Effect of Backpack Design on Craniovertebral Angle, Trunk Angle, Heart Rate and Discomfort in Female Young Adults - A Pilot Study

Nuttika Nakphet[*1] and Montakarn Chaikumarn[2]

[1]Faculty of Physical Therapy and Sport Medicines, Rangsit University, Pathum Thani, Thailand
[2]Faculty of Allied Health Sciences, Chulalongkorn University, Bangkok, Thailand
[*]Corresponding author, E-mail: nnakphet@gmail.com

Abstract

The research aimed to determine the effect of backpack design on posture, heart rate, and muscular discomfort among female university students. A randomized control trial was used, the participants were the frameless backpack (n=25) and the internal frame backpack (n=25). The participants loaded the backpack with 15% of their body weight. Heart rate was measured by a polar heart rate monitor and discomfort scores were measured by VAS scale. The craniovertebral angle and trunk angle were measured. An analysis of variance was used for statistical analysis to evaluate the effect of backpack design on each parameter. There was a significant difference in craniovertebal angle though no significant difference was found in trunk angle between the backpacks, and the internal frame backpack had significantly increased in heart rate. A significant increase of discomfort was also found only at the neck region when carrying the frameless backpack. The internal frame backpack gave the students more comfortable only mostly at the neck region when compared to the frameless backpack. Moreover, the internal frame backpack had increased the heart rate. Also, the application of this study was to advise the young adult to choose a suitable backpack for daily activity.

Keywords: *Backpack, Craniovertebral angle, Posture, Heart rate, Discomfort, Students*

1. Introduction

Several pieces of researches showed that students and adolescents carry heavy backpacks (Whittfield et al., 2005; Trevelyan & Legg, 2011). The adverse effect of daily carriage of a backpack is included neck and shoulder pain (Murphy et al., 2007; Kim et al., 2008), spinal pain (Grimmer et al., 1999), and lower back pain (Rodríguez-Oviedo et al., 2012).

When carrying a heavy backpack, there are several changes in the body due to loading. These are changed in oxygen uptake and energy expenditure (Hong & Brueggemann, 2000), cardiopulmonary parameters (Li et al., 2003; Chow et al., 2005; Fiolkowski et al., 2006), and trunk and head posture (Goodgold et al., 2002; Grimmer et al., 2002; Chow et al., 2006).

Besides reducing the load of carrying, the design of the backpack was also concerned. As Backpack is a bag for carrying things that has two shoulder straps and is carried on the back. There are three basic designs of backpacks: external frame, internal frame, and frameless. External frame backpacks are heavy, good ventilation, and the frame is prone to damage when traveling by public transport. Whilst, internal frame backpacks usually have thicker, more comfortable shoulder straps than frameless models, greater inner storage space, but they aren't having ventilation between the user's back and pack, larger models and heavier than frameless backpacks. In addition, the frameless backpack is a sack with shoulder straps. Most models have side pockets, but not all have compression straps and hip belts. They're simple, lightweight, and inexpensive. However, they're uncomfortable if carrying heavy loads for a long time (Backpack, 2021).

An internal frame backpack was designed to help the users feel better comfort when carrying for a long distance or period. In a comparison of external and internal frame backpacks, Kirk and Schneider (1992) found no significant differences for any metabolic, cardiorespiratory, or perceptual variables, whereas Johnson et al (1995) reported rating of perceived exertion was significantly different in favor of internal frame backpacks.

The authors were interested in the use of the internal frame and frameless backpacks since they were popular among university students. However, there is a lack of systematic data regarding the local effects of the internal frame and frameless backpack carriage directly on the change of neck and trunk posture, heart rate, and discomfort in the university students.

2. Objectives

The objectives of the study were to determine the effect of the design of a backpack (*i.e.* internal frame and frameless backpack) on a craniovertebral angle, trunk posture, heart rate, and body part discomfort in a group of female university students aged between 18 to 25 years old.

The study hypothesized that an internal frame backpack will make the user more comfortable and less in heart rate increasing, trunk forward lean, forward head than that of carrying the frameless backpack.

3. Materials and Methods

Research design

This experimental study was a randomized controlled trial design where the participants were randomly allocated into two groups based on the types of the backpack as follows: (a) internal frame-group; (b) frameless group.

Participants

Fifty female university students (25 persons for frameless backpacks, 25 persons for internal frame backpacks) aged 18-25 years agreed to participate in this study. The participants were healthy and had experience in using a backpack. Besides, the participants had no injury to the back, spine surgery, and major surgery during the last 6 months and did not have a history of low back pain during the last 7 days. The participants were excluded if they wanted to withdraw from the study or they became injured during the study. This study recruited only female participants since the females were prone to have an adverse effect from carrying a backpack (Grimmer et al., 1999). There were only 25 participants per group since this research was a pilot study.

Backpack

The dimension of an internal frame backpack was 43 x 33 x 25 cm, weighed 0.6 kg. The frameless backpack had a dimension of 42 x 33 x 21 cm, weighed 0.3 kg.

Procedure

After each participant was enrolled in the study, basic anthropometric measurements were taken including age, weight, and height. At the beginning of a session, the participant's weight was taken to confirm the accurate backpack loading as a percentage of body weight and was asked about the feelings of body part discomfort on the Modified Borg's category rating 10 scale (CR-10).

Then, the participant completed an initial questionnaire that obtained basic demographic information, then they have placed the markers on the left side of the body at the following locations: spinous process of C7, tragus of the ear, acromioclavicular joint, greater trochanter of femur, lateral knee joint line, lateral malleolus. All participants had a chance to adjust the straps before the tests started. Besides, the participant was measured heart rate by using the polar heart rate monitor.

The photograph of participants was shot when they stand at the "L" marked on the floor. The lateral edge of the left foot lines up along the longer length of the L and the toe is placed on the edge of the shorter length of the L. A digital camera is set on a tripod with a 120 cm. high and 3 m. far from the longer L line and a digital photograph is on the left side (sagittal view) of the participant. Photographs were taken according to the protocol set by Kistner et al. (2011). The participants looked straight ahead at the target while a photograph was taken with the digital camera. The baseline postural measurement was also taken in the first photograph when each subject was instructed to stand still for 1 minute as ordinarily as possible without a backpack along the L marked on the floor (unloaded condition). The second photograph (initial load condition) was directly taken once the backpack with load was positioned, while the participant stood at the L marked on the floor. Then, the participants were directed to walk around the marked area for 800 m at a normal walking speed while carrying the loaded backpack. After walking, the participant stood at the L marked, and the third photograph was taken (post-walk condition). Immediately after the post-walk condition was captured, the heart rates were recorded, the participants were asked to rate their feelings of body discomfort on Modified Borg's category rating 10 scale (CR-10). All tests were done in random order.

The digital photographs were analyzed to identify the craniovertebral angle and trunk angle by using the "Kinovea" Version 0.8.15. Kinovea is free software from kinovea.org that can be used to measure the angle by using the line, angle, and goniometer tool. The researcher (MC) did the angle analysis. The intra-rater reliability of accuracy of angle measurement was 0.75.

Craniovertebral angle is the angle formed at the intersection of a horizontal line through the spinous process of C7 and line of the tragus of the ear (Figure 1).

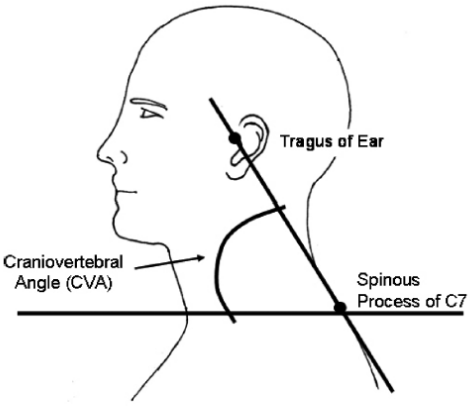

Figure 1 Craniovertebral angle (Chansirinukor, 2001)

Trunk angle is the angle formed at the intersection of a horizontal line through the hip joint and line of the acromioclavicular joint (Figure 2).

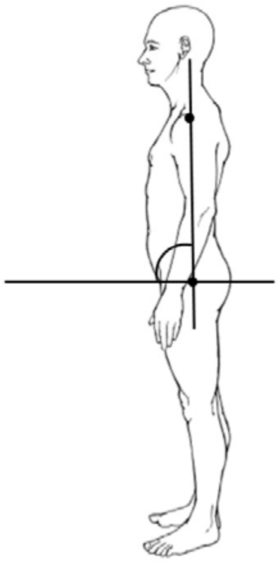

Figure 2 Trunk angle

Statistical analysis

Means and standard deviations (SD) of heart rate (HR), posture (CVA and Trunk angle), and discomfort were calculated for each backpack design. Normality and equal variance of the data was confirmed using a Kolmogorov-Smirnov test. Two-way repeated-measures analysis of variance (ANOVA) was used to test for the main effect of the backpack design. Post hoc tests using the Bonferroni correction were used. Statistical tests were considered significant if $p < 0.05$.

4. Results and Discussion

4.1 Results

The demographic data of the participants were shown in Table 1.

Table 1 Participant demographics **(**N=50**)**

Demographic Features	Frameless group Mean (SD) N=25	Internal frame-group Mean (SD) N=25	Between groups p-value
Age (years)	21.4 (1.0)	21.8 (0.8)	0.510
Weight (kg)	52.8 (5.3)	54.4 (7.8)	0.628
Height (m)	1.6 (0.1)	1.6 (0.1)	0.082
BMI (kg/m^2)	20.8 (1.9)	20.7 (2.8)	0.567
CVA-unload (degree)	55.2 (4.5)	56.5 (4.8)	0.288
Trunk-unload (degree)	95.4 (3.2)	95.8 (3.5)	0.89
Neck-unload (discomfort)	1.0 (1.6)	0.8 (1.6)	0.487
Lt.shoulder-Unload (discomfort)	0.9 (1.5)	0.8 (1.5)	0.762
Rt.shoulder-Unload (discomfort)	1.2 (1.6)	0.8 (1.3)	0.321
UB-unload (discomfort)	0.2 (0.8)	0.0 (0.2)	0.977
LB-unload (discomfort)	0.2 (0.4)	0.2 (0.4)	0.716
HR-unload (bpm)	82.6 (9.3)	82.7 (10.4)	0.930

4.1.1 Craniovertebral angle (CVA)

There was a significant design effect on the Craniovertebral angle (F (1,24) = 900.92, p =0.000). In the frameless backpacker group, the participants had a significant decrease in CVA when comparing CVA unloading with initial load and with post-walk (Figure 3), meaning that the participants have increased forward head posture while carrying the frameless backpack both of initial load and post-walk.

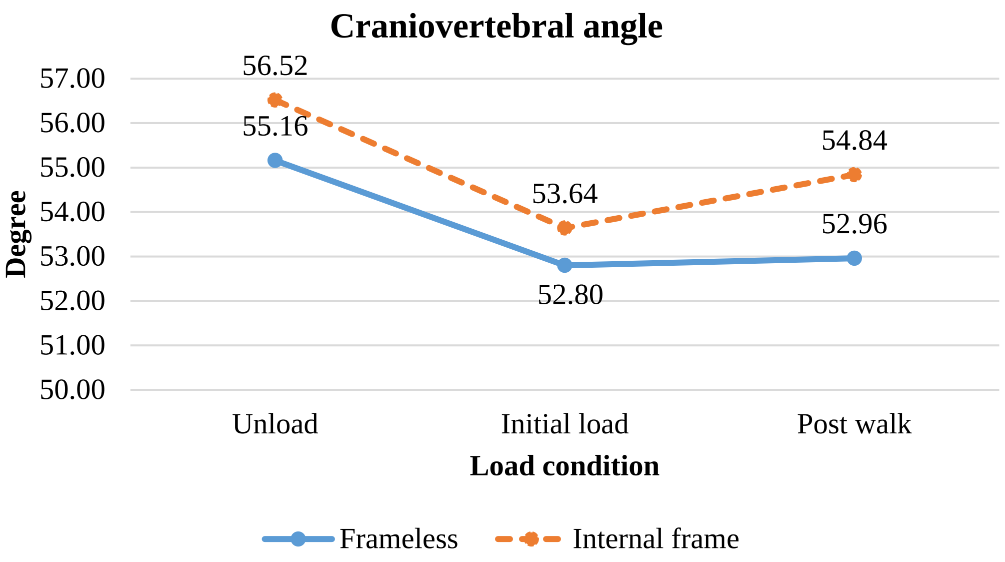

Figure 3 Craniovertebral angle in three load-conditions

4.1.2 Trunk angle

There was no significant design effect on the trunk angle (F (1,24) = 1.23, p =0.278). However, both groups of participants had adopted trunk lean forward posture over time (Figure 4).

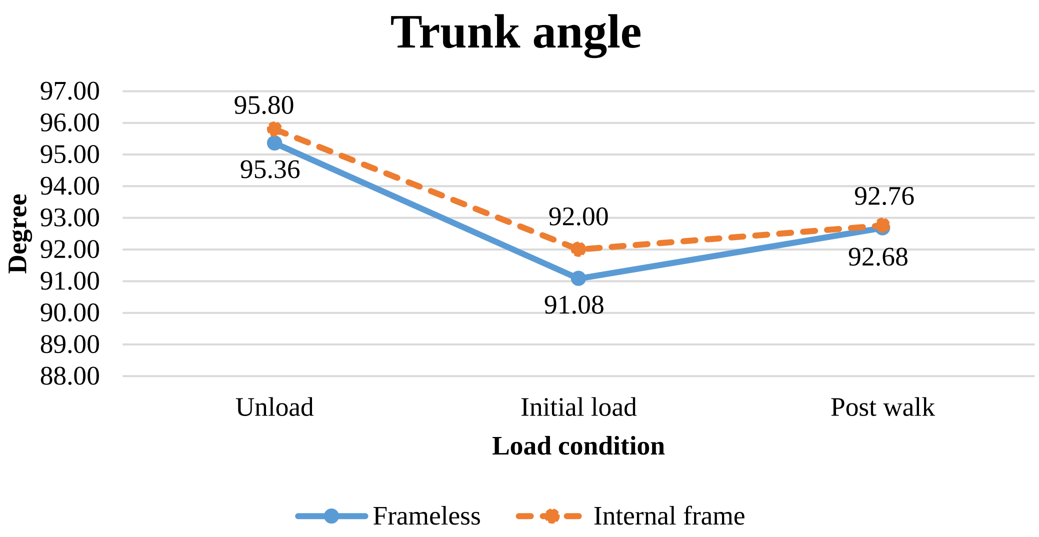

Figure 4 Trunk angle in three load conditions

4.1.3 Heart rate (HR) and discomfort

There was no significant effect of the backpack design on heart rate at the initial loading time F (1,24) =58.91, p = 0.711. The heart rate was significantly affected by the backpack design (F (1,24) = 38.91, p =0.000). The result showed that after walking with the internal frame backpack the HR was increases compared to that of the frameless backpack group.

There was no significant effect of backpack design on discomfort at the initial loading time F (1,24) =214, p = 0.989. The discomfort ratings increased in all areas of the body after the post-walk condition. The frameless group had higher discomfort than that of the internal frame group in the neck, Lt. shoulder, and upper back areas. There was a significant design effect on the Neck area ($F(1,24) = 1181.25$, $p = 0.000$), Lt. Shoulder ($F(1,24) = 8.15$, $p = 0.000$), and Upper back ($F(1,24) = 56.25$, $p = 0.000$).

4.2 Discussion

The purpose of this study was to determine the effect of the design of the backpack, that is an internal frame and frameless backpack, in a group of female university students, age between 18 to 25 years old. This study used a 15% BW backpack load, which is too hard to maintain normal posture in teenagers (Chansirinukor et al., 2001) and increased forward head posture (Kistner et al., 2012). Both frameless and internal frame backpack users, the 15% BW load immediately increases forward head posture at initial loading. The CVA change from 55.16 to 52.80 degrees. After walking 800 meters both groups have the same result. Some participants are increasing in CVA, which shows a more forward head posture than the initial load and some are decreasing CVA but still have forward head posture. The CVA change from 55.16 (unload) to 52.96 (post-walk) degrees.

A decrease of the craniovertebral angle was indicating a more forward head posture whilst carrying a backpack. The closer the points at the shoulder and C7 are, the bigger the sagittal shoulder angle is. Therefore, the more anterior head position observed in most subjects in this study when carrying a frameless backpack may contribute to an enlarged sagittal shoulder angle. Further study using a three-dimensional approach is required to identify the relationship between body landmarks. Moreover, the subjects in this study walked in a controlled environment, that is, walking on the same level, at the same pace, on an even surface, which may not reflect a realistic environment for most students during normal day-time backpack carriage.

The previous study found that trunk posture will change with 20% BW (Hong & Cheung 2003) but we used only 15% BW backpack load. Both frameless and internal frame backpack users, the 15% BW immediately changes the posture of the participants. Although some were increased in trunk flexion and some were increasing in trunk extension. The trunk posture has increased flexion at the initial loading from 95.36 to 91.08 degrees. After walking 800 meters, the results were the same as that of the initial load condition. Trunk posture changed from 95.36 (unload) to 92.68 (post-walk) degrees. Thus, there were no different changes when compare the frameless backpack group with the internal frame backpack group. Orloff and Rapp (2004) reported that there was a significant increase in the lumbar curvature because the participants fatigued while carrying load mass 13.8% BW. However, this study found that backpack design does not cause a significantly different effect on cervical and trunk posture. The forward inclination of the trunk with increasing backpack load is therefore presumably to maintain the position of the combined center of gravity above the base of support. The increasing forward inclination of the trunk in space as load increases appears to be due mainly to flexion of the trunk relative to the pelvis, which accounted for 4.6° of the 5.8° total increase in trunk flexion seen at 15% bodyweight backpack load (Chow et al., 2006).

While unloaded-condition, there was no significant difference in heart rate with the different backpack designs. However, the mean heart rate increased significantly by 20.3 beats per minute from a resting value of 82.6 to 102.9 beats after walking in a frameless backpack and increased 25.9 beats per minute from a resting value of 82.7 to 108.6 beats after walking in an internal frame backpack. According to the results of Hong et al. (2000), they reported the heart rate in all load conditions that were significantly increased after walking in the first 5 minutes and then slowly increased over time during walking

The present study found significantly different increased heart rate of the internal frame backpack compared to the frameless backpack. There was no prior study found about the effect of backpack design on heart rate and the information that analysis of the heart rate did not provide (Devroey et al., 2007). Only the study by Ramadan and Al-Tayyar (2019) have noticed that backpack the carried load on the back (50% of the load) and on the sides (25% of the load on each side), which almost like an internal frame backpack had increased in heart rate when students carried with 15% BW of load, which might be due to the design of backpacks. Since an internal frame backpack has thick shoulder straps than a frameless backpack. Thus the shoulder strap may cause the tightening of the chest wall and made the participants breathe difficultly. The Difficulty of breathing indicates the body for more oxygen uptake, which increased the work of breathing and heart rate **(**Cabello & Mancebo, 2006)**.**

There was an increase in discomfort in five body regions reported by the participants in this study from both backpack design groups. Our study had shown the same results as Sharan and colleagues (2012) reported that the pressure of the backpack was leading to discomfort on the underlying soft tissue due to blood occlusion. So the participants had more discomfort at both shoulders and upper and lower back. Moreover, the downward gravitational force acting on the backpack made muscle fatigue in the upper trapezius after 10 minutes of walking with a 20% BW (Hong et al., 2008).

In this study, the participants reported significantly higher neck discomfort in the frameless group compared to the internal-frame group. This result was coincident with the study of Simson et al. (2011), which found that participants with a load carriage backpack and a decrease in craniovertebral angle (increase in forwarding head posture) were led to neck discomfort.

Limitation of the study

This study did not control the physical activity of the participants, so the participants who have more physical activities can adapt the body to an exercise stimulus and control the heart rate better than the participants who have lower physical activities (Hallman et al., 2015).

5. Conclusion

In conclusion, the analysis of posture, heart rate, and discomfort scores showed a significant change in the discomfort of the neck, shoulder, and upper back areas in the frameless backpack. Therefore, confirming the hypothesis that is an internal frame backpack has more comfortable than a frameless backpack. However, in the other parts of the body were no significant differences between the groups of backpack design. Contrasting the hypothesis about heart rate, this study found an internal frame backpack had significantly increased heart rate more than a frameless backpack. The clinical application of this study was to advise the young adult to choose a suitable backpack for daily activity.

6. Acknowledgements

We would like to thank all participants for their good corporation.

7. References

Backpack. (2021). Backpack 2021. Retrieved January 25, 2021, from https://www.thehikinglife.com/gear/backpack/

Cabello B., & Mancebo J. (2006). Work of breathing. *Intensive Care Medicine,32*(9):1311-1314.

Chansirinukor, W., Wilson, D., Grimmer, K., & Dansie, B. (2001). Effects of backpacks on students: measurement of cervical and shoulder posture. *Australian Journal of Physiotherapy, 47*(2):110-116.

Chow, D.H., Ng, X.H., Holmes, A.D., Cheng, J.C., Yao, F.Y., & Wong, M.S. (2005). Effects of backpack loading on the pulmonary capacities of normal schoolgirls and those with adolescent idiopathic scoliosis. *Spine (Phila Pa 1976), 30*(21): E649-E654.

Chow, D.H., Kwok, M.L., Cheng, J.C., Lao, M.L., Holmes, A.D., Au-Yang, A., Yao, F.Y., & Wong, M.S. (2006). The effect of backpack weight on the standing posture and balance of schoolgirls with adolescent idiopathic scoliosis and normal controls. *Gait & Posture, 24*(2):173-181.

Chow, D.H., Kwok, M.L., Cheng, J.C., Lao, M.L., Holmes, A.D., Au-Yang, A., Yao, F.Y., & Wong, M.S. (2006). The effect of backpack weight on the standing posture and balance of schoolgirls with adolescent idiopathic scoliosis and normal controls. *Gait & Posture, 24*(2):173-181.

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.

Fiolkowski, P., Horodyski, M., Bishop, M., Williams, M., & Stylianou, L. (2006). Changes in gait kinematics and posture with the use of a front pack. *Ergonomics, 49*(9):885-894.

Goodgold, S., Corcoran, M., Gamache, D., Gillis, J., Guerin, J., & Coyle, J.Q. (2002). Backpack use in children. *Pediatric Physical Therapy, 14*(3):122-123

Grimmer, K.A., Williams, M.T., & Gill, T.K. (1999). The associations between adolescent head- on-neck posture, backpack weight, and anthropometric features. *Spine (Phila Pa 1976), 24*(21):2262-2267.

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, 17*:3-10.

Hallman, D.M., Mathiassen, S.E., & Lyskov, E. (2015) Long-Term Monitoring of Physical Behavior Reveals Different Cardiac Responses to Physical Activity among Subjects with and without Chronic Neck Pain. *Biomedical Research International*, *2015*:907482.

Hong, Y., & Brueggemann, G.P. (2000). Changes in gait patterns in 10-year-old boys with increasing loads when walking on a treadmill. *Gait & Posture*, *11*(3):254-259.

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

Hong, Y., & Cheung, C.K. (2003). Gait and posture responses to backpack load during level walking in children. *Gait & Posture*, *17*(1):28-33.

Hong, Y., Li, J.X., & Fong, D.T. (2008). Effect of prolonged walking with backpack loads on trunk muscle activity and fatigue in children. *Journal of Electromyography and Kinesiology*, *18*(6):990-996.

Johnson, R.F., Knapik, J.J., & Merullo, D.J. (1995). Symptoms during load carrying: effects of mass and load distribution during a 20-km road march. *Perception and Motor Skills*, *81*(1):331-338.

Kim, M.H., Yi, C.H., Kwon, O.Y., Cho, S.H., & Yoo, W. G. (2008). Changes in neck muscle electromyography and forward head posture of children when carrying schoolbags. *Ergonomics, 51*(6):890-901.

Kirk, J., & Schneider, D.A. (1992). Physiological and perceptual responses to load-carrying in female subjects using internal and external frame backpacks. *Ergonomics*, *35*(4):445-455.

Kistner, F., Fiebert, I., W & Roach, K. (2012). Effect of backpack load carriage on cervical posture in primary schoolchildren. *Work, 41*(1):99-108.

Li, J.X., Hong, Y., & Robinson, P.D. (2003). The effect of load carriage on movement kinematics and respiratory parameters in children during walking. *European Journal of Apply Physiology*, *90*(1-2):35-43.

Murphy, S., Buckle, P., & Stubbs, D. (2007). A cross-sectional study of self-reported back and neck pain among English schoolchildren and associated physical and psychological risk factors. *Apply Ergonomics, 38*(6):797-804.

Orloff, H.A., & Rapp, C.M. (2004). The effects of load carriage on spinal curvature and posture. *Spine (Phila Pa 1976), 29*(12):1325-1329.

Ramadan, M.Z., & Al-Tayyar, S.N. (2019). Comparison between the physiological responses and subjective ratings of a group of male students to three backpack designs. *International Journal of Environmental Research and Public Health,* 16(21):4104.

Rodríguez-Oviedo, P., Ruano-Ravina, A., Pérez-Ríos, M., García, FB., Gómez-Fernández, D., Fernández-Alonso, A., Carreira-Núñez, I., García-Pacios, P., & Turiso, J. (2012). School children's backpacks, back pain and back pathologies. *Archive of Disability Child*, *97*(8):730-732.

Sharan, D., Ajeesh, P.S., Jose, J.A., Debnath, S., & Manjula, M. (2012). Back pack injuries in Indian school children: risk factors and clinical presentations. *Work*, *41* Suppl 1:929-932.

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. *Apply Ergonomics*, *42*(3):403-410.

Trevelyan, F.C. & Legg, S.J. (2011) Back pain in school children--where to from here? *Apply Ergonomics, 37*(1):45-54.

Whittfield, J., Legg, SJ., & Hedderley, D.I. (2005). Schoolbag weight and musculoskeletal symptoms in New Zealand secondary schools. *Apply Ergonomics*, *36*(2):193-198.