Applied Human Factors and Ergonomics International

Effect of Backpack Carriage Position on Physiological Cost and Subjective Responses of University Students

Salil Joseph and Arijit Sengupta

Department of Mechanical and Industrial Engineering
New Jersey Institute of Technology
Newark, NJ 07102-1982, USA

ABSTRACT

The purpose of this study was to determine the effect that the position of a backpack has on physiological cost and perceptual responses of university students. Twelve male volunteers walked at a brisk pace along a half-mile indoor course that included level hallways, stairs, and ramps carrying books weighing 15% of their body weight in a backpack on upper back vs. lower back placement vs. no load condition. Average heart rate (HR) and subjective body discomfort ratings in neck, shoulder, upper back and lower back were significantly higher ($p<.05$) for carrying the backpack as compared to walking with no load. The peak HR was significantly higher ($p<.05$) for upper backpack position (122 bpm) compared to that for lower backpack position (117 bpm). Average HR, body discomfort ratings, and fatigue measures of bilateral trapezius muscles showed increasing trends from no load to lower backpack to upper backpack positions; however the increases were not statistically significant. The results indicated that wearing the backpack on upper back may impose additional physical stress on male university students.

Keywords: Backpack, Load position, Heart rate, Discomfort, EMG

INTRODUCTION

Young adults carrying heavy book bags are common occurrence (Negrini et al. 1999; Negrini and Carbalona 2002). Increased prevalence of self-reported annual back pain by college students has been found to be associated with heavy backpack carriage (Heuscher et al., 2010). Therefore, it is essential to determine the method of load carriage that best minimizes physical stress on the human body.

A large number of studies have evaluated various aspects of backpack load carriage (Knapik et al. 1996). These studies involved diverse user populations such as, school children, college students, hikers, and soldiers. The studies involving book bags have focused mostly on the weight of the bag, or different types of bags. Some of them have used weights rather than educational materials such as books, to fill the bag (Smith et al., 2006; Al-Khabbaz et al., 2008; Simpson et al., 2011), and have used artificial settings to test individuals such as walking on platforms (Devroey et al., 2007) or walking on a flat walking course (Bobet and Norman, 1984) to recreate a college atmosphere. Another issue of the past studies is that there seems to be a controversy as to which backpack position is optimal: high or low (Bobet and Norman, 1984; Holewijn 1990; Johnson et al. 2000; Grimmer et al., 2002;

Stuempfle et al., 2004; Devroey et al., 2007). This study has utilized university students in a university setting to investigate which backpack position has the optimal efficiency of load carriage that will involve minimal energy expenditure and the least physical stress.

METHOD

Participants

The study was approved by the institutional review board. Twelve male university students participated in the study. The recruitment was done on campus with flyers, and participants received ten dollars an hour for their time. All participants were healthy students, regularly used backpacks, reported no fatigue or pain prior to the experimental session, and had no injury or any medically diagnosed cardiovascular or respiratory problems that could interfere with their performance in the experiment. The average and standard deviation of age, height, and weight were 24(8.7) years, 178(3.6) cm and 75(14.7) kg, respectively.

Experimental Procedure

The walking course designed for the experiment comprised of indoor laps around the second and third floor of Guttenberg Information Technology Center of New Jersey Institute of Technology. The course included hallways, staircases, and ramps that a typical university student encounters daily in an academic setting. The participants were instructed to walk briskly to complete the course. Participants were required to sign in at checkpoints throughout the course to confirm that they are completing the course correctly. The total length of the course was approximately half a mile and participants took ten to eleven minutes to complete the course for each trial. Each participant completed the course three times, once without carrying a backpack, once carrying a backpack fastened to the upper back, and once carrying a backpack fastened to the lower back position. For the high backpack position, the top of the bag was leveled at the shoulder line, and for the low backpack position the bottom of the backpack was leveled at L5 lumbar vertebra (Figure 1). The order of the three trials was randomized for participants.

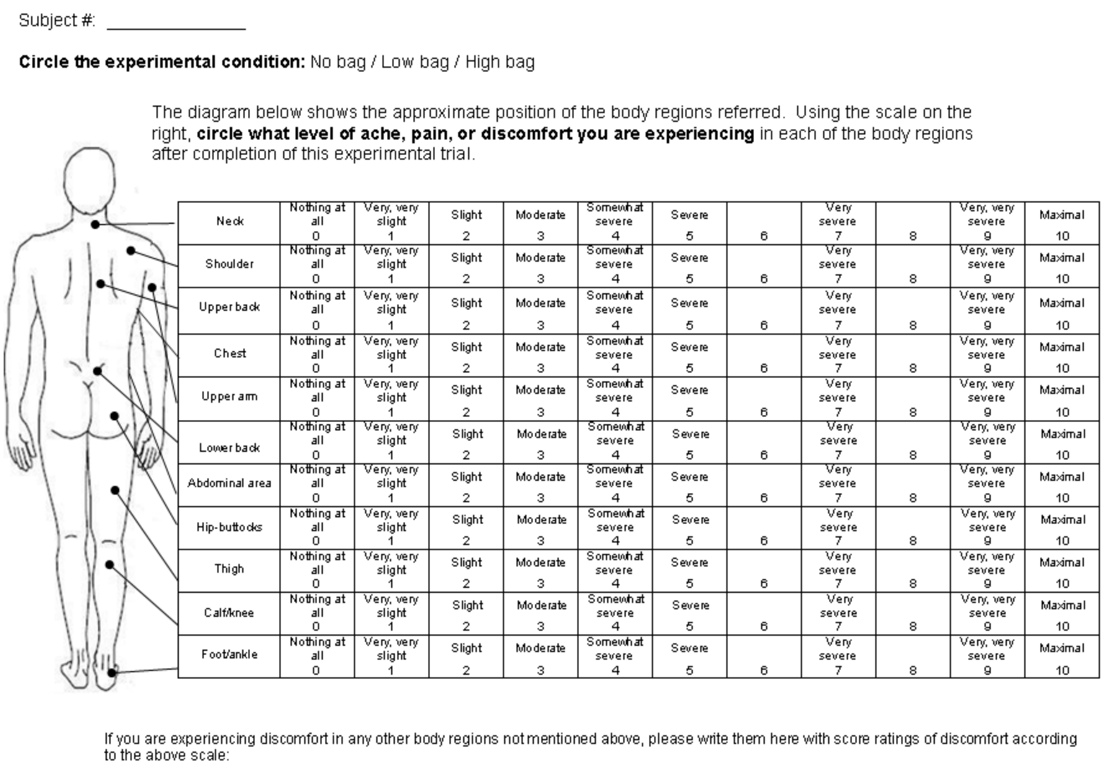
Figure 1. The high and low position of the backpack

The book bag used for the study was an Under Armour® two-strap book bag made from nylon fabric. It was unframed and the shoulder straps were anatomically shaped and padded. The bag was chosen for its comfortable padding as well as for the length of the shoulder straps that would accommodate participants both tall and short. The backpack was filled with books and notepads. Participants carried the backpack at 15% of their body weight, which was the limit recommended in previous studies (Wang et al., 2001; Devroey et al., 2007; Al-Khabbaz et al., 2008).

Data collection and analysis

Participants were not allowed to have a heavy meal or drink two hours prior to the experiment. After a participant signed informed consent, he was familiarized with the course and the experimental protocol, and the book bag was prepared to have 15% of his body weight. For each experimental trial, heart rate (HR) was collected using Polar T31 chest band, comprising of electrodes and a wireless transmitter, and an Oregon Scientific Smart Sync wireless heart rate logger. The heart rate logger sampled the heart rate every two seconds.

At the end of each trial, participants noted location and intensity of discomfort level in a scale of 0 (nothing at all) to 10 (maximal) using a body map diagram (Figure 2), which was adapted from Cornell Musculoskeletal Discomfort Questionnaire (2010). Discomfort was mapped to 11 body regions, including the neck, shoulder, upper back, chest, upper arm, lower back, abdominal area, hip-buttocks, thigh, knee/calf, and ankle/foot. Participants were verbally encouraged to report all uncomfortable body regions.



Subject #: ______________

Circle the experimental condition: No bag / Low bag / High bag

The diagram below shows the approximate position of the body regions referred. Using the scale on the right, **circle what level of ache, pain, or discomfort you are experiencing** in each of the body regions after completion of this experimental trial.

Neck	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Shoulder	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Upper back	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Chest	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Upper arm	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Lower back	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Abdominal area	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Hip-buttocks	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Thigh	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Calf/knee	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10
Foot/ankle	Nothing at all 0	Very, very slight 1	Slight 2	Moderate 3	Somewhat severe 4	Severe 5	6	Very severe 7	8	Very, very severe 9	Maximal 10

If you are experiencing discomfort in any other body regions not mentioned above, please write them here with score ratings of discomfort according to the above scale:

Figure 2. Subjective discomfort body map adapted from Cornell Musculoskeletal Discomfort Questionnaire (2010) used to determine discomfort levels reported by participants after each half a mile brisk walk within university building.

In previous backpack studies (Devroey et al., 2007; Simpson et al., 2011), backpack carriage predominantly produced higher level of discomfort in the neck and shoulder regions. To investigate if such discomfort was related

https://openaccess.cms-conferences.org/#/publications/book/978-1-4951-2105-0

to local fatigue from static muscle tension in the shoulder/neck, the bilateral upper trapezius muscle groups were selected for monitoring muscle fatigue. EMG surface electrodes were affixed on the left and right upper trapezius muscles, slightly lateral to the midway between C7 cervical vertebra and acromion (Jensen et al., 1993). The skin surface was cleaned with rubbing alcohol and conductive gel was applied prior to applying the surface electrodes with double sided adhesive tape. The surface electrodes (Biometrics Ltd., Model SX 230W) employed a preamplifier (gain 1000), and high pass and low pass filter circuitry to reduce external interference. The EMG signals were collected at a rate of 1000 Hz using Biometrics DLK800 base unit and Datalink analysis software (Biometrics Ltd.) and stored in a personal computer for further processing.

EMG data was collected for maximum voluntary contraction (MVC) of the bilateral trapezius muscle groups for approximately six seconds, and repeated three times. The MVC task was two-handed upward pulling of a static handle, while standing erect and keeping arms and forearms vertical. This task elicited high EMG activity for trapezius muscle. EMG was processed with a root mean square (RMS) filter with 100 msec sliding window, and averaged over 3 sec and the largest value of the MVC trials was later used for normalization of task EMG data.

Immediately after completion of each walking trial, EMG was collected while the participant held a 20 pound dumbbell in each hand for six sec, keeping upper body and arms vertical and static. The average of 3 sec normalized RMS amplitude (NRMS), and the average of the Median Frequency (MF) computed over 1024 data points were calculated to assess muscle fatigue (Cifrek et al. 2009).

Between each walking trials, participants rested for ten minutes. At the end of the experiment, participants noted their preferred backpack position and why they preferred that position.

Minitab16 statistical software was used to perform a repeated measure analysis of variance for no bag (NB), low bag (LB) and high bag (HB) positions with participant as the random factor. Tukey’s test for contrast of means was performed for post hoc analysis.

RESULTS

Walking Speed

The average time to complete the course in NB, LB and HB conditions were 10.75, 11.17 and 11.25 min, respectively. Time taken for HB was significantly longer than NB ($p=0.097$), but was no different from LB ($p=0.93$). The time to complete the half a mile indoor course corresponded to 4.50, 4.33 and 4.30 km/hr, respectively.

Heart Rate

The typical HR plots, recorded from two participants at every 2 sec for NB (red), LB (blue) and HB (green) are presented in Figure 3. The plots revealed a pattern of peaks and valleys that were repeated in all three conditions. The peaks represented physically demanding parts of the route, typically when the participants had to climb a staircase or walk up a ramp. A customized Matlab routine was used to smooth the HR data with a moving average window of 15 data points, and then to find the peaks. Figure 4 depicts the smoothed HR data of Figure 3, with the peak values circled.

HR data from nine participants could only be used for the analysis due to data collection errors with three participants. Due to instrument malfunction, HR data were missing for part of one or more trials. The average HR (AHR) over a trial, and average of the three middle peaks (PHR) in a trial, were used for statistical analysis. Average AHR for nine participants were 105.7, 106.9 and 112.3 beats per min (bpm), for NB, LB and HB conditions, respectively (Figure 5). AHR for HB was significantly higher than AHR for NB ($p<.05$), but not significantly different from LB. The corresponding values for PHR were 113.9, 118.0, and 121.7 bpm, and all three means were significantly different from each other at $p<.05$.

https://openaccess.cms-conferences.org/#/publications/book/978-1-4951-2105-0

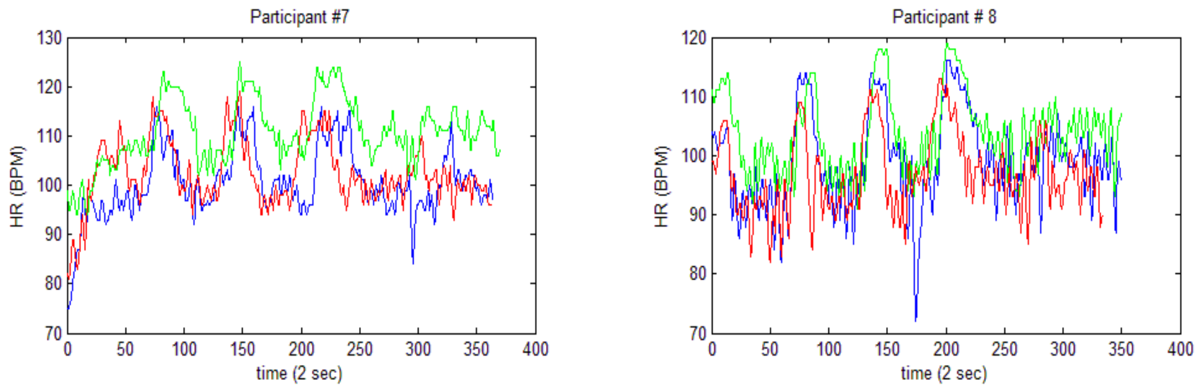


Figure 3. Sample HR raw data for participant #7 & #8 for high (green), low (blue) and none (red) backpack conditions.

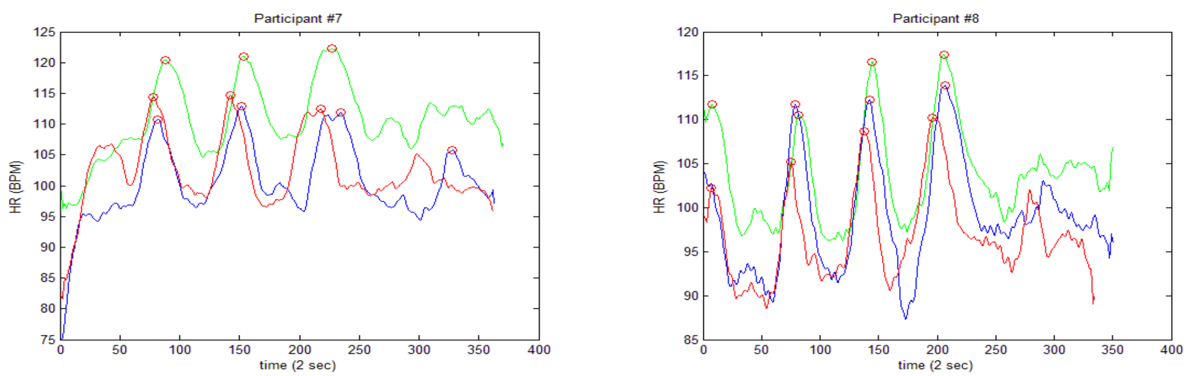


Figure 4. HR data for participant #7 & #8 smoothed and peak identified for high (green), low (blue) and none (red) backpack conditions.

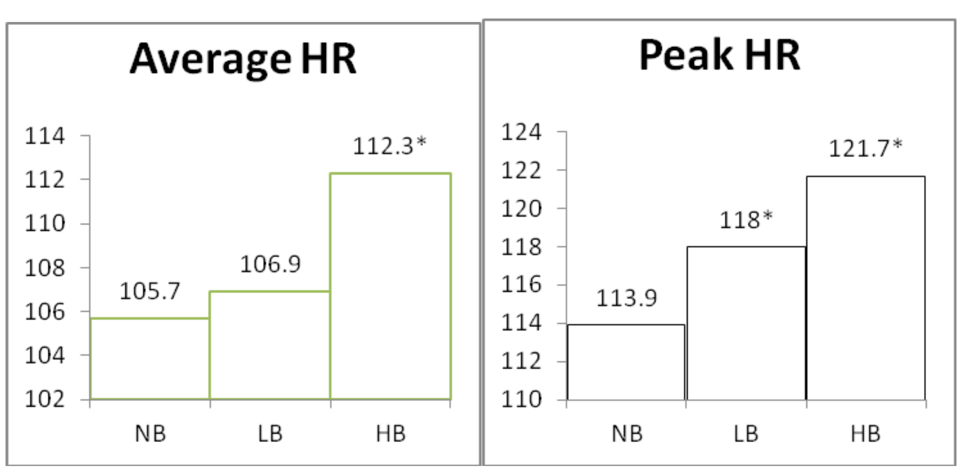


Figure 5. Average and peak HR (bpm) for no bag (NB), low bag (LB) and high bag (HB) position of the backpack (n=9).

Average HR *=p<.05 with NB; Peak HR *<.05 between NB, LB & HB.

Discomfort scores

Average discomfort scores in neck, shoulder, upper back, chest, upper arm, lower back, abdominal area, hip-buttocks, thigh, knee/calf, and ankle/foot in a scale of 0-10 for 12 participants are presented in Figure 6. An increasing trend was noticed for most of the discomfort scores for NB to LB to HB. Average scores corresponded to slight or moderate discomfort, were noted in neck, shoulder, and upper back for load carriage. The rest of the body regions received 'not at all' to 'very very slight' discomfort ratings. Load carriage in LB and HB produced significantly ($p<.05$) increased discomfort in neck, shoulder, upper back, and lower back regions compared to no load condition. However, discomfort scores were not different for LB and HB conditions.

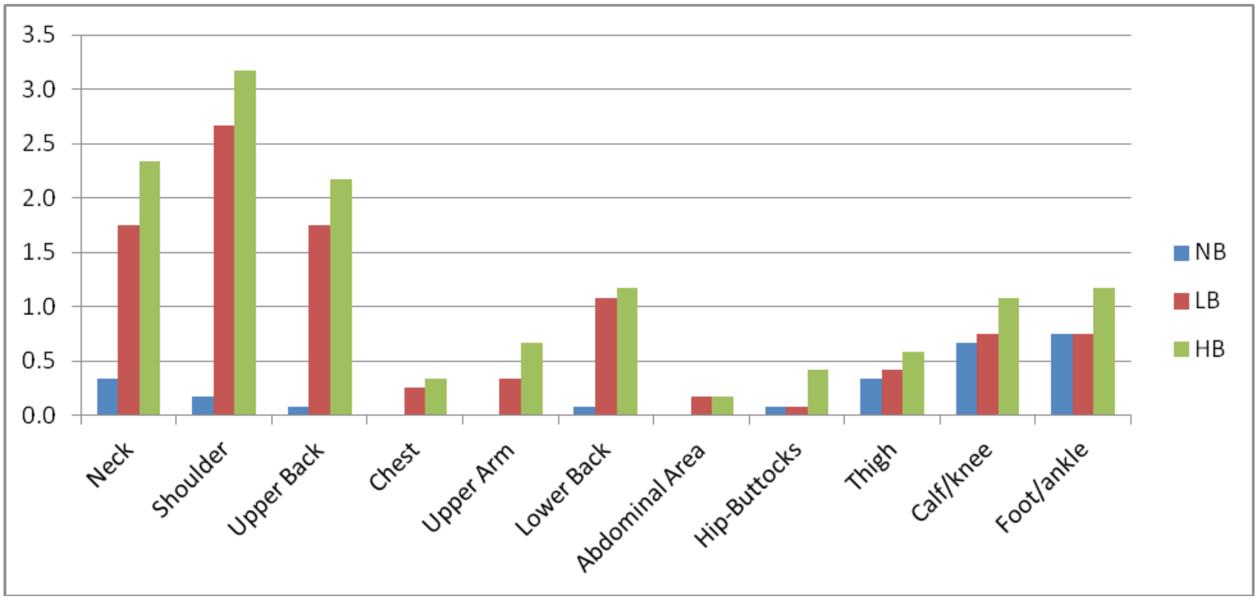


Figure 7. Average discomfort scores in a scale of 0 – 10 for no bag (NB), low bag (LB) and high bag (HB) positions

Muscle Fatigue

Averages (n=12) of the normalized root mean square (NRMS) values for NB, LB and HB were 20.0%, 19.9%, and 21.2% respectively (Figure 8). Rise in the NRMS for HB, as compared to LB and NB, should indicate muscle fatigue (Cifrek et al., 2009), however the differences were not statistically significant. Averages of the median frequencies (MF) were 62.5, 61.5, and 61.8 Hz respectively for NB, LB and HB (Figure 8). Reduction of MF from NB condition is also indicative of muscle fatigue (Cifrek et al., 2009) however none of the differences were significant.

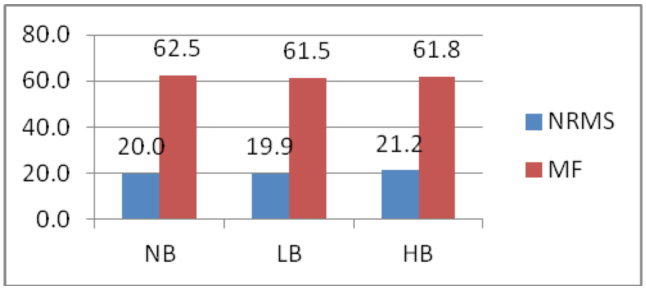


Figure 8. Average normalized NRMS (%) and average median frequency (MF Hz) for no bag (NB), low bag (LB) and high bag (HB) positions.

DISCUSSION AND CONCLUSION

Unlike backpack studies that involved walking on a treadmill (Stuempfle et al., 2004), or that used simulated weights, such as sand bags (Al-Khabbaz et al., 2008; Simpson et al., 2011) or cement blocks (Smith et al., 2006) to evaluate the effect of load carriage, this study used realistic brisk walking within a college building carrying books and notebooks in a backpack. Indoor walking with a speed of 4.3 to 4.5 km/hr for ten to twelve minutes is a reasonable representation of university students walking in a typical school day (Mackie and Legg, 2008). HR and subjective body discomfort ratings in neck, shoulder, upper back, and lower back were significantly higher for carrying the backpack as compared to walking without a backpack. This was expected, because 15% additional body weight on the back was bound to produce additional cardiovascular response and discomfort.

The average HR for seven participants increased from LB to HB, and it decreased for two participants. The overall average increase of HR was 5.4 bpm from LB to HB, but the increase was not statistically significant. Similar statistically non-significant difference in average HR was noted in previous studies with respect to backpack position (Bobet and Norman, 1984; Holewijn 1990; Johnson et al. 2000; Stuempfle et al., 2004; and Devroey et al., 2007). Since HR is a global measure of rate of metabolic work, this result seemed to indicate that overall metabolic work intensity and the total energy expenditure was not affected appreciably from change in the load position. Lloyd and Cooke (2000) found similar non-significant effect of load position on HR when walking on level or downhill slopes, where the metabolic intensity was below 120 bpm. But in the same study, for uphill walking at 10%, 15% and 20% gradient, load position effect on HR became statistically significant. Sagiv et al. (2000) also found significant effect of load amount on HR for walking on a trade mill with 5% and 10% incline as opposed to no effect on level walking. We noticed a similar effect in this study. The mean peak HR was significantly ($p<.05$) higher for high backpack position (122 bpm), compared to that for low backpack position (117 bpm). Peak HR for the participants were associated with climbing staircases and walking on uphill ramps within the indoor course. It is well known that at moderate to high intensity physical work, the stroke volume (SV) maximizes and the cardiac output (CO) is proportional to HR. However, both SV and HR are adjusted to match the CO demand in low intensity physical work, and as a result, the change in HR may not reflect a proportional change in the intensity of physical work. Thus although the average HR over the whole walking course was not different between HB and LB, significantly higher peak HR for HB indicates additional metabolic cost for HB.

The average physiological and perceptual responses in terms of average HR, body discomfort ratings in neck, shoulder, and upper back, and muscle fatigue measures in terms of NRMS increased from to low backpack to high back condition, although the increases were not statistically significant.

In the previous backpack studies, HB load placement was associated with higher EMG amplitude for torso and shoulder muscles (Bobet and Norman, 1984; Devroey et al., 2007), higher contact pressure under shoulder straps (Holewijn, 1990), and greater forward lean of the upper body (Grimmer et al., 2002; Devroey et al., 2007) when unframed backpacks were used. Two studies that recommended LB load placement, used heavier load levels and used either a framed backpack suitable for hikers (Stuempfle et al. , 2004) or used a specially designed adjustable height implement (Johnson et al., 2000) for soldiers, which renders the recommendation inapplicable for unframed backpack use.

Thus, it can be concluded from this study, that carrying a backpack weighing 15% of one's body weight for 10 to 12 min inside university buildings sustains significant physiological cost and body discomfort. When the backpack is carried in upper back position, it causes an additional physiological cost in terms of higher peak heart rate as compared to lower backpack position. These results are valid for male university students only.

REFERENCES

Al-Khabbaz, Y. S. S. M., Shimada, T., & Hasegawa, M. (2008). The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. Gait and Posture, 28(2), 297-302.

Bobet, J., & Norman, R. W. (1984). Effects of load placement on back muscle activity in load carriage. European Journal of Applied Physiology and Occupational Physiology, 53(1), 71-75.

Cifrek, M., Medved, V., Tonković, S., & Ostojić, S. (2009). Surface EMG based muscle fatigue evaluation in biomechanics. Clinical Biomechanics, 24(4), 327-340.

Cornell Musculoskeletal Discomfort Questionnaire (2010), CUErgo website: http://ergo.human.cornell.edu/Pub/AHquest/mmsdqall.pdf

Devroey, C., Jonkers, I., de Becker, A., Lenaerts, G., & Spaepen, A. (2007). Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological and subjective measures. Ergonomics, 50(5), 728-742.

Heuscher, Z., Gilkey, D. P., Peel, J. L., & Kennedy, C. A. (2010). The association of self-reported backpack use and backpack weight with low back pain among college students. Journal of Manipulative and Physiological Therapeutics, 33(6), 432-437.

Holewijn, M. (1990). Physiological strain due to load carrying. European Journal of Applied Physiology and Occupational Physiology, 61(3-4), 237-245.

Grimmer, K., Dansie, B., Milanese, S., Pirunsan, U., & Trott, P. (2002). Adolescent standing postural response to backpack loads: A randomised controlled experimental study. BMC Musculoskeletal Disorders, 3, 1-10.

Jensen, C., Vasseljen, O., & Westgaard, R. H. (1993). The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle. European Journal of Applied Physiology and Occupational Physiology, 67(3), 266-273.

Johnson, R.C., Pelot, R.P., Doan, J.B., and Stevenson, , J.M. (2000). The Effect of Load Position on Biomechanical and Physiological Measures during a Short Duration March, Paper presented at the RTO HFM Specialists' Meeting on "Soldier Mobility: Innovations in Load Carriage System Design and Evaluation", held in Kingston, Canada, 27-29 June 2000, and published in RTO MP-056. http://ftp.rta.nato.int/public/PubFullText/RTO/MP/RTO-MP-056/MP-056-04.pdf

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

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

Mackie, H. W., & Legg, S. J. (2008). Postural and subjective responses to realistic schoolbag carriage. Ergonomics, 51(2), 217-231.

Negrini, S., & Carabalona, R. (2002). Backpacks on! schoolchildren's perceptions of load, associations with back pain and factors determining the load. Spine, 27(2), 187-195.

Negrini, S., Carabalona, R., & Sibilla, P. (1999). Backpack as a daily load for schoolchildren. Lancet, 354(9194), 1974.

Sagiv, M., Ben-Fal, S., & Ben-Sira, D. (2000). Effects of gradient and load carried on human haemodynamic responses during treadmill walking. European Journal of Applied Physiology, 83(1), 47-50.

Simpson, K. M., Munro, B. J., & Steele, J. R. (2011). Effect of load mass on posture, heart rate and subjective responses of recreational female hikers to prolonged load carriage. Applied Ergonomics, 42(3), 403-410.

Smith, B., Ashton, K. M., Bohl, D., Clark, R. C., Metheny, J. B., & Klassen, S. (2006). Influence of carrying a backpack on pelvic tilt, rotation, and obliquity in female college students. Gait and Posture, 23(3), 263-267.

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

Wang, Y., Pascoe, D. D., & Weimar, W. (2001). Evaluation of book backpack load during walking. Ergonomics, 44(9), 858-869.