexion increased by 43.4% NL and by 26.3% in BPLMGH condition. This shows that effect of speed is more than load on kinematic changes at pelvic joints. It can be further inferred that load rather dampens the angular changes.

Trunk flexion increased significantly in all load conditions at FS1, MST, TS and TO when fast speed walking was compared to slow speed walking. At FS1 trunk flexion increased by 4.5° at NL and 2.7° at BPLMGH. However, when fast speed walking is compared to slow speed walking in terms of percentage increase, the increase in trunk flexion angle in NL was 1500% and in BPLMGH it was 35.1%. These observations indicated that trunk changes were influenced more by speed than by load like other joints. Though the present study showed significant changes in ankle, knee, hip, pelvis and trunk at different events of stance phase, the effective ROM for these joints remain unaltered, except for hip ROM, when responses of fast walking speed was compared with that of slow walking speed. This was caused possibly as the extent of change of minimum and maximum angle remained almost similar to the NL condition.

4.2 Kinetic Study

Ground Reaction Forces (GRF)

When the body makes contact with the ground, according to Newton's Third Law, there is always an equal reaction to the action of body contact. In other words, the force of ground contact is met with an equal and opposite ground reaction force, exerted by the floor/ground. After the initial contact, the type of reaction deciding the magnitude of GRF depends on walking on different surfaces. GRFs are measured on a force platform and recorded in Newton (N). GRF is a three dimensional vector which is broken down into three components: mediolateral (x-axis), anteroposterior (y-axis) and vertical (z-axis). Present study investigated the magnitude increases of GRF vectors with addition of light military loads.

4.2.1 Load versus NL

Overall significance was observed in right foot for maximum braking force (Fy1), maximum propulsive force (Fy3) and % support time of associated temporal variable corresponding to Fy3 (i.e., Ty3) in the anteroposterior axis. Post hoc test showed that for right foot, changes were significant for Fy1 during HSRifleH, BP, HSLMGH, BPRifleH and BPLMGH. Fy1 of the right foot was 1.8 (0.3) $N.kg.BW^{-1}$ during NL and increased maximally to 2.8(0.4) $N.kg.BW^{-1}$ during BPLMGH, an increase in 56% from NL value whereas the load carried increased by 27.2% of BW. Overall significance for Fy1 was observed in left side. Post hoc test revealed that only BPLMGH was significant in comparison to NL. In NL, Fy1 in left side was 2.3(0.4) $N.kg.BW^{-1}$ and it increased to 3.3(0.7) $N.kg.BW^{-1}$ for BPLMGH, an increase of 43.5% with maximum load.

For right foot Fy3 changed significantly in BP, HSLMGH, BPRifleH, BPLMGH. In NL, Fy3 was -2.4(0.4) $N.kg.BW^{-1}$ and for BPLMGH Fy3 was -3.0(0.5) $N.kg.BW^{-1}$, an increase by 25%. Significant changes in Fy3 of the left foot were observed for LMGH, HSRifleH, BP, HSLMGH, BPRifleH and BPLMGH. For left side Fy3 was -1.8 (0.2) $N.kg.BW^{-1}$ in NL and -2.4 (0.2) $N.kg.BW^{-1}$ in BPLMGH, i.e., an increase by 33.3%.

Present study shows that the increase in anteroposterior braking force (Fy1) was almost double than the corresponding addition in system weight when NL was compared with load conditions. The propulsive force (Fy3) was found to increase by about 1.5 times with added system weight when NL was compared with load conditions. This trend observed in the present study was similar to the result obtained by Lloyd and Cooke (2000b). They also found that Fy1 and Fy3 increased significantly in comparison to without load (NL) condition but these increases were not 'nearly proportional to system weight' as reported in the literature (Kinoshita and Bates 1981, Kinoshita 1985). An increase in anteroposterior braking force (Fy1) was almost double and the propulsive force (Fy3) increased by about 1.5 times than the added system weight when NL was compared with load conditions. This observation in the present study may be attributed to increase in the forward lean throughout the support phase (Majumdar et al. 2010). Such changes may produce difference in momentum of the upper body, which could influence the braking and propulsive forces. In case of braking force, there is an increased risk of injury potential of the ankle but the forward inclined posture while carrying BP system might have facilitated propulsion of the It was observed in the present study that the increase in magnitude of Fy1 and Fy3 in right side was more than that in left side. Kinoshita (1985) found that the inclined posture while carrying BP system facilitated forward propulsion of the body whereas the erect posture with double pack inhibited the forward advancement in his subjects.

Overall significances were observed in both right and left foot for maximum braking force (Fz1), force minimum (Fz2) and maximum propulsive force (Fz3) in the vertical axis. Post hoc test showed that for right foot, changes were significant for Fz1 in HSLMGH, BPRH and BPLMGH when load conditions were compared against NL. Fz1 of the right foot was 12.1(0.6) $N.kg.BW^{-1}$ in NL and increased maximally to 14.9(1.0) $N.kg.BW^{-1}$ in BPLMGH resulting in an increase of 23.1%. Right foot Fz2 changed significantly for BPRH and BPLMGH. Fz2 component of the right foot was 7.4(0.6) $N.kg.BW^{-1}$ in NL and increased maximally to 8.9(0.9) $N.kg.BW^{-1}$ in BPLMGH. The increase in Fz2 peak force component was 20.2% with addition of 17.5kg load (BPLMGH) in hand. The Fz3 peak for right foot showed significant increase in load conditions as compared to NL during HSLMGH, BPRH and BPLMGH. The Fz3 peak of the right foot was 11.0(0.7) $N.kg.BW^{-1}$ during NL and increased maximally to 13.7(0.7) $N.kg.BW^{-1}$ during BPLMGH resulting in an increase of 24.5%.

In case of left foot, significant changes were observed for Fz1 peak in HS, LMGH, HSRH, BP, HSLMGH, BPRH and BPLMGH conditions as compared to NL. The peak Fz1 value during NL was 11.4 (2.4) $N.kg.BW^{-1}$ and increased to 14.9(1.1) $N.kg.BW^{-1}$ during BPLMGH, the increment being 30.7% with maximum load. The peak Fz2 value for left side showed significant increase during HSRH, BP, HSLMGH, BPRH and BPLMGH. The Fz2 value for NL was 6.8 (1.6) $N.kg.BW^{-1}$ and for BPLMGH it was 8.6(1.0) $N.kg.BW^{-1}$ indicating an increment in peak force value by 26.5%. The peak Fz3 value for left side showed significant increase during RH, HS, LMGH, HSRH, BP, HSLMGH, BPRH and BPLMGH. The Fz3 value for NL was 10.8 (2.7) $N.kg.BW^{-1}$ and for BPLMGH it was 14.1(0.7) $N.kg.BW^{-1}$ indicating an increment in Fz3 peak force value by 30.6%. The increase in vertical component of GRF in right and left side in Fz1, Fz2 and Fz3 were found to be linearly proportional to increase in system weight, supporting previous studies (Kinoshita and Bates 1981, Kinoshita 1985, Lloyd and Cooke 2000, Birrell et al. 2007).

As observed in the present study, earlier studies also observed significant increases in antero-posterior and vertical GRFs with increment in load magnitude (Kinoshita and Bates 1983, Lloyd and Cooke 2000b). GRF and trunk inclination are important criteria to determine the acceptable backpack loads for carriage.

4.2.2 Left Side Kinetics versus Right Side Kinetics

The peak mediolateral component showed significant differences between right and left side data at all conditions. The peak anteroposterior component showed significant differences between right and left side data at all conditions except BP. For all load conditions left foot anteroposterior force component showed greater force magnitude than corresponding right side. Among associated stance phase time, Ty2, the percentage of stance time at which force minimum (Fy2) magnitude in the anteroposterior axis was 0, differed significantly in left side as compared to right side during NL, LMGH and HSRH. During NL for right foot Ty2 occurred at 51.2% of stance phase and in left side it occurred at 56.5%, with an increase in delay in occurrence time of this event by 10.7%. This indicated that even without carrying load, there was inherent difference in kinetics of left and right feet, or between the ipsilateral and contralateral side while walking with load. The peak vertical GRF did not show significant differences in any load and NL condition when left side kinetic data was compared to right side data. However, Fz3 showed significant changes during RH and HS only and no particular trend of change was observed in other load and NL conditions. Results of the present study indicated some degree of asymmetry in the gait of our subjects in terms of mediolateral GRF and anteroposterior GRF was observed during NL and load carriage conditions. As the results for NL also demonstrated asymmetry, then it may not be only the load component that influenced gait asymmetry. This study indicated that there was some inherent differences in the left and right side kinetic behaviour in the subjects studied.

The significant difference in peak mediolateral component between left and right kinetic data in the present study may be considered to be an important observation. It had been suggested in the literature that the significant increases in the mediolateral impulses with increases in load may be due to decrease in stability and continual shift in body's CoM. It had been earlier established that CoM should be least displaced for maintaining body's greater static stability while carrying load (Birrell et al. 2007, Birrell and Haslam 2008).

4.2.3. Load Carriage on Shoulder versus Hand

The statistical analysis showed that there were no significant differences in any GRF components of walking with load in hand and on shoulder. Among time components significant difference was observed for Ty1 during LMG and for Ty3 during R. As the force and time components of GRF remained almost unchanged in other conditions when hand loading was compared with shoulder loading, the two significant changes observed may be assumed as some experimental artifact and may be ignored as such. In the literature, no reported study exist in which shoulder load carriage, as carried out in military operation, is compared with hand carriage of load. The load administered in the present study (27.2% BW) may not be sufficient to cause kinetic parameters to change appreciably in these modes of load carriage. Future studies with higher magnitudes of load need to be carried out before coming to any conclusion on such modes of load carriage.

5.0 CONCLUSIONS

It was observed that step length, stride length and cadence increased with increase in both load and speed, causing increase in ankle and hip angular changes. A delay in MST was noticed for LMG and BPLMG for right side of the body in comparison to NL and the corresponding MST for left side for same condition occurred earlier than that of NL. Similar to the results of previous studies with heavier load, increases in ankle dorsiflexion, knee and hip flexion during initial foot strike was also observed with lower loads. Trunk forward leaning increased with increases in load and speed to counterbalance the shift of CoM of the body-BP system back to NL condition. These changes can be attributed to some intrinsic adaptive phenomenon in the individual to counterbalance load effect and speed effect. Significant increases in vertical and anteroposterior GRFs along with increased forward leaning of trunk indicated possible increase in musculoskeletal stress even at smaller load increments.

Increased joint angular changes, ankle and hip ROM changes along with excess forward inclination of trunk while carrying much lower load magnitudes were observed in the present study. These results obtained were similar to the results of previous studies on load carriage operations which administered much higher load magnitudes. As these changes were more predominant with BP and it's combinations, it indicated that there may be some design artifact that may produce appreciable degree of discomfort to the soldiers and needed to be corrected. The scaffolding structure of the BP and the dimensions of the existing BP was found to be incompatible with the body dimensions of soldier population. This makes it necessary to redesign the existing BP used in military operations for reducing the kinematic and kinetic stresses of the soldier during load marches.

The effects of fast walking speed along with additional load carriage on kinematic parameters further revealed that a slow walking speed must be maintained during load carriage, as observed in the present study, to avoid undue stress on skeletomuscular system of the body.

In modern times, a new strategy of aggressive intervention known as low intensity conflict (LIC) has been introduced in which, the war is intense in nature and of short duration. During such situations the mobility of soldier becomes very important and carrying heavy loads only cause hindrance to the combat fitness of the soldiers. Therefore, efficacy of lighter and compact load in comparison to heavier load carriage in improving the soldier's performance in the such short and intense war situations as LIC environments require to be evaluated to assess their resultant stress effect. Results of the present study will have implications in future designing of load carriage ensembles, especially heavy military BP, by incorporating the kinematic and kinetic aspects of military load carriage in the initial design for better soldier performance with minimal postural loading.

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