The Hong Kong Polytechnic University

Department of Health Technology and Informatics

Biomechanical Effects of Load Carriage on Spine Curvature and Proprioception

by

Chris X. G. WANG

A thesis submitted in partial fulfillment of the requirements for

The Degree of Master of Philosophy

March 2008

Certification of Originality

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

(Chris Xinguang WANG)

March 2008

Abstract

Low back pain is a common problem affecting people. At least 90% of school children were reported to use backpacks in the developed countries. The excessive loading due to daily backpack carriage was reported to increase the stress across the joint and be associated with increased risk of back pain. However, the quantitative studies rebated to the effects of different backpack weights and carrying methods on spine curvature and proprioception are still limited.

In this study, 63 normal subjects with age between 11 and 15 years old were recruited. A backpack with a self-designed inside frame was applied to the subjects. The weight of backpack was proportional to the subject's body weight (BW). Each subject was asked to repeat upright stance for 6 times without backpack or carrying a backpack (10%BW, 15%BW or 20%BW) with different backpack centre of gravity (CG) locations (T7, T12 and L3) and carrying methods (anterior and posterior). The spine curvature and repositioning error were determined using a self-developed electrogoniometric system. Statistical analysis was performed to investigate the effects of backpack weight, backpack CG location and carrying method on the spine curvature and repositioning ability.

Both anterior and posterior carriages were found to induce different postural responses. For the posterior carriage, the cervical extension and lumbar flexion were shown to respond to the posterior load. The pelvic anterior tilt was triggered when the backpack weight was heavier than 15%BW. A turning region was also observed at the thoracic region in posterior carriage. A shift of increased repositioning error up the lumbar spine with increased backpack load was demonstrated in posterior carriage. For the anterior carriage, the upper thoracic kyphosis increased significantly

in response to the anterior load. The pelvic posterior tilt was triggered with the increase of load from 10%BW to 15%BW. Low CG location (T12 and L3) was shown to induce less postural changes in 10%BW and 15%BW carriages when comparing to the high CG location (T7). In 15%BW carriages, it was also found that the spine levels above the backpack CG location extended to counterbalance the front load. The 20%BW carriages may result in a different strategy in balancing the front load.

In this study, the electrogoniometric system was shown to be a feasible method for spine curvature quantification and proprioception assessment. Different patterns of spine curvature and repositioning error were demonstrated to respond to the anterior and posterior carriages. The effects of backpack CG location were not obvious for posterior carriage. Anterior carrying method seems to have no apparent benefit to the spine when comparing to posterior load carriage. The lower CG location may be better when the load has to be carried anteriorly. The poor repositioning ability induced by both anterior and posterior carriages at different spine levels may result in a high demand to the spine. A deeper understanding of the implication of the reduction in repositioning ability may provide insight whether this is related to the increased back pain observed in adolescents.

Acknowledgements

"Deep as the Peach Blossom Lake can be,

it is not so deep as the song you sing for me."

I would like to express my sincere thanks to my supervisor, Prof. Daniel H. K. Chow who helps me step by step, to shape this thesis. Thanks for his kindness, his patience, and the many hours he spent working with me. I will be forever grateful for everything he has done.

I also want to take this opportunity to thank Prof. Malcolm Pope for his review of this thesis with valuable comments.

I would especially thank Mr. Sammy Leung for his technical assistance with the experiment.

Thank to Alon Lai, Jacqueline Ting, Yen Wong, Ricci Lam, Lowena Lo, Allison Wong, Sammy Siu, Amy Wong, Peter Ma, Debbie Ou and Mandy Tse for their wisdom, humor and good-hearted nature. They made this a wonderful experience for me, and I'm glad to call them my friends.

To all the subjects who were involved in this project, I would like to thank for their time to my study. Without their active participation, this study would not be possible.

I would like to give my heartfelt thanks to my dearest family for their tender love and for understanding what I have been pursuing all these years.

This thesis is what it is today because of one special people, Vicky, my wife. I would like to thank her for her love and everything she has done for me.

Tables of Contents

List of Figures

List of Tables

CHAPTER 1 INTRODUCTION

At least 90% of school children was reported to use backpacks in the developed countries (Sheir-Neiss, Kruse, Rahman, Jacobson, & Pelli, 2003). The modest load of backpacks was reported to be in the range from 10% to 20% body weight (BW) (Pascoe, Pascoe, Wang, Shim, & Kim, 1997; Sheir-Neiss et al., 2003; Whittfield, Legg, & Hedderley, 2001). In Hong Kong, the survey conducted by the Democratic Alliance for the Betterment and Progress of Hong Kong[1] indicated the average weight of schoolbag was 3.9 kg in 2007, and 56.9% backpack was over 10%BW which was the recommended load limit for school children. However, it has been parents' concern whether carrying schoolbag will cause any adverse effect to children particularly if the backpack is 'heavy'.

Many biomechanical investigations have been carried out to address the issue. The changes in head posture, trunk posture, spine posture and pelvis were found to be affected by different backpack weights (Chow et al., 2006; Devroey, Jonkers, de Becker, Lenaerts, & Spaepen, 2007; Goodgold et al., 2002; Korovessis, Koureas, Zacharatos, & Papazisis, 2005; Orloff & Rapp, 2004; Wang, Chow, & Pope, 2007) and different backpack centre of gravity locations (Chow et al., 2006; Devroey et al., 2007; Grimmer, Dansie, Milanese, Pirunsan, & Trott, 2002; Stuempfle, Drury, & Wilson, 2004). The effects of load carriage on physiological or functional performance of children were also evaluated in different load weights. Significant changes in oxygen uptake and energy expenditure (Chow, Kwok et al., 2005; Hong & Brueggemann, 2000), cardiopulmonary parameters (Li, Hong, & Robinson, 2003), gait patterns (Hong & Brueggemann, 2000), and pulmonary function (Chow, Ng et

[1] http://www.dab.org.hk/tr/main.jsp?content=article-content.jsp&articleId=5598&categoryId=1212 (Access date: Mar 12, 2008)

al., 2005) were found in carrying backpack of 10%BW to 20%BW. Based on modified functional performance, backpacks with load of 10%BW to 15%BW were recommended as safe limits for school children (Brackley & Stevenson, 2004). The spine proprioception in terms of repositioning ability was demonstrated to be decreased in backpack carriage conditions (Brumagne, Lysens, & Spaepen, 1999b; Feipel et al., 2003; Maffey-Ward, Jull, & Wellington, 1996; Swinkels & Dolan, 1998), as well as in patients with back pain syndrome (Cholewicki & McGill, 1996; Gill & Callaghan, 1998; Newcomer, Laskowski, Yu, Johnson, & An, 2000). According to the previous research, both the weight of the carriage and the wearing method of load carriage were associated with back pain (Korovessis et al., 2005; Negrini & Carabalona, 2002; Sheir-Neiss et al., 2003), but the relationship is still unclear. Moreover, epidemiological studies showed that 'heavy' backpack load was one of the risk factors for back pain in adolescent. There is an increasing prevalence of low back pain in children (Mackenzie, Sampath, Kruse, & Sheir-Neiss, 2003). Therefore, it is important to study whether load carriage will cause any adverse effect to the children's spine.

The objective of the current study is therefore, to investigate the direct effects of load carriage on children's spine performance. In this study, the weight of load carriage, centre of gravity location of load carriage and the carrying method on spine curvature and proprioception were investigated.

CHAPTER 2 LITERATURE REVIEW

2.1 Back Pain

Back pain is a common musculoskeletal problem and has been reported to be one of the leading causes for seeking clinical support (Cypress, 1983). Over 60% of the adult population has reported back pain (Harreby, Kjer, Hesselsoe, & Neergaard, 1996). It was also estimated that over 80% of the population would report low back pain (LBP) during their lives (Walker, 2000). Adolescents with back pain were suggested to be in risk to experience back pain in adult life (Harreby et al., 1996).

2.1.1 Prevalence of low back pain in children

Numbers of reports have revealed that the prevalence of back pain in children was rising and was resembling the prevalence of back pain in adults (Smith, 2001). Around 11% to 51.2% of children reported that they experienced LBP (Kristjansdottir, 1996; Newcomer & Sinaki, 1996; Taimela, Kujala, Salminen, & Viljanen, 1997; Troussier, Davoine, De Gaudemaris, Fauconnier, & Phelip, 1994; Viry, Creveuil, & Marcelli, 1999). The lumbar region was noted to be the main source of pain from the complaints by 36.8% children (Troussier et al., 1994). The occurrence of back pain in children was also found to increase with age. Burton et al. (1996) reported that the prevalence of LBP was 11.6% for 11 years old children, and increased to 50.4% for the children 15 years old children. The prevalence of back pain in children was noted to vary in different genders. The most rapid rate of increase in reported back pain occurred in girls of age between 12 and 13 years and in boys of age between 13 and 14 years (Korovessis, Koureas, & Papazisis, 2004).

2.1.2 Risk factors

Epidemiological studies have identified several risk factors associated with the increase in the prevalence of LBP during adolescence, such as female gender (Grimmer & Williams, 2000; Troussier et al., 1994; Viry et al., 1999), poorer general health (Sheir-Neiss et al., 2003), low physical activity (Troussier et al., 1994; Viry et al., 1999), competitive sports participation (Balague et al., 1994; Kujala, Taimela, Erkintalo, Salminen, & Kaprio, 1996), prolonged sitting (Grimmer et al., 2002), history of back injury (Troussier et al., 1994) and family history of back pain (Balague et al., 1995; Troussier et al., 1994; Viry et al., 1999), as well as a poor psychological profile (Balague et al., 1995; Coste, Paolaggi, & Spira, 1992; Mikkelsson, Salminen, Sourander, & Kautiainen, 1998).

Recently, heavy backpack weights (Sheir-Neiss et al., 2003) and exposure to backpack loads (prolonged load carriage) (Grimmer & Williams, 2000; Negrini & Carabalona, 2002; Sheir-Neiss et al., 2003) have become a concern among school children, parents, healthcare professionals, as well as governments. It was reported that school backpacks caused back pain in 46.1% of school children (Negrini & Carabalona, 2002). In addition, back pain at young age may be an important risk factor for experiencing back pain in adult life (Harreby, Neergaard, Hesselsoe, & Kjer, 1995). Therefore, the backpack was thought to be a possible contributing factor to the increase of back pain, although there was still limited information available on how backpack carriages affect the spine performance. Further investigation on the effect of backpack carriage on spine for adolescents seems to be of great value.

2.2 Daily Use of Load Carriage

Nowadays, the use of heavy backpack is common in school age population. At least 90% of school children were reported to use backpacks in the developed countries

(Sheir-Neiss et al., 2003). The weight of a backpack is commonly given as a percentage of a subject's body weight (BW). The mean backpack weights were found to increase with increasing ages or grade levels in school children and also varied by school and country. The backpack loads were reported to be around 8.2% of students' body weights (BW) and increased with grade level in US, from 6.2%BW among kindergarteners to 12.0%BW among fifth graders (Forjuoh, Lane, & Schuchmann, 2003). White et al. (2000) documented the average backpack load carried by US elementary school children. They indicated that the backpacks carried by fourth graders weighed 15%BW, while the mean weight of the backpack used by fifth graders increased to 17%BW. In New Zealand, the third form students carried backpack weighing 13.2%BW, while the sixth form students carried backpack with 10.3%BW (Whittfield et al., 2001). In summary, the modest load of backpack was in the range from around 10%BW to 20%BW (Forjuoh et al., 2003; Pascoe et al., 1997; Sheir-Neiss et al., 2003; White et al., 2000; Whittfield et al., 2001).

A survey conducted by the Democratic Alliance for the Betterment and Progress of Hong Kong[2] in 2007 reported that the average weight of backpack used by school children was around 3.9kg. Around 59.6% of backpacks were heavier than 10% of school children's body weight which was commonly thought to be a weight limit for school children. The issue of carrying heavy load carriage is an increasing concern for the parents and community of Hong Kong.

2.3 Load Carriages and Low Back Pain

Load carriage was considered to be a potential factor to changes of the spine subsystem components and may further induce back problem. For school children,

[2] http://www.dab.org.hk/tr/main.jsp?content=article-content.jsp&articleId=5598&categoryId=1212 (Access date: Mar 12, 2008)

the relationship between load carriage and LBP was investigated; however, the relationship was not proven to be direct (Negrini & Carabalona, 2002; Viry et al., 1999).

Various studies have been conducted on the effects of extra loading induced by load carriage and the linkage with back pain. Goh et al. (1998) found an increase in the peak lumbosacral forces by 27% and 30% while walking with 15%BW and 30%BW load carriage comparing with no load condition. The spine anatomical structure was also reported to be affected by external load (Kimura, Steinbach, Watenpaugh, & Hargens, 2001). In this study, it was found that load carriage significantly narrowed the lumbar dural sac and changed the intervertebral angle. However, the changes of intervertebral heights and angles in adult population were measured in supine position using Magnetic Resonance Imaging (MRI). The results may not be applied to school children, as the musculoskeletal system of children is still under development. In addition, the observations in supine position may not be comparable to the effects of load carriage on spine for the different muscle activities. For school children, Negrini and Carabalona (2002) conducted a research to investigate whether there was any association between year 6 students' subjective sensations of the backpack weight and back pain. They concluded that daily backpack carrying was a frequent cause of discomfort for school children and there was an association between the backpack load and back pain. However, the relationship was not direct. This conclusion was also in agreement with the study by Viry et al.'s (1999) in which backpack carriage was shown to be related to back problem in 14 years old school children. They also suggested that fatigue and time spent on backpack carriage were associated with back pain. These studies indicated that there is the potential relationship between load carriage and back problem. However, there was still no direct information on the effect of load weight, load location, as well as carrying method on spine performance.

2.4 Effects of Load Carriage

The effects of backpack carriage on body posture, physiological performance, gait pattern and the muscle activities have been widely investigated. These studies mainly focused on the effects of backpack load and carrying method so as to determine the suitable recommendation for load carriage to reduce the risk of injury (Brackley & Stevenson, 2004).

2.4.1 Effects of weight of load carriage

Heavy backpack loads have been shown to affect the posture of different body parts in children, including the head, shoulder, cervical spine, thoracic spine, lumbar spine, trunk, pelvis as well as knee and ankle joint. However, there is a scarcity of information on the effects of backpack load on spine curvature and how different spine segments response to the external load especially when the load is carried anteriorly.

Head posture and shoulder posture

An increase in head backward inclination was found to be associated with the backpack weight during posterior carriage (Chow et al., 2006). In order to investigate the effects of the backpack on head posture, the craniovertebral angle (CVA) was introduced to quantify the head posture in school children (Grimmer, Williams, & Gill, 1999). The CVA was defined as the angle between the line joining the ear tragus to C7 and horizontal. They found consistent and significant differences in absolute CVA between the backpack carriage conditions and the no backpack condition. However, it was claimed in this study that CVA might not to be sensitive enough for head posture measurement. In the study conducted by Chansirinukor et al. (2001), an increase in forward head posture in terms of decreased CVA was noted when carrying a backpack, especially with a heavy load. A 15%BW backpack was suggested by Chansirinukor et al. to be too heavy for adolescents to maintain the normal posture in stance. Beside the head posture, the effects of backpack on shoulder position were also investigated in the same study. A further forward shoulder position relative to C7 was found in backpack carriage conditions. In addition, the single strap school bag was found to result in elevation in shoulder when compared the shoulder posture in no load condition with single strap school bag carrying condition (Pascoe et al., 1997).

Trunk posture

As a compensatory strategy to balance the change of body centre of gravity (CG), trunk forward lean (TFL) was found in response to the external load (Chow, Leung, & Holmes, 2007; Goodgold et al., 2002; Grimmer et al., 2002; Pascoe et al., 1997). It was further found that TFL increased with the increase of backpack load (Chow et al., 2007; Goodgold et al., 2002). The effect of single strap school bag on the spinal posture was also studied (Pascoe et al., 1997). A lateral bending of trunk was adopted to balance the asymmetric loading. Beside the static posture measurement, the changes in trunk posture were investigated during dynamic situation. Hong and Brueggemann (2000) examined the effect of backpack weight (0%BW, 10%BW, 15%BW and 20%BW) on children during walking using a treadmill. They observed that 15%BW and 20%BW backpack would increase the TFL significantly when compared with no backpack condition. This result was also confirmed in the study by Li, et al. (2003), where a backpack over 10%BW was found to induce significant TFL.

Spine curvature

In a recent study, Chow et al. (2007) investigated the effect of backpack carriage with different weights on the spine curvature. Spine curvature was monitored by affixing reflective markers on children's back. A significant decrease in lumbar lordosis and an increase in upper thoracic kyphosis were found with increasing backpack load. In addition, Orloff and Rapp (2004) investigated the effects of backpack on spine curvature using a backpack with spring-loaded rods. They revealed that the curvature at thoracic to lumbar region changed significantly during fatigue conditions. The curvature changes were in agreement with those found by Chow et al. (2007).

Physiological functions

Apart from the body posture and spine curvature changes, it was demonstrated that physiological performance may be affected by backpack carrying. Increases in heart rate, blood pressure and energy expenditure were found during walking with backpack carriage (Hong, Li, Wong, & Robinson, 2000). The pulmonary function was also noted to be affected when carrying backpack (Chow, Ng et al., 2005; Lai & Jones, 2001). A significantly decreased forced expiratory volume (FEV1) and forced vital capacity (FVC) was shown when a heavy backpack weight with 20%BW to 30%BW was carried (Lai & Jones, 2001). The changes of FEV1 and FVC were further shown to be associated with backpack load, FEV1 and FVC were found to decrease significantly with increase of backpack weight (Chow, Ng et al., 2005).

Several studies have also focused on the effects of load carriage on gait performance. Significant differences in walking speed, cadence, stride length, stride frequency, swing duration and double support time were observed with increasing load (Chow, Kwok et al., 2005; Hong & Brueggemann, 2000; Pascoe et al., 1997). However, different observations were reported by some studies. Goh et al. (1998) observed that walking speed and stride length remained unchanged in normal male adults when carrying backpack with 0%BW, 15%BW and 30% BW. Hong and Cheung (Hong & Cheung, 2003) also found no significant differences in stride length, cadence, velocity, single support time or double support time when carrying backpack loads of 0%BW, 10%BW, 15%BW and 20%BW. The differences in the findings may be due to gender, sample size and the age of subjects studied in these studies.

The muscle activities were studied when carrying load carriages. The backpack was balanced either by the relaxation of the back muscles or the contraction of the abdominal muscles (Motmans, Tomlow, & Vissers, 2006). A significant increase in activation of rectus abdominis and obliquus externus abdominis was found with increasing load, while the muscle activation of trapezius pars descendens, sternocleidomastoideus, rectus femoris and biceps femoris were affected minimally by load carriages (Devroey et al., 2007). In addition, the anterior load was reported to result in higher erector spinae activation than that in static stance (Anderson et al., 2007).

Backpack weight limits

According to the studies on the effect of backpack carriage on spinal posture and the body performance, researchers attempted to provide a backpack weight limit. A load limit of 10%BW was suggested based on the results of the gait pattern, heart rate and blood pressure for school boys around 10 years old (Hong & Brueggemann, 2000). As the changes in head posture, trunk posture and muscle activities, as well as the gait pattern, a backpack load limit of 15%BW was recommended for 13 to 16 years old students (Chansirinukor et al., 2001), college age students (Devroey et al., 2007) and 10 years old boys (Hong & Cheung, 2003). Brakely and Stevenson (2004) reviewed epidemiology, physiology and biomechanical studies on the load limit for children’s backpacks and recommended that load carriage for school children should be between 10%BW and 15%BW. In 2007, the American Academy of Pediatrics (2007) released a guideline for school children backpack use which recommended that the weight of backpack should not exceed 20%BW.

2.4.2 Effects of backpack carrying method on body performance

The carrying methods mainly denoted the location of backpack centre of gravity (CG) which was quantified in three directions (i.e. vertical, anteroposterior and mediolateral direction).

High backpack CG location or Low backpack CG location

By measuring the spine extension, pelvis anterior tilting and hip flexion in two backpack CG location (i.e. thoracic placement and lumbar placement), an increase in these parameters was found in thoracic CG location compared to lumbar CG location (Devroey et al., 2007). Similar result was also found in Grimmer et al.’s study (2002), a larger posture compensation was found when a backpack with CG located at T7 was carried, and it was suggested that the backpack should be carried at lower position. In addition, Bobet and Norman (1984) measured erector spinae and trapezius EMG activity in two backpack CG locations (i.e. ear level and mid back). This study indicated that the high backpack CG resulted in significantly higher levels of muscle activity than the low CG location. However, the physiological performance in terms of metabolic cost (i.e. oxygen consumption, minute ventilation, rating of perceived exertion) was lowest when backpack located at the position highest and closest to the body (Obuset, Harman, Frykman, Palmer, & Billis, 1997; Stuempfle et al., 2004). The results of this study also suggested that backpack CG location played an important role in the physiological and perceptual responses to load carriage, and high backpack CG location may be the most energy efficient method for backpack carriage. However, researchers investigated effect of backpack CG location using subjective scores (Devroey et al., 2007). It was found that students preferred the lower backpack CG location (lumbar level) rather than the higher backpack CG location (thoracic level). Therefore, further investigations are needed to explain the differences in these observations.

Anterior or Posterior

Most of the previous studies focused on the effect of posterior backpack carriage on the body posture and physiological performance. It was suggested that the optimum method of carrying backpack was to place the backpack CG as close as possible to the individuals' back (Datta & Ramanathan, 1971; Howe & Getchell, 1995; Legg, 1985). However, there is little information on the effect of anterior load carriages on body performance. In the current study, it is hypothesized by anterior load carriage may result in different changes in spine curvature and stress distribution compared to posterior carriage.

Asymmetrically or Symmetrically

It was reported that 73.2% of school children carried their backpacks with only one strap or the single book bag (Pascoe et al., 1997). The shift of upper trunk and shoulder and cervical lordosis was found when carrying asymmetrical backpack (Korovessis et al., 2005). It was also confirmed in Pascoe et al.'s study (1997) that the single strap load carriage resulted in a significant elevation of shoulder, as well as lateral bending of the spine in school children, and this could be a possible factor contributing to the high percentage of school children with scoliosis.

The load carriage with double straps has been more and more widely used recently. It was accepted that backpacks should be designed to be worn over two shoulders to distribute the weight evenly about the spine and across the shoulders (Grimmer & Williams, 2000; Negrini & Carabalona, 2002; Sheir-Neiss et al., 2003). Health professionals discouraged wearing a pack on one shoulder as it would create a torque around the spine which may be the potential cause of back problem (Cottalorda et al., 2003; Filaire et al., 2001; Reid, Stevenson, & Whiteside, 2004).

Suspended Backpack

During walking, the hip joint normally moves vertically in the range of around 5cm to 7cm which resulted in an increased energy cost (Gard, Miff, & Kuo, 2004). Recently, an interesting study focused on the suspended backpack (Figure 2.1) whose CG location was flexible along the vertical direction (Rome, Flynn, & Yoo, 2006). This suspended backpack tried to maintain stability of the backpack CG during walking so as to reduce the peak vertical forces acting on the body, as well as the metabolic cost during walking.

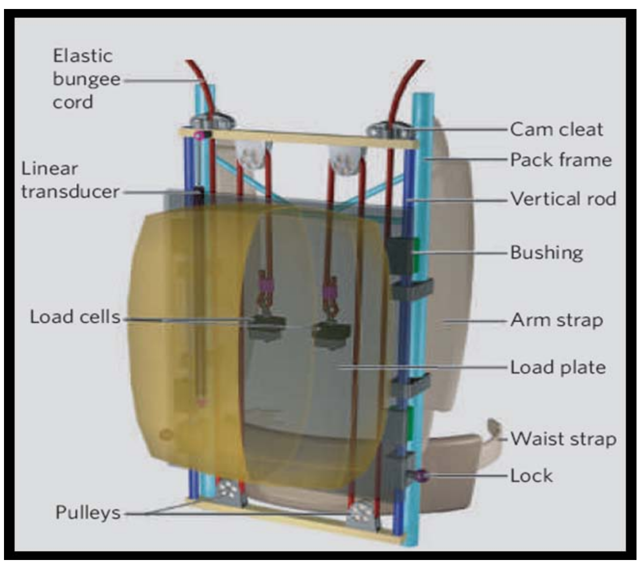


Figure 2.1 Suspended backpack

In summary, backpack carriages with different weights and carrying methods were shown to affect the body posture, physiological performance, as well as the muscle activities and gait pattern. However, there is a scarcity of information on the effects of backpack with different CG locations and weights to be carried either anteriorly or posteriorly on spine performance. As load carriage has been suggested to be associated with back problems in school children, the effects of load carriage on spine performance should be investigated.

2.5 Proprioception

2.5.1 Introduction of proprioception

Proprioception (from Latin proprius, meaning "one's own" and perception) was defined by Charles Scott Sherrington (1857-1952) cited from the article by (Sherrington, 1947). Proprioception is the sense of the position of parts of the body, relative to other neighboring parts of the body. Working with visual and vestibular system, proprioception provides the information of body part position, orientation and the velocity, as well as feedback on human body.

Proprioceptive is derived from afferent information delivered by muscle spindles, Golgi tendon organs, joint receptors, and cutaneous receptors. It will detect and sense the absolute joint position or changes of joint position which include the information of joint angles and joint displacements to facilitate the joint movements, and coordinate limb motions and balancing tasks (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001).

2.5.2 Poor proprioception and low back pain

Proprioceptive deficits were suggested to lead to abnormal loading across joint surfaces, and thus to degenerative disease (Forwell & Carnahan, 1996). These adverse effects on spine may result in instability of local muscle control and segmental and further induce back problem. Patients with low back pain frequently demonstrated a decreased ability in adopting and maintaining position (Gill & Callaghan, 1998). Moreover, proprioceptive deficit may slow down the response of neuromuscular protective reflexes and coordination such that muscle contraction delayed to protect the joint from excessive joint movement and further resulted in pain and injury (Forwell & Carnahan, 1996). These findings have not yet been scientifically linked the proprioception deficits and back pain together, although most of the researchers agreed with the conclusion that there was a significant difference between symptomatic and asymptomatic group (Lam, Jull, & Treleaven, 1999; Newcomer, Laskowski, Yu, Larson, & An, 2000).

2.6 Proprioception Assessment and Quantification

Because of the great importance of proprioception in normal joint function, a lot of studies have been devoted to its assessment. The proprioception was usually measured by two types of tests, such as assessment of the movement sense in terms of the motion detection and the evaluation of the position sense in terms of the repositioning ability (Feipel et al., 2003). Different testing protocols were applied to examine the proprioception in both active and passive movement conditions (Allison & Fukushima, 2003; Feipel et al., 2003; Gill & Callaghan, 1998; Swinkels & Dolan, 1998; Wilson & Granata, 2003).

2.6.1 Movement sense

Motion detection was assessed by determining the thresholds to the perception of movement and direction. The movement was applied either at a constant velocity (Barrack, Skinner, & Cook, 1984; Barrack, Skinner, Cook, & Haddad, 1983; Skinner, Wyatt, Hodgdon, Conard, & Barrack, 1986) or as a constant stimulus (Grigg, Finerman, & Riley, 1973; Kokmen, Bossemeyer, & Williams, 1977, 1978). For the constant velocity method, slow passive movement was applied and proprioception was reported in terms of angular or distance thresholds of joints to the perception of the movement. In the constant stimulus method, proprioception was derived from the intensity of stimulus necessary to obtain a report of the perception of movement. In healthy people, mean motion detection thresholds were reported to be different at various joints (Barrack et al., 1984; Barrack et al., 1983; Hall & Mccloskey, 1983; Skinner et al., 1986; Swinkels & Dolan, 1998; Taylor & McCloskey, 1990). Some studies also suggested that motion detection method may not be appropriate to assess the subjects with joint disease because of the additional position information from the pain syndrome (Leinonen et al., 2003; Marks, Quinney, & Wessel, 1993; Parkhurst & Burnett, 1994; Revel, Andre-Deshays, & Minguet, 1991; Taimela, Kankaanpaa, & Luoto, 1999).

2.6.2 Position sense

"Repositioning error" (RE) was often used as a term to quantify joint position sense which has been widely used in various studies (Brumagne et al., 1999b; Feipel et al., 2003; Gill & Callaghan, 1998; Maffey-Ward et al., 1996; Newcomer, Laskowski, Yu, Johnson et al., 2000; Newcomer, Laskowski, Yu, Larson et al., 2000). The definition of RE was not exactly the same in different studies due to the different experiment designs and testing protocols. There were two different definitions including absolute error (AE) and variable error (VE). AE was determined by the difference between the position of the subject's response and the target position. VE was the average deviation between the subject's results on each trial (Schmidt, 2005) which represented the inconsistency of the subject's performance around the mean response.

In most of the recent studies, indirect measurement methods were used to assess spinal proprioception. The subject with increased RE was considered to be difficult to find the original position and difficult to keep the spine alignment which may be further related to joint diseases. This association between joint disease and position sense had led to a growing interest in measuring proprioception in the spine. Several studies have been conducted to determine position sense focusing on the trunk, cervical, thoracic and lumber spine (Ashton-Miller, McGlashen, & Schultz, 1992; Feipel et al., 2003; Gill & Callaghan, 1998; Jakobs, Miller, & Schultz, 1985; Parkhurst & Burnett, 1994; Preuss, Grenier, & McGill, 2003; Revel et al., 1991; Revel, Minguet, Gregoy, Vaillant, & Manuel, 1994; Taylor & McCloskey, 1988, 1990). Patients with low back disorders were demonstrated to have poorer position sense than normal subjects (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000; Gill & Callaghan, 1998; Parkhurst & Burnett, 1994).

2.6.3 Position sense assessment

In the previous studies, various experimental protocols were employed to assess the position sense in terms of repositioning ability both in the normal subjects and the subject with back problem. It was reported that normal subjects were able to reposition their spine accurately (Swinkels & Dolan, 1998). An electromagnetic movement sensor system was used in this study to measure the spinal position sense at T1, T7, L1 and S2 spine level both in reproducing upright stance and flexion positions. The results indicated that spinal position sense was reproducible with a mean of 3.79º in upright postures and a mean of 5.27º in flexed postures. At the lumbar region, the mean RE over three trials was reported to be 2.6º for the subject without low back pain by using 3Space Fastrak (Maffey-Ward et al., 1996). The repositioning ability was also investigated at lumbar spine for healthy subjects using an electromagnetic system (Preuss et al., 2003). It was claimed that the lumbar RE was around 1.3º in standing posture, 2.7º in sitting posture and 4.0º in four point kneeling posture. In Feipel et al.'s study (2003), the repositioning ability was evaluated at lumbar spine using a spine motion analyzer. The RE was measured as 4.5º in flexion posture. The measuring accuracy of RE between a piezoresistive electrogoniometer and a 3D video analysis system was compared in stance posture (Brumagne et al., 1999b). It was concluded that the both the two measurement systems were accurate enough for the RE assessment. The variability in the values of repositioning error reported in the literatures may partially be explained by the different conditions and testing protocols, as well as the different instruments used to in RE measurements.

As patients with low back pain were commonly observed to have difficulty in maintaining posture (Bergmark, 1989; Cholewicki & McGill, 1996), several studies have been conducted to compare repositioning ability between the subjects with and without back pain. The repositioning error was 4.45º in normal subjects and 6.71º in back pain patients at lumbar spine (Gill & Callaghan, 1998). Significant differences in proprioception were reported between the subjects with and without back pain. However, some studies failed to find a significant difference between the back pain patients and normal subjects. Lam et al. (1999) conducted a study measuring RE in back pain patients. The RE of 2.25º obtained in this study was similar to that of asymptomatic subjects reported in previous study (Maffey-Ward et al., 1996). Again, Koumantakis et al. (2002) claimed that no proprioception deficits could be clearly identified for the group of patients with low back pain when compared to the asymptomatic group. The potential cause may be that the subjects with low back pain may attempt to use extra mechanoreceptive cues to compensate kinesthetic deficit.

Newcomer et al. (2000) could not find significant difference between the normal subject group and the patient with back pain. By using a modified testing protocol (Newcomer, Laskowski, Yu, Johnson et al., 2000) found that RE in patients with low back pain was significantly higher than normal subjects in flexion. The different conclusions on the repositioning ability of the subject with or without back pain may partially due to the criteria of selection of back pain subjects, as well as the experimental design.

2.6.4 Factors affecting position sense

Spinal repositioning ability was influenced by many factors, such as testing position, motion range, trunk and foot position, visual inputs, as well as the number of trials. In order to achieve a relative accurate RE, all these factors should be considered in the assessment of the spine proprioception.

Gill and Callaghan (1998) assessed the spinal position sense in two body postures (i.e. standing and four point kneeing). They found RE was slightly more accurate in standing than in four point kneeing. It was also reposted that RE of spine in sitting position was less reliable when comparing RE between upright standing position and sitting position (Brumagne, Lysens, & Spaepen, 1999a). Similar conclusion was drawn in other studies. It was revealed that position sense was better in an upright standing posture than in a non-upright position (Preuss et al., 2003; Swinkels & Dolan, 1998).

Knee and foot positions were revealed to affect the RE test and it was suggested that knee and foot position should be strictly restrained during the experiment. The study conducted by Newcomer et al. (2000) demonstrated no significant difference in RE at different flexion amplitudes. This result was a little bit different from the others' (Cholewicki & McGill, 1992; Forwell & Carnahan, 1996; Gill & Callaghan, 1998).

A further study was conducted to identify the effects of knee joint position on RE evaluation by the same team (Newcomer, Laskowski, Yu, Johnson et al., 2000). After limiting the knee joint movement, a significant difference in RE between the two groups was found. Moreover, Allison and Fukushima (2003) also found that by bending the knees, normal subjects had slightly increased accuracy in their ability to replicate targets. This may potentially due to an increased active role of the muscles crossing the knee joint (Bouet & Gahery, 2000; Lonn, Crenshaw, Djupsjobacka, Pedersen, & Johansson, 2000).

Not only did the knee bending and foot positions bring additional proprioceptive information, but visual inputs contributed to postural control. The precision and accuracy RE could not be compensated by the vestibular or proprioceptive system in the situation without visual input (Silfies, Cholewicki, & Radebold, 2003). RE was significantly increased when visual feedback was removed (Wilson & Granata, 2003). The absolute value of RE was found to increase significantly in the RE assessment from around 1º with visual feedback to 3º when visual feedback was not available.

The number of trials taken in the assessment of spine repositioning ability was shown to affect the RE measurement. It was suggested that six trials should be conducted in order to obtain reliable results (Allison & Fukushima, 2003).

From the literatures, spinal proprioception was assessed by measuring repositioning error and a relationship between the poorer repositioning ability and back problem was found. As load carriage may be a potential cause of back problem, an identification of the relation between the load carriages and proprioception may reveal the relationship between load carriage and back pain. In the current study, it is hypothesized that backpack carriage may affect spine proprioception in adolescent population.

2.7 Equipments on Spine Posture Measurements

Spine curvature and repositioning ability could be measured using different equipments such as electromagnetic system, Lumbar Motion Monitor, Spine Motion Analyzer, TV system, as well as radiographic methods (Table 2.1). It should be carefully selected according to the requirements of the particular experimental design. For the backpack study, the subjects would be asked to carry a backpack during the experiment. Not all of these systems are suitable for studying the effects of backpack carriages due to the feasibility and/or the invasive nature of the methods. An electrogoniometric system was therefore proposed to be used in this study with its advantages that it could be used without the necessity of modifying the backpack and it is a non-invasive approach for curvature measurements.

2.8 Summary

In reviewing the previous studies, backpack carriage (Chansirinukor et al., 2001; Grimmer et al., 1999; Hong et al., 2000) and improper carrying methods (Cottalorda et al., 2003; Filaire et al., 2001; Korovessis et al., 2005; Reid et al., 2004) could induce extra loading on spine and change the trunk posture (Chow et al., 2006; Goodgold et al., 2002), as well as body performance (Chow, Ng et al., 2005; Devroey et al., 2007; Hong et al., 2000). These changes may be further associated with back pain (Goodgold et al., 2002; Negrini & Carabalona, 2002; Sheir-Neiss et al., 2003). Furthermore, children who had experienced low back pain were more prone to have low back pain in adults (Mackenzie et al., 2003). Recent studies have also demonstrated proprioception deficits in back pain patients and suggested that a poorer proprioception may be a potential cause of back problems (Cholewicki & McGill, 1996; Gill & Callaghan, 1998; Newcomer, Laskowski, Yu, Johnson et al., 2000). Despite the exact relationship between spine curvature changes and back pain is still unclear, it is fairly important to investigate the effect of backpack carriage on spine performance so as to provide additional information to the significance of backpack carriage on the spine. It was hypothesized in the current study that the backpack carriage could induce adverse effects on spine curvature and repositioning ability which may further lead to early onset of back problem in adolescents.

Table 2.1 Comparison of different measuring systems

Equipments	Dimension	Accuracy	Advantages	Disadvantages	Reference
Electromagnetic system	3D	1.8 mm	Small sensor for easy attachment 3D measurements	Accuracy decreased when away from source Signals can be adversely affected by the presence of metals	(Lam et al., 1999; Maffey-Ward et al., 1996; Newcomer, Laskowski, Yu, Johnson et al., 2000; Preuss et al., 2003; Swinkels & Dolan, 1998)
Lumbar Motion Monitor	3D	0.96º (sagittal) 1.71º (frontal) 0.50º (transverse)	3D range of motion, velocity, and acceleration measurement	Heavy Chest harness may affect the measuring results	(Gill & Callaghan, 1998)
Spine Motion Analyzer	3D	0.1°	3D repeatable data	Require an external linkage which may affect spine movements	(Feipel et al., 2003)
TV system	3D	0.6°	3D kinematic and kinetic data	Need markers attaching onto body surface	(Brumagne et al., 1999b; M. J. Pearcy, Gill, Whittle, & Johnson, 1987)
Radiography	2D	-	Accurate determination of spine curvature and movement	Invasive 2D static measurement	(M. Pearcy, 1986; Weitz, 1981)

CHAPTER 3 METHODODLGY

3.1 Subjects

The experiment was approved by the Human Ethics Committee of the Hong Kong Polytechnic University. The consent from the participants' parents or guardians was obtained prior to data collection. As school children of age between 11 and 15 years were found to have higher prevalence of back pain, male and female school children of age between 11 and 15 years were recruited. Children with any history of musculoskeletal disorder or reported back pain in the previous 12 months were excluded. The subjects were selected by convenience sampling and a total of 295 schoolchildren were invited from 5 schools (including 4 secondary schools and 1 primary school) via either the school principles or the school teachers.

3.2 Experiment Design

A 3-way repeated measures experimental design with mixed samples was adopted in the study. One between-subject factor for backpack weight and two within-subject factors for backpack carrying method and backpack centre of gravity (CG) location were investigated. Effects of these factors on spine curvature and repositioning performance were evaluated. Each subject was asked to complete 7 conditions in the experiment. These included no backpack condition, as well as carrying backpack either anteriorly or posteriorly with different backpack CG locations (Table 3.1). The weights of backpack tested were expressed as proportions of subject's body weight (BW), i.e. 10%BW, 15%BW and 20%BW. For each subject, only one backpack weight was assigned and tested so as to avoid prolonged testing for the same subject.

The amount of backpack weight was randomly assigned and the subject was tested for one backpack weight for 7 testing conditions.

In each testing condition, measurements in upright stance were performed. The subject was asked to reproduce six times the upright stance. The spine curvature was measured by six accelerometers attached to the occipital protuberance (OC), C7, T7, T12, L3 and S1 using double-sided adhesive tape and the average of the six trials of each posture was taken for data analysis. The spine repositioning ability was quantified by the standard deviation of the 6 trials for each posture (Allison & Fukushima, 2003).

Table 3.1 Seven experiment conditions were tested for each subject

Experiment Condition	Description
NoBP	No backpack condition
AT7	Anterior carriage with backpack CG located at T7 level
AT12	Anterior carriage with backpack CG located at T12 level
AL3	Anterior carriage with backpack CG located at L3 level
PT7	Posterior carriage with backpack CG located at T7 level
PT12	Posterior carriage with backpack CG located at T12 level
PL3	Posterior carriage with backpack CG located at L3 level

3.3 Instrumentation

3.3.1 Testing backpack

A testing backpack was used in the experiment (TA-542 Mountain Wolf, Canada) (Figure 3.1). The characteristics of the backpack are:

- Size: 47 × 29 × 20 cm, the volume of the backpack is 35 liters.
- Double straps which could be used to adjust to the backpack location.
- Vertical grove on the contact area for avoiding compression of the accelerometers on the subject’s back by the backpack.

A self-designed frame was put inside the backpack (Figure 3.2). The frame was used to allow adjustment of the weight and center of gravity (CG) of the backpack by adding different dead weights at different positions.

Figure 3.1 Testing backpack

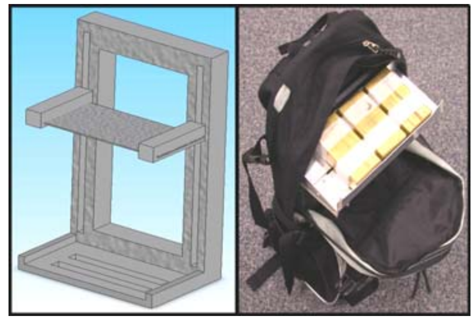


Figure 3.2 The self-designed frame for controlling backpack CG location

Different dead weights were prepared so that backpack weight of range between 3kg and 10kg could be set with an increment of 0.5kg. The number of weights to be used for each experiment was calculated based on the subject's body weight and the one closest to the required backpack weight was used for the experiment. A lever system was used to determine the CG location of the testing backpack (Figure 3.3).

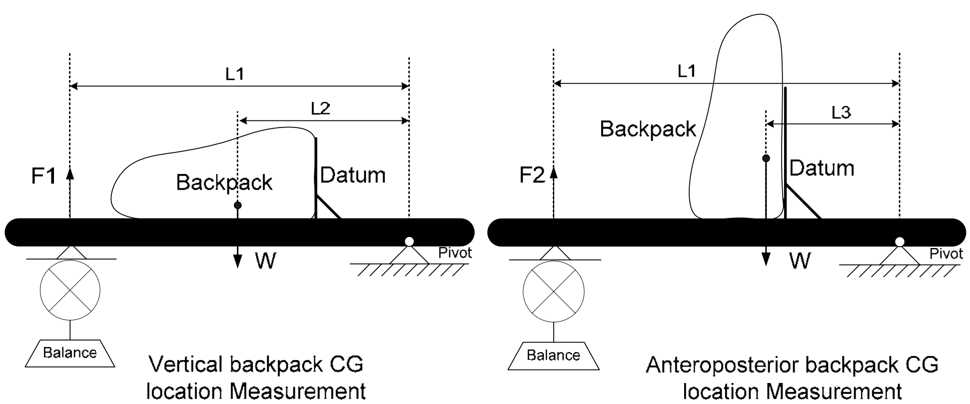


Figure 3.3 The lever system for determining the CG location of the backpack

$$F_1 \times L_1 = W \times L_2 \qquad (3.1)$$

$$F_2 \times L_1 = W \times L_3 \qquad (3.2)$$

In equations 3.1 and 3.2, F_1 denoted the reading of the balance when measuring the backpack CG in vertical direction, F_2 denoted the reading of the balance when measuring the backpack CG in anteroposterior direction, W denoted the weight of the backpack, L_1 denoted the distance between the pivot of the lever system and the balance, L_2 denoted the distance between the pivot of the lever system and the CG of the backpack when measuring the backpack CG in vertical direction, L_3 denoted the distance between the pivot of the lever system and the CG of the backpack when measuring the backpack CG in anteroposterior direction. By shifting the position of dead weights using the self-designed frame, the backpack CG could be adjusted. Prior to the experiment, the backpack weight and the required heights ($H_{BackpackCG}$) of the spine levels for positioning the backpack CG for each subject were firstly determined. For each required backpack weight, the height of dead weights location ($H_{Deadweights}$) was determined using equation 3.3 (Appendix 5). The CG positions identified during posterior carriage were then shifted to the front of the body for the anterior carriage. In the anteroposterior direction, the backpack CG was in the range between 4.4 cm and 6.2 cm relative to the back cover of the backpack depending on the backpack weight (Appendix 5).

$$H_{Deadweights} = a \times H_{BackpackCG} + b \qquad (3.3)$$

where a and b was the proportional constant and offset used for determining the position of dead weights to be put inside the backpack so as to achieve the required backpack CG height (Appendix 5).

3.3.2 Data acquisition system

An electrogoniometric system was developed for measuring spine curvature. The output of the accelerometer in voltage was converted to the angle of inclination relative to the vertical. A data acquisition system was used to capture the analogue data from the accelerometers.

An analogue to digital (A/D) converter (DAQ6225, National Instruments, USA) was used for data acquisition (Figure 3.4). Totally 6 accelerometers were connected to the A/D converter. The output of each accelerometer was sampled at 100Hz and stored in the computer for further angle calculation and data processing.

In order to acquire the analogue data of accelerometers through the A/D converter, a program was developed using LabVIEW8.0 (NI, USA). The angle relative to the vertical of each accelerometer could be displayed in real time (Figure 3.5).

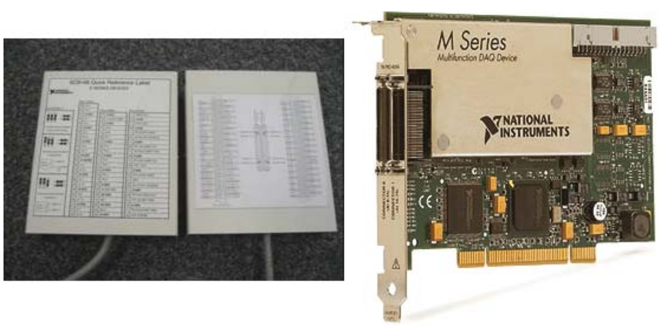


Figure 3.4 A/D converter for data acquisition

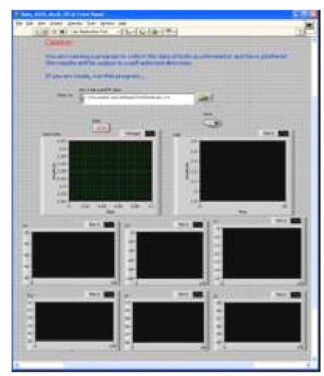


Figure 3.5 Data capture interface

3.3.3 Electrogoniometric system

The electrogoniometric system was used to monitor the spine curvature and spine repositioning performance of school children when carrying different backpacks. The electrogoniometric system consisted of six accelerometers (ADXL311, Analog Devices Inc., USA) and an interface box (Figure 3.6).

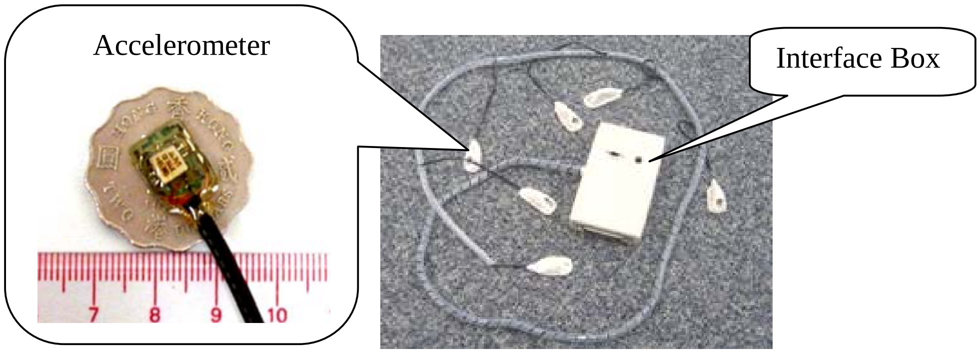


Figure 3.6 Electrogoniometric system

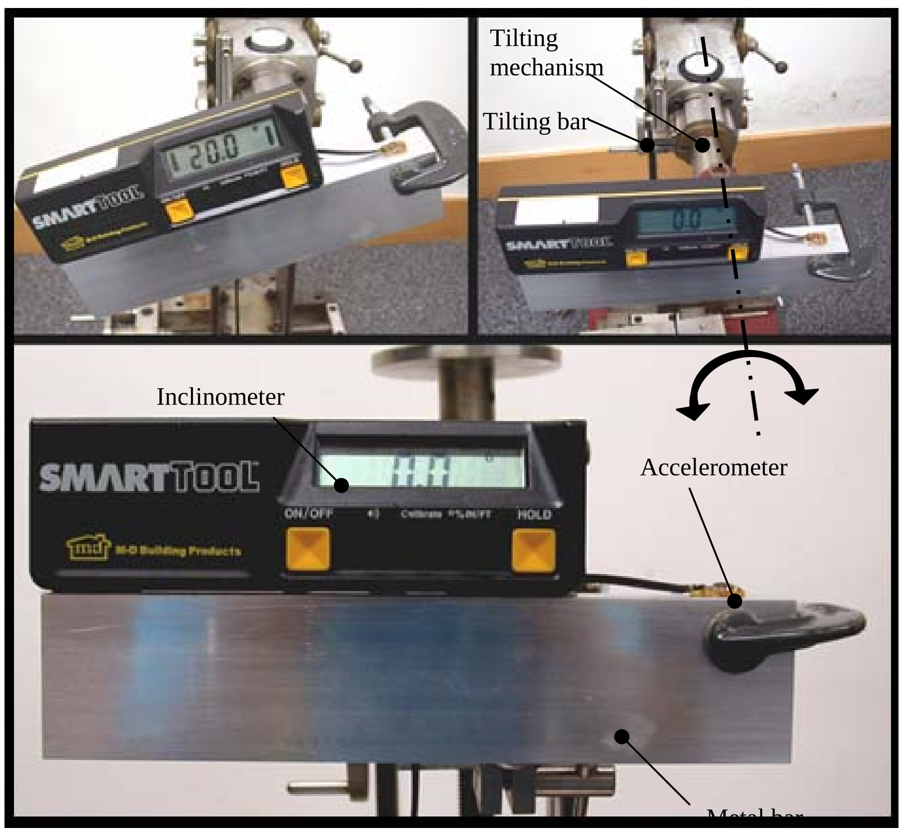


Figure 3.7 Calibration jig

Prior to the experiment, a calibration test was conducted using a calibration jig to determine the relationship between the output signal of each accelerometer and the inclination of the accelerometer relative to the vertical. The calibration jig consisted of a tilting mechanism and an inclinometer (ST-60, Level Developments Ltd. UK) (Figure 3.7). Each accelerometer was affixed to a metal bar which was in turn attached to the tilting mechanism. The inclination of the metal bar could be adjusted by the tilting mechanism and monitored by the inclinometer with an accuracy of 0.1º. The output of the accelerometer was analogue voltage which was digitized by the A/D converter. According to the operating principle of the accelerometer, its output should be linearly proportional to the sine value of its angular inclination relative to the vertical. This linear relationship was firstly verified and subsequently the errors of the accelerometers for angular measurements were estimated.

The inclination of the metal bar together with the accelerometer was tilted from -90° to +90° with an interval of 10° using the tilting mechanism. At each inclination, the signal from the accelerometer was sampled at 100Hz for 2 seconds. The data from 0.5s to 1.5s of the signal were filtered by a low pass filter (cutoff frequency: 3Hz; order:3) (Winter, 2005) and averaged. The mean voltage output was then plotted against the input inclination (Figure 3.8).

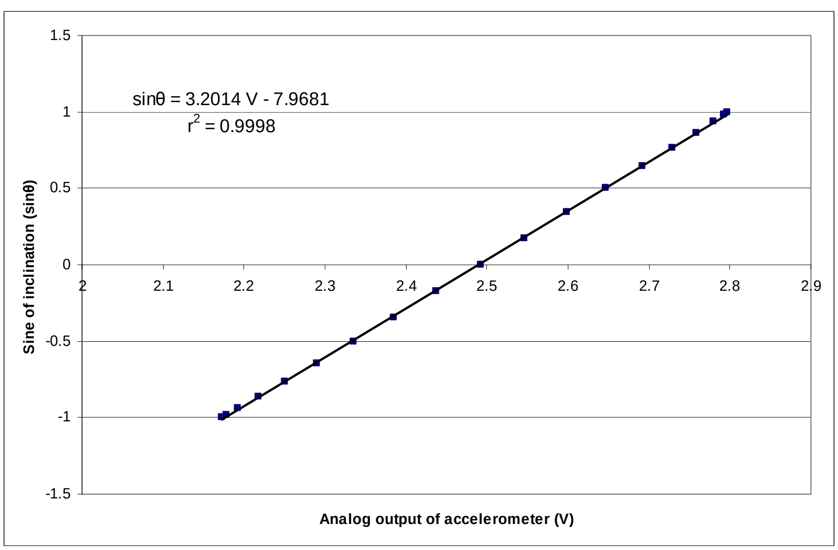


Figure 3.8 The plot of the output of the accelerometer and the sine of the input inclination

A linear regression equation was determined for the plot of the analog outputs (V) of the accelerometers against the sine values of the inclinations (θ) (Equation 3.4).

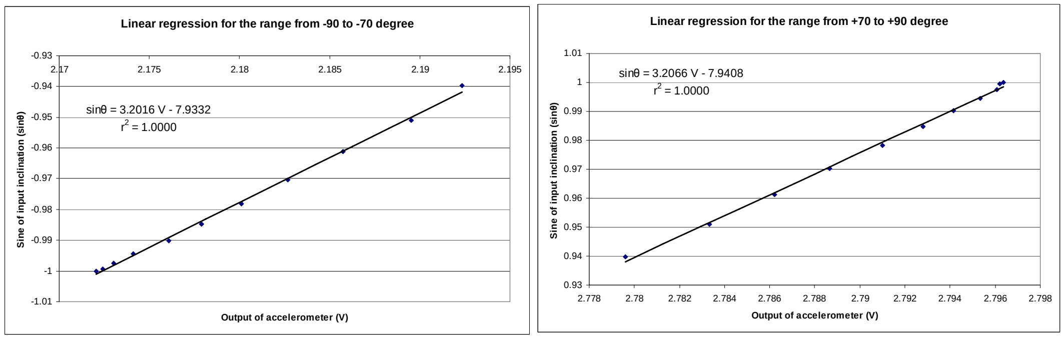
$$\sin\theta = k \times V + b \qquad (3.4)$$

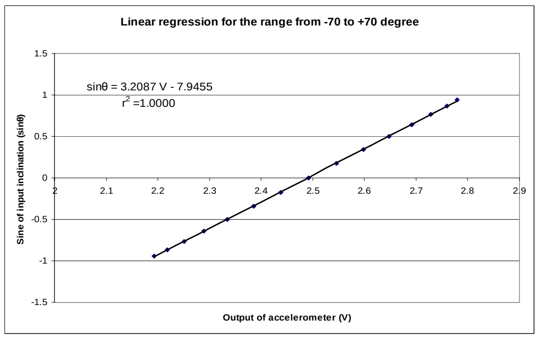
where k and b denoted the proportionality constant and offset of the linear regression equation respectively. The differences between the angles calculated by the output voltage using the linear regression equation and the input inclination were used to determine the root mean square (RMS) error of the accelerometers for the input range from -90° to +90°. The RMS errors were found to have range from 0.6° to 2.7° (Table 3.2).

Table 3.2 RMS errors of accelerometers for the input range from -90° to +90°

Accelerometer No.	Error (°)
1	0.8
2	2.5
3	1.2
4	0.6
5	2.7
6	1.2

From the results of the calibration test, it was found that when the input angles close to -90° or +90°, there was relatively large deviation from the linear regression line. In order to reduce the error of the measurements, three linear regression lines were used for three different regions, i.e. (1) -90° to -70°, (2) -70° to +70° and (3) +70° to +90°. At the regions of -90° to -70° and +70° to +90°, additional calibration tests were conducted with input interval of 2° (Figure 3.9).





x denoted the output of accelerometer;

y denoted the sine of inclination of input angle

Figure 3.9 Linear regression of the output voltage and inclination of the accelerometer

Three sets of proportionality constant and offset for these three linear regression lines were obtained for each accelerometer (Table 3.3, Table 3.4).

Table 3.3 Three linear regression equations were used for angular measurements of each accelerometer

Equations	Angle Range	
$\sin\theta_1 = k_1 \times V_1 + b_1$	[-90, -70)	3.2a
$\sin\theta_2 = k_2 \times V_2 + b_2$	[-70, +70]	3.2b
$\sin\theta_3 = k_3 \times V_3 + b_3$	(+70, +90]	3.2c

where k_1, b_1; k_2, b_2; k_3, b_3 are the proportionality constants and offsets of the linear regression lines obtained in the three regions

Table 3.4 Three sets of proportionality constant and offset for each accelerometer

Accelerometer No.	[-90,-70)			[-70,+70]			(+70,+90]		
	k_1	b_1	r^2	k_2	b_2	r^2	k_3	b_3	r^2
1	3.2016	-7.9332	1.0000	3.2087	-7.9455	1.0000	3.2066	-7.9408	1.0000
2	2.9798	-7.4736	0.9997	3.2002	-7.9594	1.0000	3.4056	-8.5256	0.9999
3	3.1337	-7.7841	1.0000	3.2052	-7.9391	1.0000	3.2266	-7.9981	1.0000
4	3.1788	-7.9213	1.0000	3.2248	-8.0205	1.0000	3.2204	-8.0081	1.0000
5	2.9384	-7.3589	0.9994	3.2085	-7.9525	1.0000	3.5269	-8.8287	0.9993
6	3.0959	-7.7025	1.0000	3.1908	-7.9094	1.0000	3.2547	-8.0854	1.0000

The differences between the angles calculated from the output voltages and the input inclinations were calculated and the RMS errors of the six accelerometers were estimated (Appendix 2). The RMS errors were found to have range from 0.4° to 0.7° (Table 3.5).

Table 3.5 RMS errors of the accelerometer when 3 linear regression lines were used

Accelerometer No.	Error (°)
1	0.5
2	0.6
3	0.5
4	0.6
5	0.7
6	0.4

In the experiment, the accelerometers were attached to subject's back and the accuracy of the accelerometers was affected by body sway. The errors of the electrogoniometric system during dynamic situation were therefore estimated. Six subjects were recruited. The accelerometers were attached to the occipital protuberance (OC), C7, T7, T12, L3 and S1. The data of accelerometers were captured for 2 seconds in upright stance. For the six subjects, 1 second (from 0.5 s to 1.5 s) data were extracted and filtered using the same method and parameters in calibration (Appendix 3). The standard deviations were calculated and averaged for each accelerometer to represent the error of the accelerometers in the dynamic situation (Table 3.6).

Table 3.6 Error estimation in dynamic situation

Accelerometer No.	Level of Attachment	Error (°)
1	OC	0.5
2	C7	0.2
3	T7	0.2
4	T12	0.2
5	L3	0.1
6	S1	0.1

It was found that higher the spine level, larger the mean standard deviation. This might be due to the distance of the accelerometer from the hip which was thought to be the axis of rotation of the whole body.

3.4 Reliability of Accelerometer Attachment

The identification of anatomical landmarks for accelerometer attachment was trained by an experience physiotherapist. Six accelerometers were attached onto 7 subjects' skin surface at OC, C7, T7, T12, L3 and S1. Inclinations of the accelerometers were recorded 6 times with the subject in upright stance posture. Between successive data capture, the subject was asked to flex, extend, side flex and axially rotate the trunk before the next measurement was performed. The accelerometers were then removed and attached again onto the subjects. The inclinations of the accelerometers were recorded again 6 times using the same procedures.

Intra-class correlation coefficient ICC(3,6) was used to quantify the test-retest reliability for the accelerometer attachment process for spine curvature measurements. ICC(3,6) was found to range from 0.828 to 0.978 (Table 3.7).

Table 3.7 Results of the reliability test for the accelerometer attachment

Accelerometer	ICC(3.6)
OC	0.957
C7	0.915
T7	0.967
T12	0.873
L3	0.828
S1	0.978

3.5 Spinal Parameters

In the current study, intersegmental angles were defined as the angular parameters to quantify the spine curvature.

3.5.1 Angular parameters

The intersegmental angles were defined as the relative angle between the neighboring spine levels. Intersegmental angle between OC and C7 denoted the cervical lordosis, intersegmental angle between C7 and T7 denoted the upper thoracic kyphosis, intersegmental angle between T7 and T12 denoted the lower thoracic kyphosis, intersegmental angle between T12 and L3 denoted the upper lumbar lordosis and intersegmental angle between L3 and S1 denoted the lower lumbar lordosis. The regional angles were defined as the angles between C7 and T12, as well as between T12 and S1, named as thoracic kyphosis and lumbar lordosis, respectively (Table 3.8, Figure 3.10).

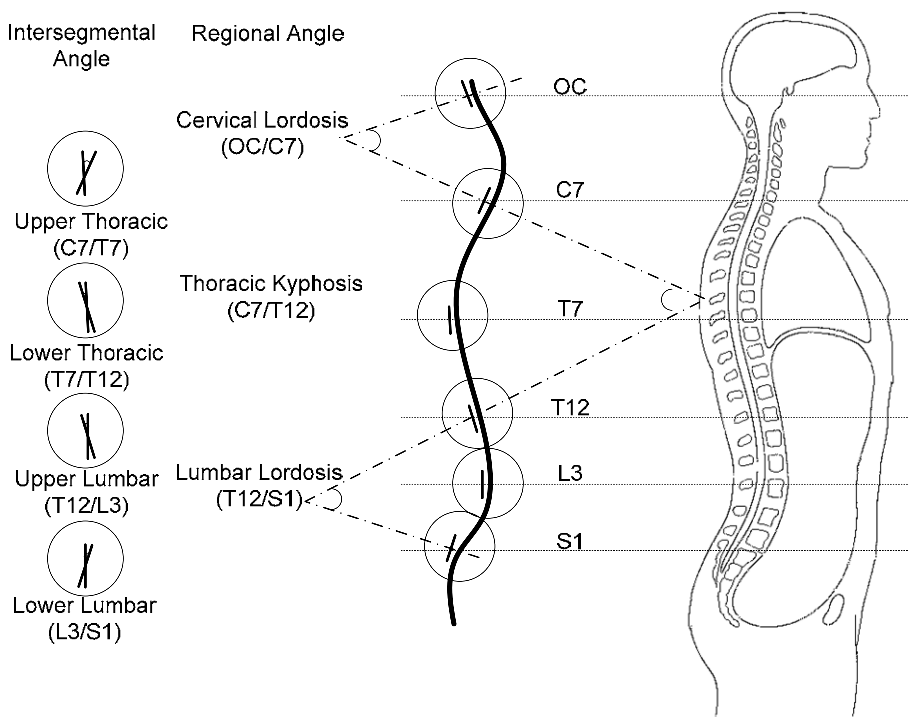


Figure 3.10 Illustration of angular parameters definition

Table 3.8 The definitions of the angular parameters

Spine level	Description
Cervical spine	Relative inclination between occipital protuberance (OC) and C7
Upper thoracic	Relative inclination between C7 and T7
Lower thoracic	Relative inclination between T7 and T12
Upper lumbar	Relative inclination between T12 and L3
Lower lumbar	Relative inclination between L3 and S1
Pelvic tilt	Relative inclination between S1 and the vertical
Thoracic spine	Relative inclination between C7 and T12
Lumbar spine	Relative inclination between T12 and S1

3.5.2 Repositioning ability

The standard deviation of the angular parameters from six trials was calculated as repositioning error (RE) to quantify the repositioning ability of the subject’s spine in upright stance. Large RE denoted the poor performance of repositioning ability, as well as the poor proprioception (Gill & Callaghan, 1998), while the small RE value represented the good performance in proprioceptive system.

3.6 Experimental Procedures

Prior to the experiment, the subjects were asked to sign an informed consent form (Appendix 1). A measuring tape was adhered to a vertical wall and a perpendicular board was used to measure the subject’s body height and eye level height. An electronic bathroom scale (Tanita, HD-313, Tanita Corporation Tokyo, Japan) was used to measure the subject’s body weight. Body weight and height were used to calculate the required backpack weight and the CG height. The backpack with different CG locations was randomly assigned to subjects. A pair of footprints was used to standardize the standing location for each subject during data capture (Figure 3.11). The distance of heels was around 10cm, and the angle between two feet was around 10° (Sahlstrand, Ortengren, & Nachemson, 1978).

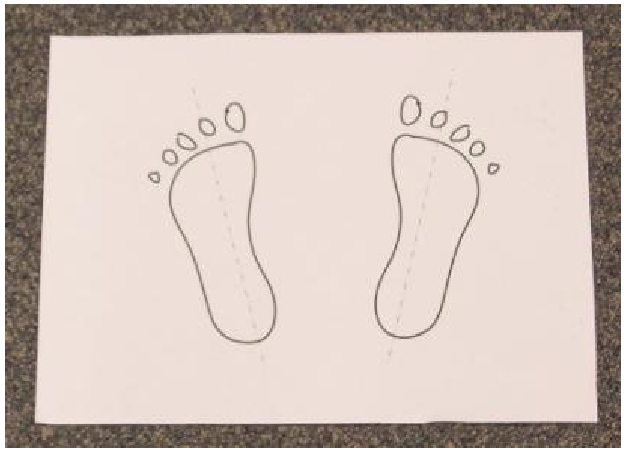


Figure 3.11 Footprint

Each subject was required to complete 7 testing conditions totally. Firstly, the condition of carrying no backpack was performed, then 6 conditions for different backpack CG positions (T7, T12, L3) and carrying methods (posteriorly or anteriorly) were performed randomly. Between consecutive conditions, the subject was allowed to take a rest for at least 3 minutes to avoid muscle fatigue (Wilder et al., 1996).

The actions taken in the experiment were then explained and demonstrated to the subject. The subject was asked to wear a loose T-shirt and shorts or loose trousers for the tests in an attempt to minimize any direct proprioceptive input from clothing. The electrogoniometric system was then attached to the skin surface by palpation over the spinal processes of occipital protuberance (OC), C7, T7, T12, L3 and S1 using double sided adhesive tape, with the subject in a semi-flexed position to minimize displacement due to skin traction during experiment (Swinkels & Dolan, 1998).

The subject equipped with accelerometers was asked to step on the footprint with bare feet. A point mark was attached to a tripod and its height was adjusted to the subject's eye level. The location of the mark point was 2 meters in the front of the subject. For each trial, the subject was instructed to stand upright with their arms relaxed aside the body naturally and with the eyes gazing at the point 2 meters in front during the data capturing. The subject was then asked to repeat upright stance for 6 times. Between trials, the subject was asked to bend forward, backward and laterally freely to eliminate the short-term memory of the previous action. During the experiment, data from each accelerometer were captured at the upright stance posture for 2 seconds at a sampling frequency of 100 Hz. The angular parameters and RE were then calculated to document the spine curvature and repositioning ability under the different loading conditions.

3.7 Data Processing and Analysis

The data from 0.5s to 1.5s were extracted from the raw data. A low pass filter (Matlab 6.5, MathWorks, Inc. US) was used to filter the extracted data to remove the noise (order 3, cut off frequency 3Hz). The cut off frequency was calculated by the residual method suggested by Winter (2005). The angular parameters (intersegmental angle and regional angles) and the standard deviation of 6 trials in upright stance were then calculated describing the spine curvature and repositioning ability, respectively.

All the statistical analyses were conducted using statistical software (SPSS v.15, SPSS Inc., Chicago, USA) with level of significance set at 0.05. A one-way repeated measures ANOVA was firstly used to compare the differences in spine curvature among the 7 loading conditions (i.e. 3 CG locations for 2 carrying methods and 1 no load condition). If the differences were statistically significant with $p<0.05$, contrast analysis would be performed to determine the angular parameters under which loading conditions were significantly different from the no load condition. The effects of testing group (i.e. 10%BW, 15%BW and 20%BW), carrying method (i.e. anteriorly and posteriorly) and backpack CG location (i.e. T7, T12 and L3) on the spine curvature were analyzed using three-way mixed repeated measures ANOVA (Orloff & Rapp, 2004) with carrying method and backpack CG location as the within-subjects factor and the testing group as the between-subjects factor. If significant interactions existed among the three factors, detailed 2-way ANOVA would be employed to analyze the effects of each pair of factors on spine curvature separately. Contrast comparisons were conducted to compare the differences among the different levels of each factor.

The repositioning ability was analyzed using 2-way mixed repeated measures ANOVA to study the effects of backpack carriage (i.e. 3 CG locations for 2 carrying methods and 1 no load condition) and testing group (i.e. 10%BW, 15%BW and 20%BW). Contrast test was performed to compare the repositioning errors between each backpack carriage condition and no backpack condition.

CHAPTER 4 RESULTS

4.1 Details of Participants

From the five schools which agreed to participate in the study, subjects were recruited via either the school principles or the school teachers. Totally, 295 schoolchildren were invited and 84 children participated in the experiment. However, 21 subjects (7 for pilot study, 1 for over age, 7 did not show up and 6 for dropped sensor) were excluded from this study. Therefore, 63 students successfully completed the experiment during the experimental period (Figure 4.1, Appendix 7). Their information and anthropometric data are summarized in Table 4.1. One-way ANOVA was performed to test the differences in body height and weight among the three test groups of different backpack weights. There were no significant differences in body height and body weight among the three groups with p=0.075 and p=0.052, respectively. Although, some children in the 20% BW group reported that the backpack was very heavy, they could tolerate it and none of them complained about back discomfort or back pain during the test.

Table 4.1 Participants' information

Test Group (backpack weight)	10% BW	15% BW	20% BW	Total
Mean (SD) age (year)	13.2 (1.7)	12.0 (1.3)	12.8 (1.1)	12.6 (1.5)
Mean (SD) body height (cm)	153.9 (6.8)	150.1 (8.3)	155.5 (7.5)	152.4 (7.8)
Mean (SD) body weight (kg)	46.3 (5.8)	41.8 (7.8)	42.3 (6.4)	43.6 (7.2)
Number of male and female subjects	M:7 / F:16	M:16 / F:13	M:9 / F:2	M:32 / F:31
Number of subjects	23	29	11	63

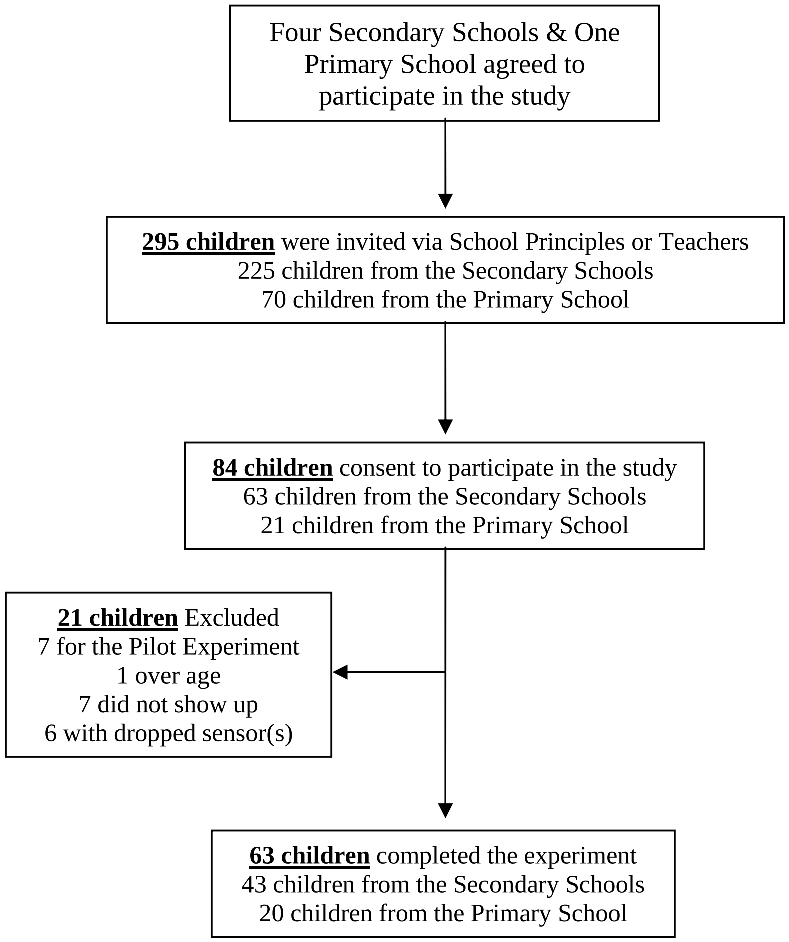


Figure 4.1 The consort diagram detailing the information of subject recruitment

4.2 Spine Curvature in Upright Stance

The spine curvature was measured in terms of intersegmental angles and regional angles using the electrogoniometric system. For the intersegmental angles, C7-T7 and T7-T12 denoted the upper and lower thoracic kyphosis while T12-L3 and L3-S1 denoted the upper and lower lumbar lordosis, respectively. For the regional angles, OC-C7 denoted the cervical lordosis, C7-T12 denoted the thoracic kyphosis, and T12-S1 denoted the lumbar lordosis. The effects of three factors were investigated in this study, namely “test group” (for backpack weight of 10%, 15% and 20%BW), "CG location" (for backpack CG positioned at T7, T12, and L3), and "carrying method" (for anterior and posterior carriage).

The intersegmental angles and RE during no backpack carriage condition between the three testing groups were compared using one-way ANOVA, and the result indicated that there was no significant difference ($p>0.05$) among the three groups (Table 4.2).

Table 4.2 The *p* value of the one-way ANOVA on the changes of intersegmental angles and RE of each spine level among the no load conditions of the different testing groups

Spine Level	*p* value	
	Intersegmental angle	RE
Cervical	0.229	0.867
Upper Thoracic	0.806	0.265
Lower Thoracic	0.439	0.678
Upper Lumbar	0.082	0.991
Lower Lumbar	0.584	0.342
Pelvis	0.135	0.670

4.2.1 Comparison between different test conditions and no load condition

The average intersegmental angles of the participants in upright stance for each loading condition were determined (Appendix 5). As each participant was only tested for one backpack weight (10%BW, 15%BW or 20%BW), the data were first analyzed separately for the three test groups. A one-way repeated measures ANOVA was used to compare the differences in intersegmental angles among the 7 loading conditions (i.e. 3 CG locations for 2 carrying methods and 1 no load condition). If the differences were statistically significant with $p<0.05$, contrast analysis was performed to determine the intersegmental angles under which loading conditions were significantly different from the no load condition (Table 4.3).

Table 4.3 The p-values of the one-way repeated measures ANOVA for the effects of test condition on the spine curvature in upright stance for each test group

Spine curvature	Significant differences (*p* value)								
	10%BW			15%BW			20%BW		
	Effect of test condition	Contrast test		Effect of test condition	Contrast test		Effect of test condition	Contrast test	
Cervical lordosis	**<0.001**	AT7	0.272	**<0.001**	AT7	**0.044**	**<0.001**	AT7	1.000
		AT12	0.101		AT12	0.392		AT12	0.108
		AL3	0.223		AL3	0.302		AL3	**0.036**
		PT7	**<0.001**		PT7	**<0.001**		PT7	**0.015**
		PT12	**<0.001**		PT12	**<0.001**		PT12	**0.001**
		PL3	**<0.001**		PL3	**<0.001**		PL3	**0.006**
Upper thoracic kyphosis	**0.001**	AT7	**<0.001**	**<0.001**	AT7	**<0.001**	**0.001**	AT7	**0.031**
		AT12	**0.002**		AT12	**<0.001**		AT12	**0.012**
		AL3	**<0.001**		AL3	**<0.001**		AL3	0.284
		PT7	0.875		PT7	0.984		PT7	0.950
		PT12	0.356		PT12	0.546		PT12	0.946
		PL3	0.364		PL3	0.823		PL3	0.352
Lower thoracic kyphosis	0.053	AT7	0.739	0.259	AT7	0.086	0.171	AT7	0.282
		AT12	0.021		AT12	0.449		AT12	0.029
		AL3	0.374		AL3	0.532		AL3	0.145
		PT7	0.116		PT7	0.990		PT7	0.167
		PT12	0.537		PT12	0.059		PT12	0.570
		PL3	0.815		PL3	0.035		PL3	0.452
Upper lumbar lordosis	**<0.001**	AT7	**0.010**	**<0.001**	AT7	0.418	**<0.001**	AT7	0.714
		AT12	**0.011**		AT12	**0.031**		AT12	0.072
		AL3	0.121		AL3	0.156		AL3	0.824
		PT7	**0.004**		PT7	**<0.001**		PT7	**0.001**
		PT12	0.053		PT12	**<0.001**		PT12	**<0.001**
		PL3	**0.006**		PL3	**<0.001**		PL3	**0.001**
Lower lumbar lordosis	**<0.001**	AT7	0.467	**<0.001**	AT7	0.619	0.921	AT7	0.736
		AT12	0.865		AT12	0.742		AT12	0.309
		AL3	0.557		AL3	0.313		AL3	0.849
		PT7	**0.005**		PT7	**<0.001**		PT7	0.783
		PT12	**<0.001**		PT12	**<0.001**		PT12	0.966
		PL3	**0.002**		PL3	**<0.001**		PL3	0.599
Pelvic tilt	**0.012**	AT7	**0.039**	**0.002**	AT7	**<0.001**	0.058	AT7	0.003
		AT12	0.677		AT12	**<0.001**		AT12	0.010
		AL3	0.411		AL3	**<0.001**		AL3	0.262
		PT7	0.330		PT7	0.605		PT7	0.443
		PT12	**0.014**		PT12	0.218		PT12	0.753
		PL3	0.118		PL3	0.978		PL3	0.629
Thoracic kyphosis	**0.011**	AT7	**0.002**	**<0.001**	AT7	**<0.001**	0.157	AT7	0.320
		AT12	0.710		AT12	**<0.001**		AT12	0.448
		AL3	0.111		AL3	**<0.001**		AL3	0.915
		PT7	0.125		PT7	0.980		PT7	0.251
		PT12	0.669		PT12	0.356		PT12	0.649
		PL3	0.491		PL3	0.109		PL3	0.264

Table 4.3 (Cont'd) The p-values of the one-way repeated measures ANOVA for the effects of test condition on the spine curvature in upright stance for each test group

Lumbar lordosis	**<0.001**	AT7	**0.008**	**<0.001**	AT7	0.767	**0.009**	AT7	0.385
		AT12	**0.003**		AT12	0.064		AT12	0.628
		AL3	**0.024**		AL3	0.540		AL3	0.991
		PT7	**<0.001**		PT7	**<0.001**		PT7	**0.040**
		PT12	**<0.001**		PT12	**<0.001**		PT12	**0.027**
		PL3	**<0.001**		PL3	**<0.001**		PL3	**0.019**

Refer to Table 3.1 for the abbreviations

<u>*Cervical lordosis*</u>

Significant differences in cervical lordosis among the 7 loading conditions were found for all the three test groups with $p<0.001$ (Figure 4.2). Compared to the no load condition, significant cervical extension was found when the backpack was carried posteriorly no matter where the CG of the backpack was positioned. The cervical spine extended by 5º - 7º, 11º - 13º and around 6º for backpack weights of 10%, 15% and 20%BW, respectively. When the backpack was carried anteriorly, the change of cervical lordosis was neither consistent nor significant in most conditions. However, there was a significant cervical extension when a 15%BW backpack was carried with the CG located at T7 and a significant cervical flexion when a 20%BW backpack was carried with the CG located at L3 (Figure 4.2).

<u>*Upper thoracic kyphosis*</u>

Significant differences in upper thoracic kyphosis among the 7 loading conditions were found for all the test groups with $p<0.05$ (Figure 4.3). When the backpack was carried anteriorly, there was a significant increase in upper thoracic kyphosis in all test conditions except when a 20%BW backpack was carried with the CG located at

L3 (Figure 4.3). The upper thoracic kyphosis during posterior carriage conditions were not significantly different from the no load with $p>0.05$.

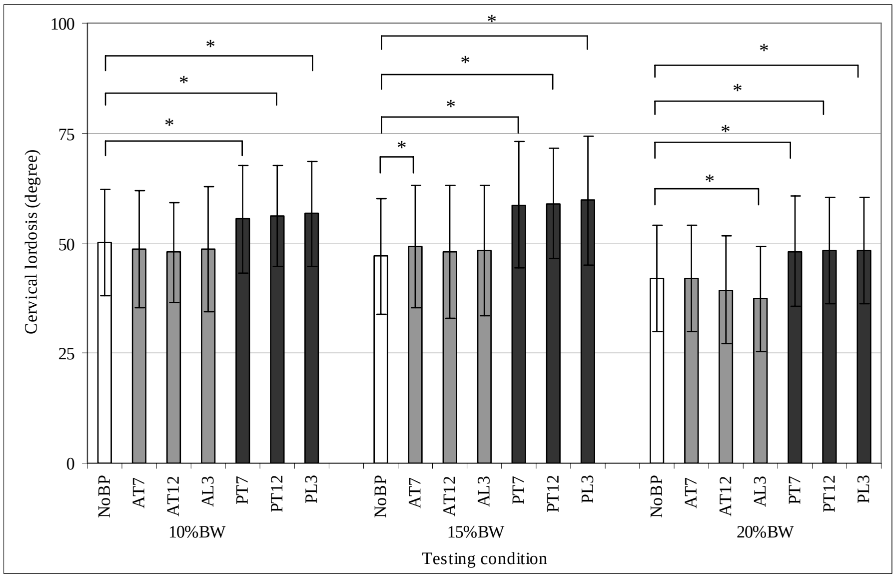


Figure 4.2 Cervical lordosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

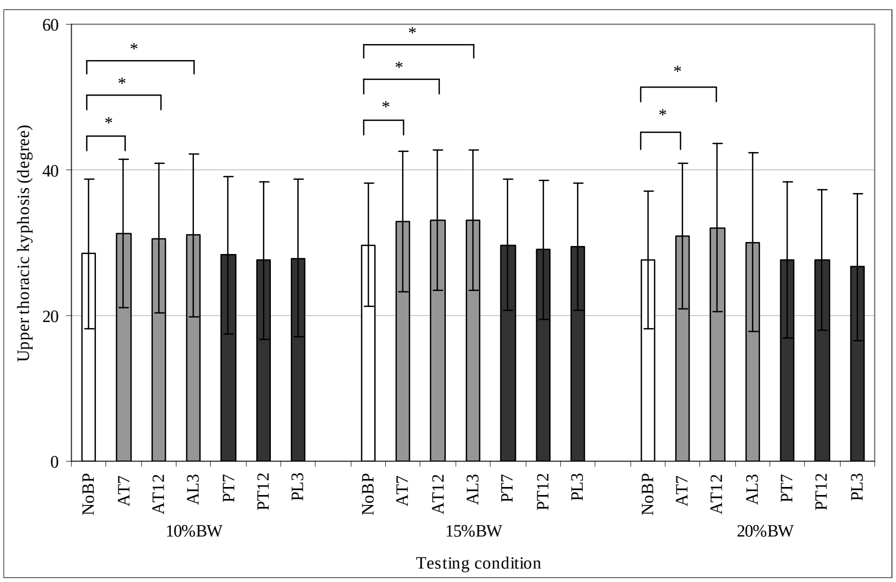


Figure 4.3 Upper thoracic kyphosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

Lower thoracic kyphosis

No significant differences were observed in lower thoracic kyphosis among the 7 loading conditions (Figure 4.4). The changes of lower thoracic kyphosis were inconsistent both in anterior and posterior carriage conditions when compared to the no backpack condition.

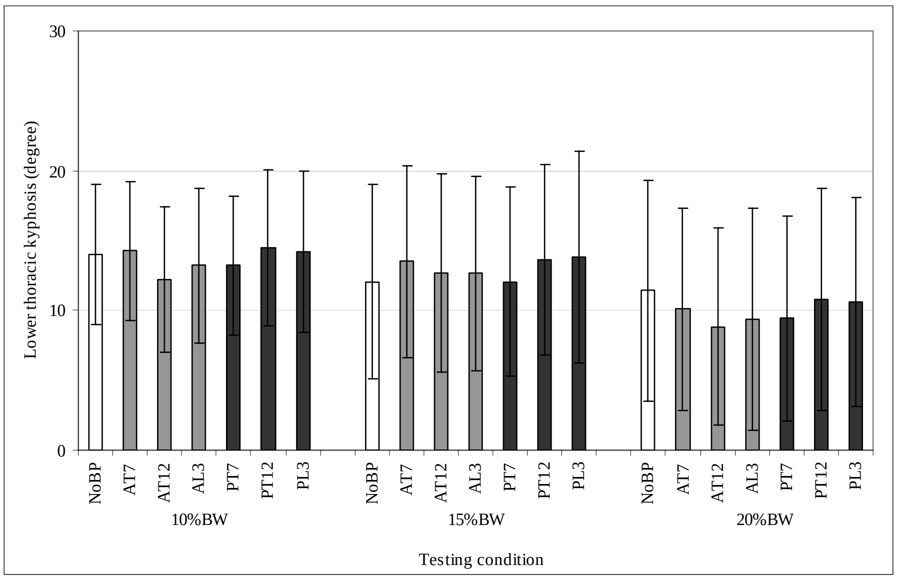


Figure 4.4 Lower thoracic kyphosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

Upper lumbar lordosis

Significant difference of upper lumbar lordosis was shown among the 7 loading conditions in all the three test groups ($p<0.001$) (Figure 4.5). In the posterior carriage conditions, a significant reduction of upper lumbar lordosis was demonstrated except when a 10%BW backpack was carried with the CG located at T12. When the backpack was carried anteriorly, a significant increase of upper lumbar lordosis was shown in the condition of 10%BW carriage with the CG located at T7 and T12, as well as in 15%BW carriage condition with the CG located at T12. No significant changes of upper lumbar lordosis were found in 20%BW anterior carriage condition no matter where the backpack CG was located.

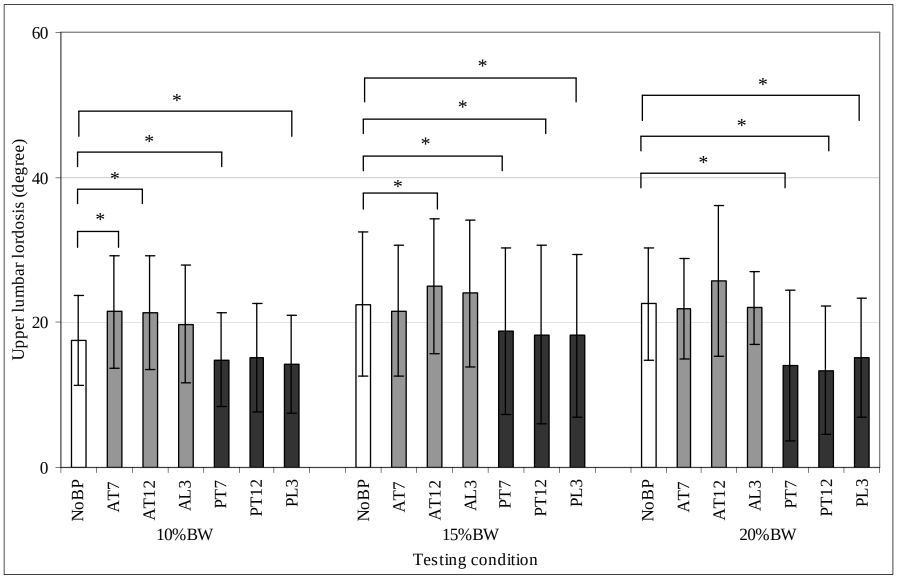


Figure 4.5 Upper lumbar lordosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

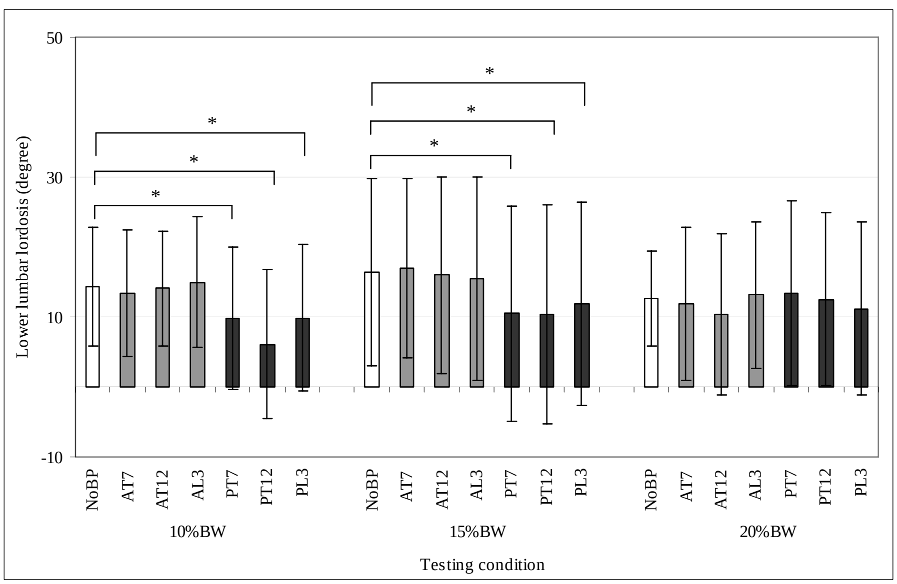


Figure 4.6 Lower lumbar lordosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

Lower lumbar lordosis

For the 10%BW and 15%BW test groups, a significant difference of lower lumbar lordosis was found with $p<0.001$ among the 7 loading conditions. In the posterior carriage conditions, a significant decrease in lower lumbar lordosis was shown in all the CG locations. No significant changes of lower lumbar lordosis were demonstrated in all the anterior carriage conditions (Figure 4.6).

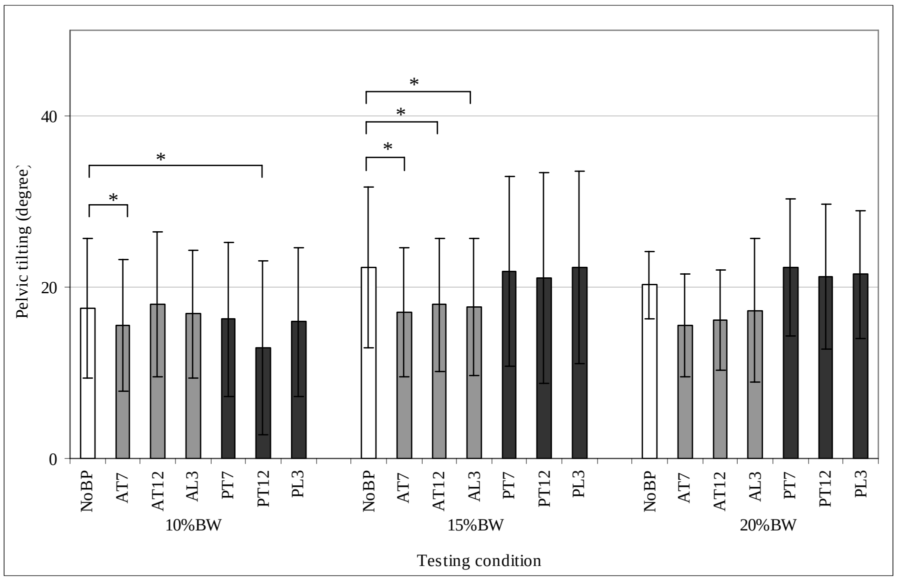


Figure 4.7 Pelvic tilt relative to vertical for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

Pelvic tilt relative to vertical

For 10%BW test group, a significant difference of pelvic tilt was noted with $p=0.012$ among the 7 loading conditions. The pelvis tilted posteriorly significantly both in the condition of anterior carriage with the CG located at T7 and in the condition of posterior carriage with the CG located at T12 (Figure 4.7). A 15%BW carriage also resulted in significant changes in pelvic tilt ($p=0.002$) among the 7 loading conditions. Significant posterior tilt was found in anterior carriage weight of 15%BW. For 20%BW test group, there was no significant difference of pelvic tilt among the 7 loading conditions, although anterior carriage was shown to make the pelvis tilt posteriorly.

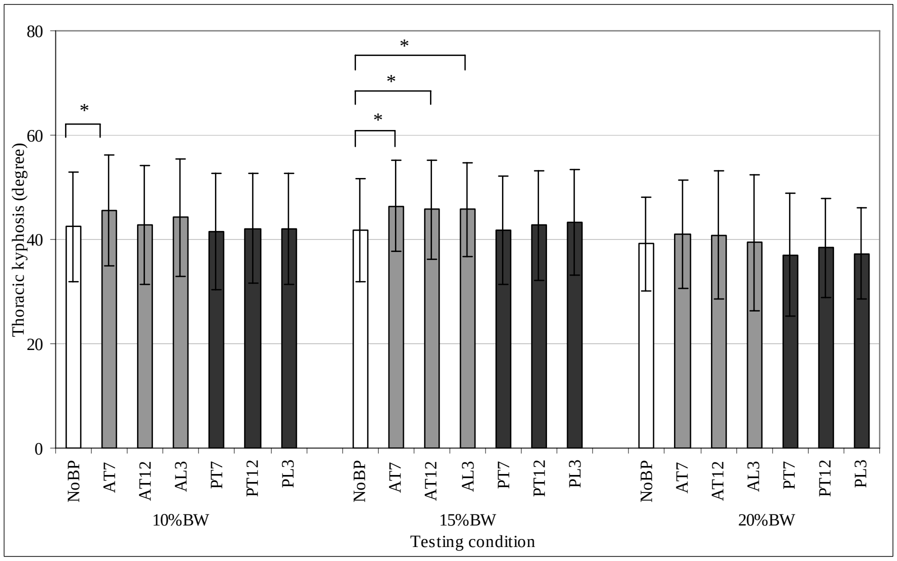


Figure 4.8 Thoracic kyphosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

<u>*Thoracic kyphosis*</u>

In 10%BW and 15%BW test groups, significant effects of backpack carriage among the 7 loading conditions were found on thoracic kyphosis with p=0.001 and p<0.001, respectively (Figure 4.8). It was shown that there was a significant increase of thoracic kyphosis in 10%BW anterior carriage with the CG located at T7. When a 15%BW anterior carriage was carried, the thoracic level increased in kyphosis significantly no matter where the backpack CG was located. The thoracic kyphosis in posterior carriages was shown to be inconsistent compared to that in the no backpack condition both in 10%BW and 15%BW carriage conditions. For the 20%BW carriage, an increase of thoracic kyphosis and a decrease of thoracic kyphosis were found in anterior and posterior carriage respectively, however the changes were not significant.

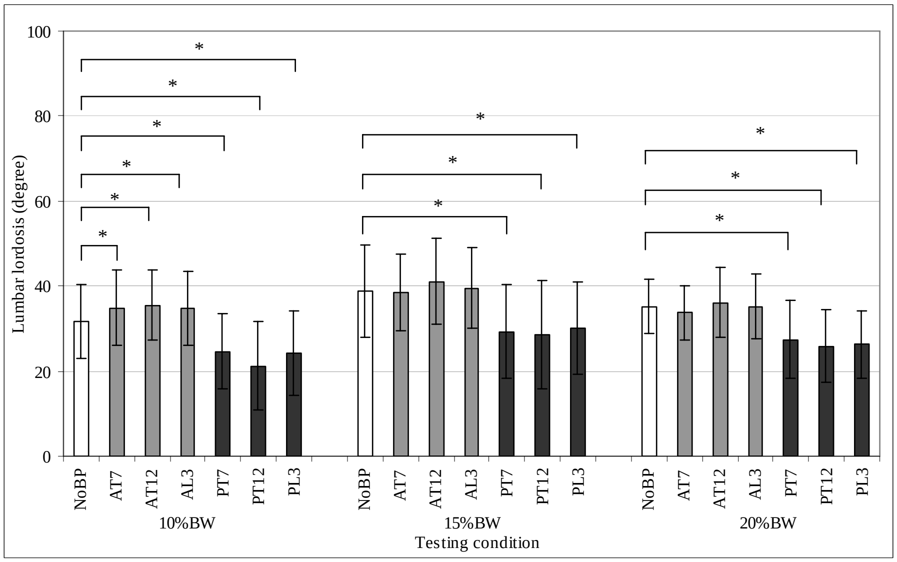


Figure 4.9 Lumbar lordosis for each backpack CG location in the three test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

<u>*Lumbar lordosis*</u>

Significant changes in lumbar lordosis were found in the 7 loading conditions compared to no backpack condition with $p<0.001$ (Figure 4.9). A significant increase of lumbar lordosis was shown in 10%BW anterior carriage. When the carriage was carried posteriorly, a significant decrease in lumbar lordosis was observed in all three test groups.

In summary, for anterior carriage conditions, a significant increase of upper thoracic kyphosis was demonstrated, as well as posterior pelvic tilt mainly in 15%BW and 20%BW loading conditions. In posterior carriage conditions, significant reduction of lordosis was found at upper and lower lumbar regions in 10%BW and 15%BW loading conditions, as well as a significant increase of cervical lordosis.

4.2.2 Effects of carrying method, CG location and test group on the changes in spine curvature

The difference in spine curvature between each loading condition and the no load condition was firstly determined. A 3-way repeated measures ANOVA with mixed samples was performed to investigate the effects of test group (between-subjects factor), carrying method and CG location (within-subjects factors) on the change of spine curvature. Significant interaction among the three factors was demonstrated for the lower lumbar lordosis and the pelvic tilt (Table 4.4). There was also a significant interaction between the carrying method and test group factors for these two spine curvature parameters. Significant interaction between the carrying method and CG location factors was also found for most spine curvature parameters, except for the upper thoracic kyphosis, lower lumbar lordosis and pelvic tilt. There was no significant interaction between the test group and CG location factors for all the parameters.

Table 4.4 The *p*-values of the 3-way repeated measures ANOVA for the effects of carrying method, backpack CG location and test group on the spine curvature

Difference of spine curvature in different test conditions comparing no backpack condition at different spine regions	Carrying method × CG location × Test group	Carrying method × CG location	CG location × Test group	Carrying method × Test group
Cervical lordosis	0.760	**0.038**	0.171	0.106
Upper thoracic kyphosis	0.944	0.536	0.183	0.879
Lower thoracic kyphosis	0.839	**<0.001**	0.834	0.854
Upper lumbar lordosis	0.068	**0.021**	0.349	0.229
Lower lumbar lordosis	**0.011**	0.600	0.344	**0.020**
Pelvic tilt	**0.040**	**0.001**	0.938	**0.003**
Thoracic kyphosis	0.676	**0.011**	0.264	0.728
Lumbar lordosis	0.878	**0.001**	0.118	0.470

As there was a significant interaction among the three factors, the effects of the three factors on the change in spine curvature was further studied using 2 separate 2-way repeated measures ANOVA tests. Contrast analysis was conducted to study the significant difference between the different levels of each factor, if the main effect was statistically significant.

The results of the 2-way ANOVA performed to investigate the effects of backpack CG location and test group on the changes of spine curvature relative to no backpack condition for each spine segment in anterior and posterior carriage conditions are shown in Table 4.5. There was no significant interaction between the backpack CG location and test group both in anterior and posterior carriage conditions at most of the spine segments, except the interaction between the two factors at the lower lumbar segment in posterior carriage condition.

Table 4.5 The *p*-values of the 2-way repeated measures ANOVA for the effects of backpack CG location and test group on the spine curvature for anterior and posterior carriage conditions

Difference of spine curvature in different test conditions comparing no backpack condition at different spine regions		CG location × Test group	CG location	Test group
Anterior carriage	Cervical lordosis	0.204	**0.033**	**0.038**
	Upper thoracic kyphosis	0.210	0.404	0.596
	Lower thoracic kyphosis	0.751	**0.010**	0.067
	Upper lumbar lordosis	0.058	**0.005**	0.231
	Lower lumbar lordosis	0.137	0.346	0.935
	Pelvic tilt	0.269	**0.011**	**0.017**
	Thoracic kyphosis	0.267	0.078	0.080
	Lumbar lordosis	0.643	**0.020**	0.144
Posterior carriage	Cervical lordosis	0.973	0.465	**<0.001**
	Upper thoracic kyphosis	0.836	0.433	0.970
	Lower thoracic kyphosis	0.908	**0.002**	0.186
	Upper lumbar lordosis	0.616	0.901	**0.002**
	Lower lumbar lordosis	**0.024**	0.062	**0.041**
	Pelvic tilt	0.122	**0.004**	0.186
	Thoracic kyphosis	0.684	0.178	0.215
	Lumbar lordosis	0.256	**0.013**	0.849

For the **anterior carriage conditions**, the changes of spine curvature relative to no backpack condition in different CG locations were compared (Figure 4.10a). Significant backpack CG effect was found at cervical flexion, lower thoracic extension, upper lumbar extension, extension of the whole lumbar spine and anterior pelvis tilt. Contrast analysis showed a significant increase of cervical flexion when the backpack CG was located at L3 and T12 compared to that in the condition with the CG located at T7. A backpack with the CG located at T12 was found to result in a significant increase in lower thoracic extension compared to that in the condition with the CG located at T7. It was also observed that the upper lumbar spine extended significantly when the backpack CG was located at T12 in comparison to that in the condition with the CG located at T7 and L3. A significant anterior pelvic tilt was noted in the condition with the CG located at T12 and L3 when compared to the tilting in the condition with the CG located at T7. The lumbar spine extended significantly in the condition with the CG located at T12 compared to the condition with the CG located at T7.

Significant effects of test group on the difference of spine curvature relative to no backpack condition were found at the cervical spine and pelvis in the conditions of anterior carriage (Figure 4.10b). A 15%BW anterior carriage induced a significant extension of the cervical spine compared to that in the 10%BW anterior carriage condition. The anterior carriage weighing 15%BW and 20%BW was found to result in a larger extension of the pelvis than in the 10%BW backpack carriage condition and the change was significant between 10%BW and 15%BW carriage conditions.

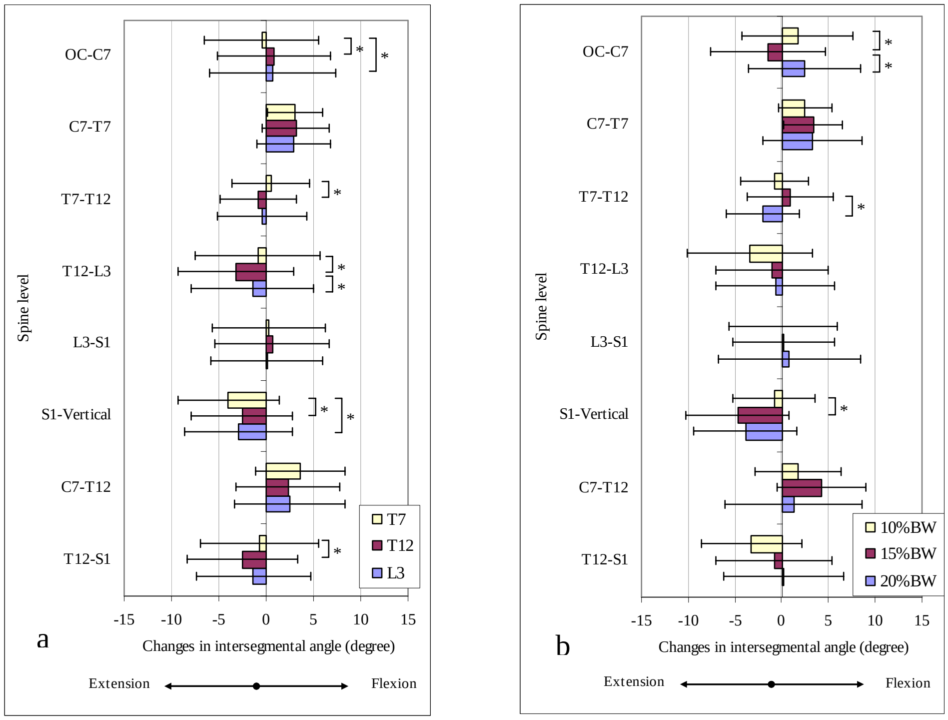


Figure 4.10 The effects of backpack CG location (a) and test group (b) on the mean difference in intersegmental angle for anterior carriage

(* significant difference)

For the **posterior carriage conditions**, no significant interaction was observed between the backpack CG location and test group at most of the spine segments except at the lower lumbar spine. Significant backpack CG effects were found at lower thoracic, lumbar and pelvis levels (Figure 4.11a). Contrast analysis indicated a significant increase of upper thoracic flexion in the condition with the CG located at T12 and L3 compared to that in the condition with the CG located at T7. As to the lumbar segment, the backpack with the CG located at T12 induced a significant flexion compared to that in the condition with the CG located at T7. A backpack with the CG located at T12 was found to result in a significant extension at pelvis compared to that in the condition with the CG located at T7 and L3.

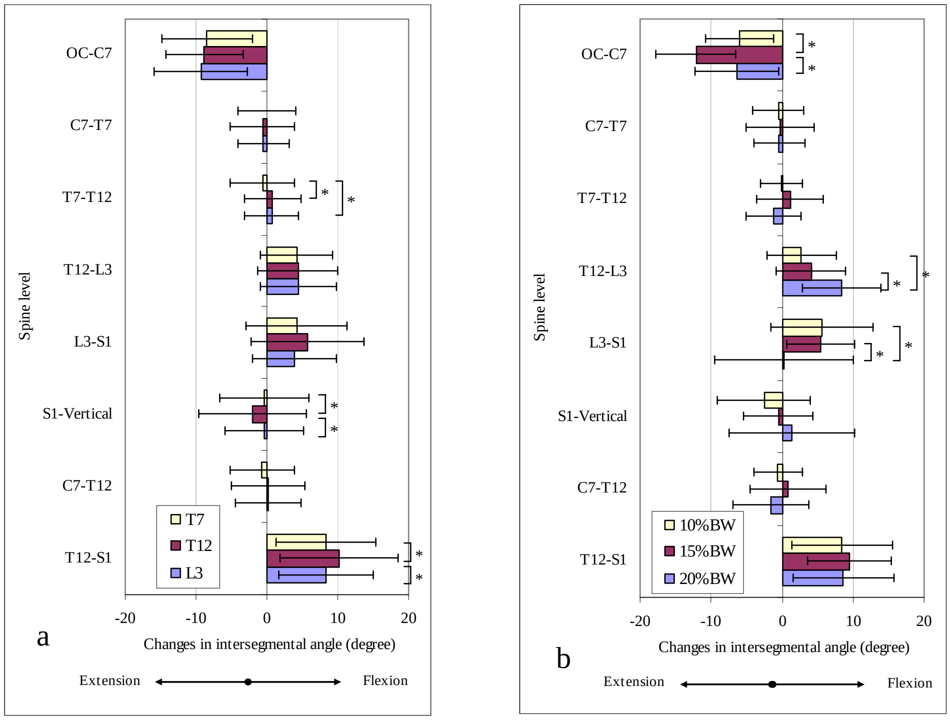


Figure 4.11 The effects of backpack CG location (a) and test group (b) on the mean difference in intersegmental angle for posterior carriage

(* significant difference)

The effects of test group were shown to be significant on the difference of spine curvature at cervical and upper lumbar spine segments (Figure 4.11b). A 15%BW backpack resulted in a significant extension of the cervical spine compared to that in the 10%BW and 20%BW posterior carriage conditions. A significant upper lumbar flexion was found when a 20%BW backpack was carried compared to that when 10%BW and 15%BW backpack carriages were carried.

There was a significant interaction between the backpack CG location and test group in posterior carriage conditions at the lower lumbar spine. The changes of lower lumbar lordosis relative to no backpack condition were compared in the different backpack CG locations (Figure 4.12). When comparing the effects between the conditions of backpack with the CG located at T7 and T12, significant interaction was found in the condition of 10%BW and 15%BW backpack carriages. In the condition of the backpack with the CG located at T12 and L3, the significant interaction was observed between the 15%BW and 20%BW backpack carriages. A significant interaction was noted between 10%BW and 20%BW backpack carriage conditions when the comparison was conducted between the conditions of the backpack with the CG located at T7 and L3. In the condition of backpack with the CG located at T7, a backpack weighing 20%BW resulted in a significant lower lumbar extension. When the backpack with the CG located at T12 was carried, a continuous decrease of lower lumbar flexion was found with the increase of backpack weight. The curvature was observed to be maintained with the condition of 10%BW and 15%BW backpack carriage. A significant decrease of lower lumbar flexion was noted when the backpack weighing 20%BW was carried.

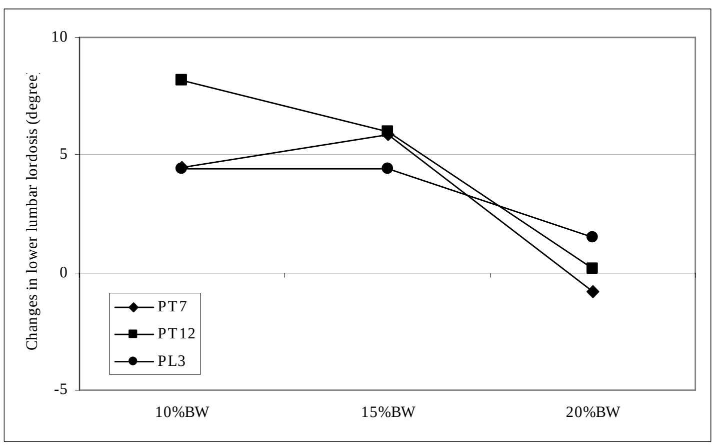


Figure 4.12 The changes of spine curvature in different CG locations comparing no load condition at lower lumbar lordosis when the carriage was carried posteriorly

In summary, for the anterior carriages, the lower thoracic, lumbar and pelvis were found to have significantly different responses for backpack CG positioned at different locations, while the changes in cervical, upper lumbar curvature were significantly different for different test groups. For the posterior carriages different backpack CG locations were found to induce significantly different curvature changes in the lower thoracic and lumbar spine as well as the pelvis. There was an interaction between backpack CG location and weight on the lower lumbar curvature changes. Cervical and upper lumbar curvatures were found to be significantly affected by different backpack weights.

4.3 Spine Repositioning Error

4.3.1 Comparison between different test conditions and no load condition

The spine repositioning error (RE) was measured in terms of the standard deviations of the angular parameters in the six trials (Appendix 6). One-way repeated measures ANOVA was applied to investigate the effects of the 7 test conditions (i.e. 3 CG locations for 2 carrying methods and 1 no load condition) on spine repositioning ability for each test group (i.e. 10%BW, 15%BW and 20%BW) in upright stance. The significant differences between each test condition and no backpack condition were investigated using contrast analysis.

Table 4.6 The *p*-values of the one-way repeated measures ANOVA for the effects of test condition on the spine repositioning error in upright stance for each test group

Spine curvature	Effect of test condition (*p* value)		
	10%BW	15%BW	20%BW
Cervical lordosis	**0.008**	**0.043**	0.563
Upper thoracic kyphosis	0.083	0.218	0.333
Lower thoracic kyphosis	0.730	0.215	0.250
Upper lumbar lordosis	0.561	0.099	**0.003**
Lower lumbar lordosis	**0.001**	**0.003**	**0.006**
Pelvic tilt	**0.003**	**<0.001**	**0.006**
Thoracic kyphosis	0.468	0.879	0.636
Lumbar lordosis	0.097	**0.019**	**<0.001**

There were significant effects of test condition on the spine repositioning error at cervical spine, lower lumbar spine and pelvis in 10%BW test group, at cervical spine, lower lumbar spine, pelvis and the whole lumbar spine in 15%BW test group, as well as at upper and lower lumbar, pelvis and the whole lumbar spine in 20%BW test group (Table 4.6).

The RE comparison between each backpack carriage condition and no load condition for each spine segment in upright stance were conducted for each test group (Table 4.7).

Table 4.7 The *p*-values of the one-way repeated measures ANOVA for the effects of test condition on the spine repositioning error in upright stance for each test group

Spine curvature	Significant differences (*p* value)								
	10%BW			15%BW			20%BW		
	Effect of test condition	Contrast test		Effect of test condition	Contrast test		Effect of test condition	Contrast test	
Cervical lordosis	**0.008**	AT7	**0.017**	**0.043**	AT7	**0.002**	0.563	AT7	0.162
		AT12	**0.003**		AT12	**0.005**		AT12	0.087
		AL3	**0.038**		AL3	**0.015**		AL3	0.340
		PT7	**0.030**		PT7	**0.022**		PT7	0.542
		PT12	0.356		PT12	**0.014**		PT12	0.109
		PL3	0.871		PL3	**0.019**		PL3	0.077
Upper thoracic kyphosis	0.083	AT7	0.002	0.218	AT7	0.124	0.333	AT7	0.044
		AT12	0.186		AT12	0.177		AT12	0.412
		AL3	0.004		AL3	0.543		AL3	0.034
		PT7	<0.001		PT7	0.001		PT7	0.074
		PT12	0.003		PT12	0.004		PT12	0.155
		PL3	0.003		PL3	0.004		PL3	0.078
Lower thoracic kyphosis	0.730	AT7	0.145	0.215	AT7	0.378	0.250	AT7	0.241
		AT12	0.358		AT12	0.032		AT12	0.539
		AL3	0.213		AL3	0.010		AL3	0.902
		PT7	0.092		PT7	0.047		PT7	0.018
		PT12	0.467		PT12	0.097		PT12	0.109
		PL3	0.462		PL3	0.084		PL3	0.029
Upper lumbar lordosis	0.561	AT7	0.259	0.099	AT7	0.017	**0.003**	AT7	0.744
		AT12	0.964		AT12	0.113		AT12	**0.029**
		AL3	0.357		AL3	0.024		AL3	0.822
		PT7	0.209		PT7	0.002		PT7	0.061
		PT12	0.190		PT12	0.019		PT12	**0.005**
		PL3	0.803		PL3	0.011		PL3	**0.007**
Lower lumbar lordosis	**0.001**	AT7	0.111	**0.003**	AT7	0.155	**0.006**	AT7	0.536
		AT12	0.935		AT12	0.128		AT12	0.654
		AL3	0.958		AL3	0.083		AL3	0.088
		PT7	**0.019**		PT7	**0.001**		PT7	**0.006**
		PT12	**0.005**		PT12	**0.002**		PT12	**0.014**
		PL3	0.145		PL3	**0.001**		PL3	**0.004**

Table 4.7 (Cont'd) The *p*-values of the one-way repeated measures ANOVA for the effects of test condition on the spine repositioning error in upright stance for each test group

Pelvic tilt	**0.003**	AT7	0.409	**<0.001**	AT7	0.511	**0.006**	AT7	0.509
		AT12	0.726		AT12	0.136		AT12	0.287
		AL3	0.253		AL3	**0.037**		AL3	0.070
		PT7	**0.028**		PT7	**<0.001**		PT7	**0.020**
		PT12	**0.009**		PT12	**0.001**		PT12	**0.012**
		PL3	**0.030**		PL3	**<0.001**		PL3	**0.002**
Thoracic kyphosis	0.468	AT7	**0.029**	0.879	AT7	0.242	0.636	AT7	0.541
		AT12	0.372		AT12	0.239		AT12	0.110
		AL3	0.243		AL3	0.251		AL3	0.145
		PT7	0.051		PT7	0.160		PT7	0.096
		PT12	0.402		PT12	0.244		PT12	0.278
		PL3	0.930		PL3	0.297		PL3	0.187
Lumbar lordosis	0.097	AT7	0.309	**0.019**	AT7	**0.042**	**<0.001**	AT7	0.114
		AT12	0.373		AT12	0.052		AT12	0.079
		AL3	0.572		AL3	**0.008**		AL3	0.236
		PT7	0.039		PT7	**<0.001**		PT7	**0.004**
		PT12	0.037		PT12	**0.008**		PT12	**0.002**
		PL3	0.112		PL3	**0.014**		PL3	**0.001**

Refer to Table 3.1 for the abbreviations

For 10%BW test group (Figure 4.13), contrast analysis indicated a significant increase of RE at cervical spine in the conditions of anterior carriage wherever the backpack CG located and in the conditions of posterior carriage with CG located at T7. At lower lumbar spine segment, the RE increased significantly in the conditions of posterior carriage with CG located at T7 and T12. The pelvic RE was observed to increase significantly when the backpack was carried posteriorly no matter where the backpack CG located.

For 15%BW test group (Figure 4.14), a significant increase in cervical RE was found in each test condition. As to the lower lumbar spine, RE was demonstrated to increase significantly in posterior carriage conditions. The pelvic RE increased significantly in the conditions of posterior carriage, as well as anterior carriage with CG located at L3. The whole lumbar RE was noted to increase significantly in all the test conditions except the condition of anterior carriage with CG located at T12.

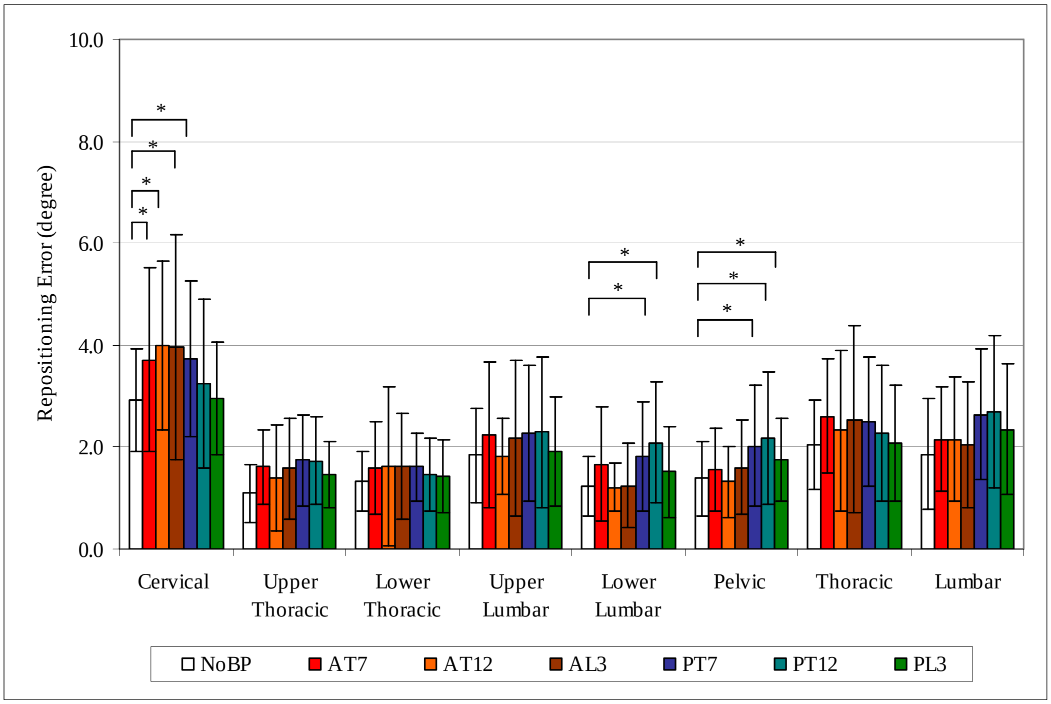


Figure 4.13 The repositioning errors of each spine region in different test conditions in upright stance for 10%BW test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

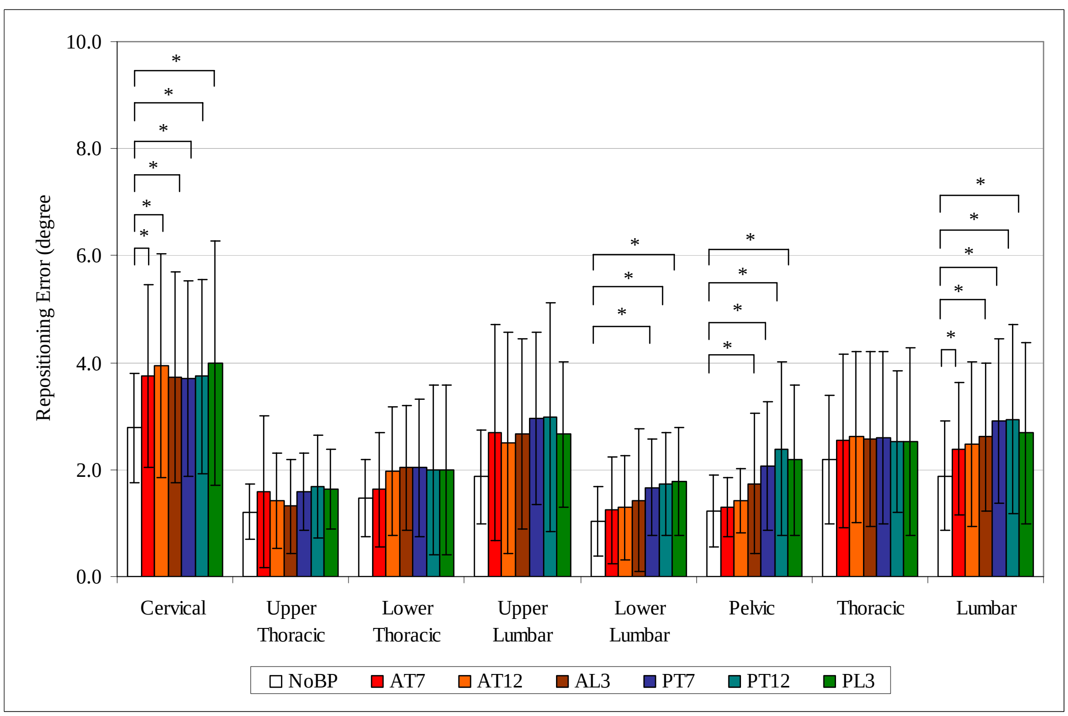


Figure 4.14 The repositioning errors of each spine region in different test conditions in upright stance for 15%BW test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

For 20%BW test group (Figure 4.15), a significant increase of RE at upper lumbar spine segment was found in the condition of anterior carriage with CG located at T12 and posterior carriage with CG located at T12 and L3. The RE at lower lumbar, pelvis and the whole lumbar increased significantly in posterior carriage conditions irrespective of backpack CG locations.

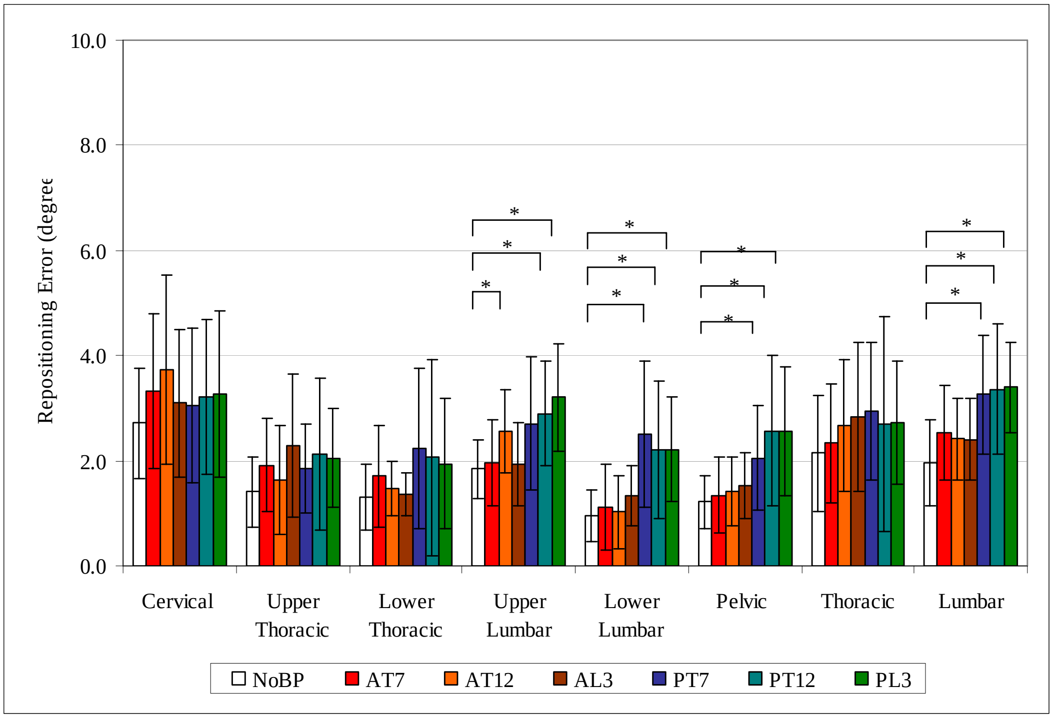


Figure 4.15 The repositioning errors of each spine region in different test conditions in upright stance for 20%BW test groups (* significant difference) *Refer to Table 3.1 for the abbreviations*

4.3.2 Effects of test condition and test group on repositioning error

A 2-way repeated measures ANOVA was applied to investigate the effects of the 7 test conditions (i.e. 3 CG locations for 2 carrying methods and 1 no load condition) and test group (i.e. 10%BW, 15%BW and 20%BW) on spine repositioning ability with the backpack carriage as within-subjects factor and test group as the between-subjects factor.

The statistical analysis showed no significant interactions between the two factors or the significant effects of test group on the repositioning error in upright stance. There were significant effects of backpack loading conditions on the spine repositioning error at all the spine regions except at the lower thoracic and thoracic spine (Table 4.8).

Table 4.8 The *p*-values of the 2-way repeated measures ANOVA for the effects of test condition and test group on the spine repositioning error in upright stance

Spine curvature	Test condition × Test group	Test condition	Test group
Cervical lordosis	0.596	**0.004**	0.534
Upper thoracic kyphosis	0.770	**0.006**	0.096
Lower thoracic kyphosis	0.584	0.083	0.225
Upper lumbar lordosis	0.500	**0.015**	0.093
Lower lumbar lordosis	0.066	**<0.001**	0.669
Pelvic tilt	0.589	**<0.001**	0.877
Thoracic kyphosis	0.988	0.274	0.684
Lumbar lordosis	0.881	**<0.001**	0.281

The repositioning errors (RE) for each spine segment in upright stance were compared (Figure 4.16). Contrast analysis indicated a significant increase of RE in all the backpack carriage conditions at the cervical and lumbar spine. There was significant increase of RE at upper thoracic and lower lumbar spine in each backpack condition except when the backpack with CG located at T12 was carried anteriorly. As to the upper lumbar spine, significant increase of RE were demonstrated in the condition of both anterior and posterior carriages except that in the condition of anterior carriage with CG located at L3. RE at pelvic increased significantly when the anterior carriage with CG located at L3 was carried, as well as in the condition of posterior carriage no matter where the backpack CG located.

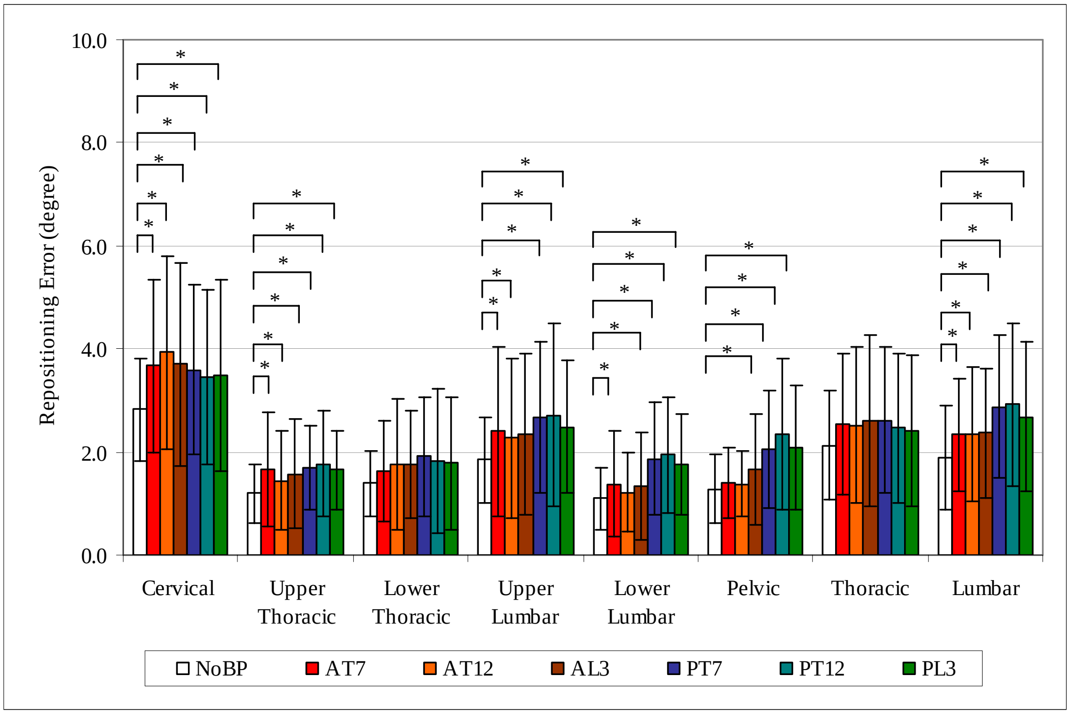


Figure 4.16 The repositioning errors of each spine region in different test conditions in upright stance (* significant difference) *Refer to Table 3.1 for the abbreviations*

CHAPTER 5 DISCUSSION

5.1 Electrogoniometric System

An electrogoniometric system was developed to quantify spine curvature under different load carriage conditions. In comparison with the use of an optoelectronic method for spine curvature measurements, the current approach does not require complete exposure of the participant's back during measurement and can be used for evaluating any commercially available backpacks. Comparing to the backpack with spring loaded displacement rods used to measure the spine curvature (Orloff & Rapp, 2004), the accelerometers used in the current study reduced the tactile effect due to the contact of the sensors and the participant's back.

The root-mean-square (RMS) errors of the electrogoniometric system for static and dynamic (due to body sway) angular measurements were estimated with a range from 0.4° to 0.7° and from 0.1° to 0.5°, respectively. The reliability of the accelerometer attachment was also high with ICC(3,6) ranged from 0.828 - 0.978 (Portney & Watkins, 2000). With this accuracy and reliability, we believe that the electrogoniometric system should be sensitive enough for measuring body posture and repositioning accuracy. Comparing to the one sensor system used in Brumagne et al.'s study (1999b), the electrogoniometric system used in this study could measure spine curvature at 6 locations simultaneously. The system could also be applied in routine clinical assessment to facilitate physical diagnosis and evaluate treatment effectiveness. However, the electrogoniometric system used in this study could only be used to measure spine curvature in the sagittal plane.

5.2 Effects of Load Carriage

Spine curvature and repositioning ability of participants under different backpack carriage conditions were measured and compared. For the sake of better appreciation of the effects of backpack on spine, the results are summarized in Table 5.1.

Table 5.1 The changes of spine curvature and repositioning error at different spine levels with different backpack CG locations relative to no load condition

Backpack CG located at T7						
Spine level	Posterior carriage			Anterior carriage		
	10%BW	15%BW	20%BW	10%BW	15%BW	20%BW
Cervical	**E** (+)	**E** (+)	**E** +	F (+)	**E** (+)	0 +
Upper thoracic	E +	0 +	E +	**F** +	**F** +	**F** +
Lower thoracic	E +	0 +	E +	F +	F +	E +
Upper lumbar	**F +**	**F** +	**F** +	**E** +	F +	F +
Lower lumbar	**F** (+)	**F** (+)	E (+)	F +	E +	F +
Pelvis	E (+)	E (+)	F (+)	**E** +	**E** +	E +
Backpack CG located at T12						
Spine level	Posterior carriage			Anterior carriage		
Cervical	**E +**	**E** (+)	**E +**	F (+)	E (+)	F +
Upper thoracic	E +	E +	0 +	**F** +	**F** +	**F** +
Lower thoracic	F +	F +	E +	E +	F +	E +
Upper lumbar	F +	**F** +	**F** (+)	E +	**E** +	E (+)
Lower lumbar	**F** (+)	**F** (+)	F (+)	F +	F +	F +
Pelvis	**E** (+)	E (+)	F (+)	F +	**E** +	E +
Backpack CG located at L3						
Spine level	Posterior carriage			Anterior carriage		
Cervical	**E** +	**E** (+)	**E** +	F (+)	E (+)	**F** +
Upper thoracic	E +	E +	E +	**F** +	**F** +	F +
Lower thoracic	F +	F +	E +	E +	F +	E +
Upper lumbar	**F** +	**F** +	**F** (+)	E +	E +	F +
Lower lumbar	**F** +	**F** (+)	F (+)	E +	F +	E +
Pelvis	E (+)	0 (+)	F (+)	E +	**E** (+)	E +

Notes:
F = Flexion relative to no load condition; **Bold** indicates a significant change
E = Extension relative to no load condition; **Bold** indicates a significant change
0 = No change in spine curvature compared to no load condition
+ = An increase in repositioning error compared to no load condition; (+) indicates a significant increase

5.2.1 Postural response during posterior carriage

When the backpack was carried posteriorly, there was a consistent increase in cervical extension together with trunk forward lean (Table 5.1) for all loading conditions. The trunk forward lean was thought to be the active postural response required to counterbalance the posterior shift of the combined CG of the body and the backpack weight. As the subjects were required to maintain a fixed gazing angle, an active cervical extension was therefore required. The same pattern of postural response was also demonstrated by Chow et al. (2007) who studied the effects of backpack weight on spine curvature with the backpack CG positioned at T12 using reflective markers affixed to the subjects' spine. The results of the current study concurred with these findings and further demonstrated that the same pattern of postural response was adopted when the backpack CG was positioned either at T7 or L3.

Biomechanically, a posteriorly carried load should be actively counterbalanced by active flexion of the trunk which should be achieved by the contraction of anterior trunk muscles (Devroey et al., 2007; Motmans et al., 2006). Accordingly, the whole spine should flex forward actively. However, this was not true from the results of the current study. From the results, it was consistently observed that the lumbar spine flexed and the cervical spine extended for all the loaded conditions.

As discussed above, cervical extension was required so that the subjects could maintain the gazing angle and lumbar flexion was required for shifting the combined body/backpack CG forward. This combined lumbar flexion and cervical extension resulted in a turning region at the thoracic region. Thus, the thoracic spine could either flex or extend depending on the balance between the demands of maintaining the gazing angle or the body equilibrium. Other factors should also be considered in studying the change of spine curvature in the thoracic spine. From the study by Hong et al. (2007), it was shown that there were increased muscle activities in the upper and lower trapezius during posterior backpack carriage. Thoracic spine motion is however relatively little due to the presence of the rib cage and it is also undergoing tidal motion due to breathing. All these factors may explain why the spine curvature change in the thoracic region was inconsistent and not significant as well as the repositioning error of the thoracic region was not significantly affected by the backpack loads.

From the results, it was interesting to observe that the trunk forward lean was accompanied by a pelvic backward tilt for low backpack weight (<20%BW) and a pelvic forward tilt for heavy backward weight (20%BW). Although these postural changes were not statistically significant, it was thought that the change from pelvic backward tilt to forward tilt suggested that pelvic active flexion was activated at heavy backpack load.

The results of the current study also showed that the repositioning error (RE) of the lower lumbar spine and pelvis increased significantly for backpack weighed 10% and 15%BW and the repositioning error of the upper lumbar spine also increased significantly for backpack weight of 20%BW. This finding concurred with those reported by Chow et al. (2007) who investigated the effects of load carriage on spine repositioning ability with backpack CG located only at T12. In the current study, we further demonstrated that the change of repositioning ability at the lumbar spine with increased backpack weight also happened when the backpack CG was positioned at L3. However, this pattern was not apparent when the backpack CG was located at T7. The trunk forward lean due to posterior backpack carriages was found to be mainly contributed by lumbar flexion. The changes of lumbar flexion for backpack CG positioned at different spine levels were slightly different. When the backpack CG was positioned at T12, the upper lumbar spine flexed and became significant when the load was heavier than 15%BW whereas the lower lumbar spine also flexed but became not significant when the load was heavier than 15%BW. When the backpack CG was positioned at L3, there was a significantly increase in upper lumbar flexion for all loaded conditions. However, the increased lower lumbar flexion became not significant when the load was heavier than 15%BW. When the backpack CG was positioned at T7, there was a significantly increase in upper lumbar flexion for all loaded conditions. However, the lower lumbar spine changed from flexion to extension when the load was heavier than 15%BW although the amount of extension was not significantly different from the no load condition.

From these findings, it could be concluded that lumbar flexion was the principle postural response for maintaining body equilibrium for posterior carriage. When the backpack weight was heavier than 15%BW, active pelvic forward tilt was activated to keep the body balance. Cervical extension was required in posterior carriage for maintaining the eye gazing. There was a turning region at the thoracic region in posterior carriage. A shift of increased repositioning error up the lumbar spine with increased backpack load might be an indication of the increased demand on postural control with load. As there was a reported association between heavy backpack with back and neck pain in school children (Taimela et al., 1997; Troussier et al., 1994; Viry et al., 1999), implications of the observed postural responses and decreased repositioning error at these region deserved further attention. The possibility of using the postural changes at cervical and lumbar spines and the changes in repositioning error at the lumbar region as indicators for evaluating different backpack designs should also be explored. The effects of backpack CG location were not clear for posterior carriage.

5.2.2 Postural response during anterior carriage

When the backpack was carried anteriorly, the postural changes of spine were different from those observed during posterior carriage conditions (Table 5.1). The postural changes of the spine were found to be different among different backpack weights and CG positions.

When the carried weight was 10%BW with CG positioned at L3, all spinal levels below T7 extended (but not significantly different from the no load condition) with only the upper thoracic spine flexed significantly to counterbalance the anteriorly carried load. The cervical spine also flexed but not statistically significant. The repositioning errors of all spinal levels were not significantly affected except those of the cervical region. Biomechanically, the extension of all spinal levels below T7 as well as pelvic posterior tilt would bring the body/backpack CG backward so as to maintain the body equilibrium. The flexion of the upper thoracic spine and cervical spine was thought to be due to the intention to maintain the gazing angle. This postural pattern agreed well with the electromyography study by Motmans et al. (2006) that contraction of back muscles was required to balance the anteriorly carried weight. When the 10%BW backpack CG was positioned at T12, the spinal levels below L3 flexed but the changes were not significantly different from the no load condition. When the 10%BW backpack CG was further shifted up to T7, significant increases in pelvic backward tilt, upper lumbar extension and upper thoracic flexion were observed. These findings suggested that there were increased intersegmental deformations along the spine as there were more regional changes in spine curvature (i.e. more regions along the spine changed from flexion to extension and from extension to flexion). Intersegmental deformations represent potential stress concentration. Thus, if 10%BW backpack was carried, its CG was preferred to be positioned at L3 other than high backpack CG conditions as it resulted in less postural changes to the spine.

When the weight of anterior carriage was 15%BW, a consistent pelvic extension was observed to balance the front load. The repositioning errors of all spinal levels were also not significantly affected except those of the cervical region and that of the pelvic region when the load CG was positioned at L3. The head was found to extend to compensate the anterior load although the changes with CG located at T12 and L3 were not statistically significant. These findings suggested that the anterior load was mainly balanced by active hip extension (i.e. pelvic backward tilt) to shift the whole body/backpack CG backwards. However, it seems that this hip extension would result in an “over-correction” of the whole spinal posture and the body equilibrium was further balanced by flexion of the upper thoracic spine. However, in order to maintain the gazing angle, an extension of the cervical spine was required. Maintaining the gazing angle horizontally is a natural posture and more in line with the practicality of walking with a backpack. Although the spine curvature changes were relatively similar for load CG positioned at different levels, it seems the position of the CG was not preferred to be positioned at T12 as it would result in more postural changes with more regional changes in spine curvature. It was not conclusive whether the load should be positioned at T7 or L3 as either it would result in more postural changes or more regional changes in spine curvature. Perhaps, this also explained why some studies found low CG was preferred to the high CG placement and vice versa (Devroey et al., 2007; Grimmer et al., 2002).

When the backpack weight was 20%BW, it was interesting to find that the only significant increase in upper thoracic flexion was observed when the backpack CG was positioned at T7 or T12 and the only significant increase in cervical extension was found when the backpack CG was positioned at L3. Moreover, the repositioning errors of all spine regions studied were not significantly affected except that of the upper lumbar region for backpack CG positioned at T12. It might be hypothesized that the strategy in balancing 20%BW anterior carriage was different from those adopted in 10%BW and 15%BW carriages. Due to increased demand in balancing the heavy carriage (20%BW), a higher activation of trunk muscles including the deep trunk muscles was required so as to maintain the body equilibrium. The spine under this “heavily” loaded condition had relatively less flexibility to adopt different postures in maintaining body equilibrium. Thus, the repositioning errors of all spinal levels were “improved”.

From the results, it could be summarized that the upper thoracic kyphosis increased passively in response to the anterior load. With the increase of load from 10%BW to 15%BW, the pelvic was triggered to tilt posteriorly to maintain the body balance. Low CG location (T12 and L3) was shown to induce less postural changes in 10%BW and 15%BW carriages when comparing to the high CG location (T7). In 15%BW carriages, it was also found that the spine levels above the backpack CG location extended to counterbalance the front load. Interestingly, 20%BW carriages may result in a different strategy in balancing the front load, where more muscle co-contraction was hypothesized to be involved in balancing the heavy load. Thus the intersegmental loads are totally to be greater.

5.3 Comparison between Anterior and Posterior Carriages

The anterior and posterior carriages were demonstrated to affect different spine regions and induced curvature compensation at these regions. It was also reported that the stress and strain distribution could be affected by the curvature changes at the intervertebral discs (Cripton, Jain, Wittenberg, & Nolte, 2000). As the spine in the sagittal plane could be regarded as a linear chain linking the head to the pelvis (Berthonnaud, Dimnet, Roussouly, & Labelle, 2005), the orientations between spine segments are closely related and have influence on the adjacent segment (Marras & Mirka, 1993). In addition, the higher muscle activation caused by anterior and posterior carriages (Anderson et al., 2007; Devroey et al., 2007; Motmans et al., 2006) makes the pressure at the intervertebral disc even larger. Therefore, the spine segments which were identified to respond to the external load may be in high risk of injury which may subsequently result in possible spinal disorders. It seems that anterior carrying method does not offer any apparent benefit to the spine as it was shown to result in more postural changes in spine curvature. As the magnitude of flexion moment induced by an anteriorly carried load to the spine is much higher than the magnitude of extension moment induced by a posteriorly carried load of equal magnitude. The postural changes observed in the current study may not support the load to be carried anteriorly. If the load has to be carried anteriorly, the CG of the location seems to be better positioned at a lower level. Option for distributing the load both anteriorly and posteriorly may be considered for further investigation. As the postural changes observed in the current study representing the immediately changes when the load was applied, the postural changes over time were not known. Further study should put focus on the effects on load carriage over time and so the effects of fatigue could be considered.

Therefore, from the results of the current study, different locations of backpack CG were found to result in different changes in spinal curvature and repositioning consistency. The changes were mainly affected by the anteroposterior position of the backpack rather than the vertical CG level. It is recommended that the load is carried alternatively between anterior and posterior positions so as to prevent a prolonged loading stress at the joint for an adopted posture. However, the findings of the current study did not show any added information for the safe limit of backpack weight for children.

5.4 Repositioning Ability

The poor repositioning ability induced by both anterior and posterior carriages were mainly demonstrated at cervical, lumbar spine and pelvis in posterior carriage conditions, as well as at cervical spine in anterior carriage conditions (Table 5.1). These spine segments are subjected to greater variations in stress and strain during backpack carriage because of the increased variability of spine posture. It is more difficult for an individual to maintain the natural spine posture in the different loading conditions. In addition, a number of studies have reported a significant decreased repositioning performance in the low back pain group (Brumagne et al., 2000; Newcomer, Laskowski, Yu, Johnson, & An, 2001; O'Sullivan et al., 2003). We may therefore hypothesize that the load carriages may result in a high demand by affecting the position sense on the spine and may be a potential risk factor on back diseases. The clinical evaluation of the effects of load carriage in relation to the chance of increase in back problems should be further investigated.

5.5 Limitations and Recommendations

Originally, the study intended to investigate the effects of gender (M/F), age (11 or 15 years old), backpack weight (10, 15 & 20%) and backpack centre of gravity (CG) location (Anterior/Posterior carriage with CG located at T7, T12 or L3) on the children's spine. Twelve groups of subjects were required with the backpack CG location as the within-subject factor. The sample size estimated based on the findings from a previous study by Leung (2005) with power and level of significance set at 0.8 and 0.05, respectively, was 30 subjects for each group. However, due to the difficulty encountered in recruiting the subjects, only 63 schoolchildren successfully completed the experiment during the study period. As the number of samples in each group was small, the data from different genders and ages were pooled for data analysis. Thus, the conclusion of the current study should be interpreted with caution as the variability due to the effects of gender and age was not considered. Further study should be conducted in a larger population to investigate the effects of these two factors on the spine performance in loading conditions. Block design with subjects of matched age and gender is also proposed for future study.

Moreover, due to the difficulty encountered in recruiting the subjects, the participants were firstly allocated to the 15%BW group as this was the recommended backpack weight limit. When more subjects were recruited, they were then allocated to the other groups. The sample sizes in the three backpack weight groups, thus, were not evenly distributed. In addition, the sequence of testing conditions with different backpack CG locations was randomized so as to minimize possible carry-over effects due to repetitive testing.

An electrogoniometric system was used in this study to quantify spine curvature changes under different backpack carriage conditions without exposure of the participant's back. However, the tactile effects due to the attachment of the sensors to the participant's back might affect the quantification of repositioning ability of the subject. Moreover, there were occasions that sensors were detached during the experiment. Sensor attachment should be regularly checked.

The backpack CG could be adjusted vertically in this study. In the horizontal direction, the distance between the backpack CG and spine was fixed to be around 5cm. Although the horizontal CG location should be close to subject's back to minimize the moment arm acted on the spine, further study should focus on the relationship between the horizontal CG location and the spine curvature changes.

In the current study, the spine curvature was measured in terms of intersegmental angles which captured the immediate effect of backpack on spine performance. Further investigations on the long term effect of the backpack weight and backpack CG location should be conducted.

In this study, the backpack was not specially designed for anterior carriage and may contribute to a source of error. Moreover, the changes observed in the current study denoted the instantaneous response of the participants. The possible adaptive changes due to prolonged carriage should be noted in future study.

In addition, it is recommended that clear instructions should be given to the subjects and a video demonstration of the experimental procedures prior to the experiment would be helpful. A seminar is also recommended to share the findings of the study with the participants as well as their parents would be helpful in future subject recruitment.

CHAPTER 6 CONCLUSION

An electrogoniometric system was developed to measure the spine curvature and repositioning accuracy along the sagittal plane. This system was demonstrated to be accurate and reliable, and also could be used for evaluating commercially available backpacks without exposure the participant's back.

Both spine curvature and repositioning ability were found to be affected by load carriage. The changes were different between anterior and posterior carriages.

For posterior carriages, cervical extension and lumbar flexion were shown to be the postural response adopted for balancing the carried load and there was a turning region at the thoracic spine which was suggested to be resulted by balancing the demands for maintaining both eye gazing angle and body equilibrium. When the backpack weight was heavier than 15%BW, active pelvic forward tilt was found to be activated to keep the body balance. The effects of backpack CG location on spine curvature were not apparent.

For anterior carriages, the changes of spine curvature and repositioning ability were found to be affected by both backpack weights and CG positions. Increase in upper thoracic kyphosis was observed in response to all anterior loads. A lower CG location (T12 and L3) was shown to induce less postural changes in 10%BW and 15%BW carriages when comparing to the high CG location (T7). When the backpack weight increased from 10% to 15%BW, pelvic posterior tilt was triggered to maintain the body balance. With the weight increased to 20%BW, a different strategy was observed to balance the anterior load, where more muscle co-contraction was hypothesized to be involved in balancing the heavy load.

Anterior carrying method was found to have no apparent benefit to the spine when comparing to posterior load carriage as it was shown to result in more postural changes in spine curvature. However, the lower CG location seems to be better when the load has to be carried anteriorly.

Furthermore, as the postural changes observed in the current study represented the immediate effects of external load, the postural changes over time remains unknown. Further study should consider the long term effects of the load carriage, as well as the effects of fatigue due to the backpack carriage.

Poor repositioning ability was shown in both anterior and posterior carriages at different spine levels. It may be hypothesized that the load carriages may result in a high demand by affecting the position sense of the spine and may be a potential risk factor for back injury. A deeper understanding of the clinical implication of the reduction in repositioning ability due to load carriages may provide insight whether this is related to the observed increased back pain in adolescents.

REFERENCES

Allison, G. T., & Fukushima, S. (2003). Estimating three-dimensional spinal repositioning error: the impact of range, posture, and number of trials. *Spine, 28*(22), 2510-2516.

American Academy of Pediatrics. (2007). Backpack safety. http://www.aap.org/advocacy/backpack_safety.pdf Retrieved Mar 15, 2007

Anderson, A. M., Meador, K. A., McClure, L. R., Makrozahopoulos, D., Brooks, D. J., & Mirka, G. A. (2007). A biomechanical analysis of anterior load carriage. *Ergonomics, 50*(12), 2104-2117.

Ashton-Miller, J. A., McGlashen, K. M., & Schultz, A. B. (1992). Trunk positioning accuracy in children 7-18 years old. *Journal of Orthopaedic Research, 10*(2), 217-225.

Ashton-Miller, J. A., Wojtys, E. M., Huston, L. J., & Fry-Welch, D. (2001). Can proprioception really be improved by exercises? *Knee Surg Sports Traumatol Arthrosc, 9*(3), 128-136.

Balague, F., Nordin, M., Skovron, M. L., Dutoit, G., Yee, A., & Waldburger, M. (1994). Non-specific low-back pain among schoolchildren: a field survey with analysis of some associated factors. *Journal of Spinal Disorders, 7*(5), 374-379.

Balague, F., Skovron, M. L., Nordin, M., Dutoit, G., Pol, L. R., & Waldburger, M. (1995). Low back pain in schoolchildren. A study of familial and psychological factors. *Spine, 20*(11), 1265-1270.

Barrack, R. L., Skinner, H. B., & Cook, S. D. (1984). Proprioception of the Knee-Joint - Paradoxical Effect of Training. *American Journal of Physical Medicine & Rehabilitation, 63*(4), 175-181.

Barrack, R. L., Skinner, H. B., Cook, S. D., & Haddad, R. J. (1983). Effect of Articular Disease and Total Knee Arthroplasty on Knee-Joint Position Sense. *Journal of Neurophysiology, 50*(3), 684-687.

Bergmark, A. (1989). Stability of the Lumbar Spine - a Study in Mechanical Engineering. *Acta Orthopaedica Scandinavica, 60,* 3-54.

Berthonnaud, E., Dimnet, J., Roussouly, P., & Labelle, H. (2005). Analysis of the sagittal balance of the spine and pelvis using shape and orientation parameters. *Journal of Spinal Disorders & Techniques, 18*(1), 40-47.

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.

Bouet, V., & Gahery, Y. (2000). Muscular exercise improves knee position sense in humans. *Neuroscience Letters, 289*(2), 143-146.

Brackley, H. M., & Stevenson, J. M. (2004). Are children's backpack weight limits enough? A critical review of the relevant literature. *Spine, 29*(19), 2184-2190.

Brumagne, S., Cordo, P., Lysens, R., Verschueren, S., & Swinnen, S. (2000). The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. *Spine, 25*(8), 989-994.

Brumagne, S., Lysens, R., & Spaepen, A. (1999a). Lumbosacral position sense during pelvic tilting in men and women without low back pain: test development and reliability assessment. *Journal of Orthopaedic & Sports Physical Therapy, 29*(6), 345-351.

Brumagne, S., Lysens, R., & Spaepen, A. (1999b). Lumbosacral repositioning accuracy in standing posture: a combined electrogoniometric and videographic evaluation. *Clinical Biomechanics (Bristol, Avon), 14*(5), 361-363.

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

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.

Cholewicki, J., & McGill, S. M. (1992). Lumbar posterior ligament involvement during extremely heavy lifts estimated from fluoroscopic measurements. *Journal of Biomechanics, 25*(1), 17-28.

Cholewicki, J., & McGill, S. M. (1996). Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain. *Clinical Biomechanics, 11*(1), 1-15.

Chow, D. H., Kwok, M. L., Au-Yang, A. C., Holmes, A. D., Cheng, J. C., Yao, F. Y., et al. (2005). The effect of backpack load on the gait of normal adolescent girls. *Ergonomics, 48*(6), 642-656.

Chow, D. H., Kwok, M. L., Cheng, J. C., Lao, M. L., Holmes, A. D., Au-Yang, A., et al. (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., Leung, K. T., & Holmes, A. D. (2007). Changes in spinal curvature and proprioception of schoolboys carrying different weights of backpack. *Ergonomics*, 1-9.

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, 30*(21), E649-654.

Coste, J., Paolaggi, J. B., & Spira, A. (1992). Classification of nonspecific low back pain. I. Psychological involvement in low back pain. A clinical, descriptive approach. *Spine*, *17*(9), 1028-1037.

Cottalorda, J., Rahmani, A., Diop, M., Gautheron, V., Ebermeyer, E., & Belli, A. (2003). Influence of school bag carrying on gait kinetics. *Journal of Pediatric Orthopaedics Part B, 12*(6), 357-364.

Cripton, P. A., Jain, G. M., Wittenberg, R. H., & Nolte, L. P. (2000). Load-sharing characteristics of stabilized lumbar spine segments. *Spine, 25*(2), 170-179.

Cypress, B. K. (1983). Characteristics of physician visits for back symptoms: a national perspective. *American Journal of Public Health, 73*(4), 389-395.

Datta, S. R., & Ramanathan, N. L. (1971). Ergonomic comparison of seven modes of carrying loads on the horizontal plane. *Ergonomics*, *14*(2), 269-278.

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.

Feipel, V., Parent, C., Dugailly, P. M., Brassinne, E., Salvia, P., & Rooze, M. (2003). Development of kinematics tests for the evaluation of lumbar proprioception and equilibration. *Clinical Biomechanics (Bristol, Avon), 18*(7), 612-618.

Filaire, M., Vacheron, J. J., Vanneuville, G., Poumarat, G., Garcier, J. M., Harouna, Y., et al. (2001). Influence of the mode of load carriage on the static posture of the pelvic girdle and the thoracic and lumbar spine in vivo. *Surgical and Radiologic Anatomy, 23*(1), 27-31.

Forjuoh, S. N., Lane, B. L., & Schuchmann, J. A. (2003). Percentage of body weight carried by students in their school backpacks. *American Journal of Physical Medicine & Rehabilitation, 82*(4), 261-266.

Forwell, L. A., & Carnahan, H. (1996). Proprioception during manual aiming in individuals with shoulder instability and controls. *Journal of Orthopaedic & Sports Physical Therapy, 23*(2), 111-119.

Gard, S. A., Miff, S. C., & Kuo, A. D. (2004). Comparison of kinematic and kinetic methods for computing the vertical motion of the body center of mass during walking. *Human Movement Science, 22*(6), 597-610.

Gill, K. P., & Callaghan, M. J. (1998). The measurement of lumbar proprioception in individuals with and without low back pain. *Spine, 23*(3), 371-377.

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

Goodgold, S., Mohr, K., Samant, A., Parke, T., Burns, T., & Gardner, L. (2002). Effects of backpack load and task demand on trunk forward lean: Pilot findings on two boys. *Work, 18*(3), 213-220.

Grigg, P., Finerman, G. A., & Riley, L. H. (1973). Joint-Position Sense after Total Hip-Replacement. *Journal of Bone and Joint Surgery-American Volume, 55*(5), 1016-1025.

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*, 10.

Grimmer, K., & Williams, M. (2000). Gender-age environmental associates of adolescent low back pain. *Applied Ergonomics, 31*(4), 343-360.

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

Hall, L. A., & Mccloskey, D. I. (1983). Detections of Movements Imposed on Finger, Elbow and Shoulder Joints. *Journal of Physiology-London, 335*(Feb), 519-533.

Harreby, M., Kjer, J., Hesselsoe, G., & Neergaard, K. (1996). Epidemiological aspects and risk factors for low back pain in 38-year-old men and women: a 25-year prospective cohort study of 640 school children. *European Spine Journal, 5*(5), 312-318.

Harreby, M., Neergaard, K., Hesselsoe, G., & Kjer, J. (1995). Are radiologic changes in the thoracic and lumbar spine of adolescents risk factors for low back pain in adults? A 25-year prospective cohort study of 640 school children. *Spine, 20*(21), 2298-2302.

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., & 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. (2007). Effect of prolonged walking with backpack loads on trunk muscle activity and fatigue in children. *Journal*. doi:10.1016/j.jelekin.2007.06.013

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.

Howe, S., & Getchell, D. (1995). Packing it in. *Backpacker*(23), 21-29.

Jakobs, T., Miller, J. A., & Schultz, A. B. (1985). Trunk position sense in the frontal plane. *Experimental Neurology, 90*(1), 129-138.

Kimura, S., Steinbach, G. C., Watenpaugh, D. E., & Hargens, A. R. (2001). Lumbar spine disc height and curvature responses to an axial load generated by a compression device compatible with magnetic resonance imaging. *Spine, 26*(23), 2596-2600.

Kokmen, E., Bossemeyer, R. W., & Williams, W. J. (1977). Quantitation of Motion Perception in Digits - Psychophysical Study in Normal Human Subjects. *Annals of Neurology, 2*(4), 279-284.

Kokmen, E., Bossemeyer, R. W., & Williams, W. J. (1978). Quantitative-Evaluation of Joint Motion Sensation in an Aging Population. *Journals of Gerontology, 33*(1), 62-67.

Korovessis, P., Koureas, G., & Papazisis, Z. (2004). Correlation between backpack weight and way of carrying, sagittal and frontal spinal curvatures, athletic activity, and dorsal and low back pain in schoolchildren and adolescents. *Journal of Spinal Disorders & Techniques, 17*(1), 33-40.

Korovessis, P., Koureas, G., Zacharatos, S., & Papazisis, Z. (2005). Backpacks, back pain, sagittal spinal curves and trunk alignment in adolescents: a logistic and multinomial logistic analysis. *Spine, 30*(2), 247-255.

Koumantakis, G. A., Winstanley, J., & Oldham, J. A. (2002). Thoracolumbar proprioception in individuals with and without low back pain: intratester reliability, clinical applicability, and validity. *Journal of Orthopaedic & Sports Physical Therapy, 32*(7), 327-335.

Kristjansdottir, G. (1996). Prevalence of self-reported back pain in school children: a study of sociodemographic differences. *European Journal of Pediatric, 155*(11), 984-986.

Kujala, U. M., Taimela, S., Erkintalo, M., Salminen, J. J., & Kaprio, J. (1996). Low-back pain in adolescent athletes. *Medicine & Science in Sports & Exercise, 28*(2), 165-170.

Lai, J. P., & Jones, A. Y. (2001). The effect of shoulder-girdle loading by a school bag on lung volumes in Chinese primary school children. *Early Human Development, 62*(1), 79-86.

Lam, S. S., Jull, G., & Treleaven, J. (1999). Lumbar spine kinesthesia in patients with low back pain. *Journal of Orthopaedic & Sports Physical Therapy, 29*(5), 294-299.

Legg, S. J. (1985). Comparison of different methods of load carriage. *Ergonomics, 28*(1), 197-212.

Leinonen, V., Kankaanpaa, M., Luukkonen, M., Kansanen, M., Hanninen, O., Airaksinen, O., et al. (2003). Lumbar paraspinal muscle function, perception of lumbar position, and postural control in disc herniation-related back pain. *Spine, 28*(8), 842-848.

Leung, K. T. (2005). *The effect of different backpack loads on spinal curvature in adolescent.* The Hong Kong Polytechnic University, Hong Kong.

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 Applied Physiology, 90*(1-2), 35-43.

Lonn, J., Crenshaw, A. G., Djupsjobacka, M., Pedersen, J., & Johansson, H. (2000). Position sense testing: influence of starting position and type of displacement. *Archives of Physical Medicine and Rehabilitation, 81*(5), 592-597.

Mackenzie, W. G., Sampath, J. S., Kruse, R. W., & Sheir-Neiss, G. J. (2003). Backpacks in children. *Clinical Orthopaedics and Related Research, 409*, 78-84.

Maffey-Ward, L., Jull, G., & Wellington, L. (1996). Toward a clinical test of lumbar spine kinesthesia. *J Orthop Sports Phys Ther, 24*(6), 354-358.

Marks, R., Quinney, H. A., & Wessel, J. (1993). Proprioceptive Sensibility in Women with Normal and Osteoarthritic Knee Joints. *Clinical Rheumatology, 12*(2), 170-175.

Marras, W. S., & Mirka, G. A. (1993). Electromyographic Studies of the Lumbar Trunk Musculature during the Generation of Low-Level Trunk Acceleration. *Journal of Orthopaedic Research, 11*(6), 811-817.

Mikkelsson, M., Salminen, J. J., Sourander, A., & Kautiainen, H. (1998). Contributing factors to the persistence of musculoskeletal pain in preadolescents: a prospective 1-year follow-up study. *Pain, 77*(1), 67-72.

Motmans, R. R., Tomlow, S., & Vissers, D. (2006). Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics, 49*(2), 127-138.

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.

Newcomer, K., Laskowski, E. R., Yu, B., Johnson, J. C., & An, K. N. (2000). Differences in repositioning error among patients with low back pain compared with control subjects. *Spine, 25*(19), 2488-2493.

Newcomer, K., Laskowski, E. R., Yu, B., Johnson, J. C., & An, K. N. (2001). The effects of a lumbar support on repositioning error in subjects with low back pain. *Archives of Physical Medicine and Rehabilitation, 82*(7), 906-910.

Newcomer, K., Laskowski, E. R., Yu, B., Larson, D. R., & An, K. N. (2000). Repositioning error in low back pain. Comparing trunk repositioning error in subjects with chronic low back pain and control subjects. *Spine*, *25*(2), 245-250.

Newcomer, K., & Sinaki, M. (1996). Low back pain and its relationship to back strength and physical activity in children. *Acta Paediatrica, 85*(12), 1433-1439.

O'Sullivan, P. B., Burnett, A., Floyd, A. N., Gadsdon, K., Logiudice, J., Miller, D., et al. (2003). Lumbar repositioning deficit in a specific low back pain population. *Spine, 28*(10), 1074-1079.

Obuset, J. P., Harman, E. A., Frykman, P. N., Palmer, C. J., & Billis, R. K. (1997). The relationship of backpack center of mass location to the metabolic cost of load carriage. *Medicine and Science in Sports and Exercise, 29*, S205.

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

Parkhurst, T. M., & Burnett, C. N. (1994). Injury and proprioception in the lower back. *Journal of Orthopaedic & Sports Physical Therapy, 19*(5), 282-295.

Pascoe, D. D., Pascoe, D. E., Wang, Y. T., Shim, D. M., & Kim, C. K. (1997). Influence of carrying book bags on gait cycle and posture of youths. *Ergonomics, 40*(6), 631-641.

Pearcy, M. (1986). Measurement of Back and Spinal Mobility. *Clinical Biomechanics, 1*(1), 44-51.

Pearcy, M. J., Gill, J. M., Whittle, M. W., & Johnson, G. R. (1987). Dynamic back movement measured using a three-dimensional television system. *Journal of Biomechanics, 20*(10), 943-949.

Portney, L. G., & Watkins, M. P. (2000). *Foundations of Clinical Research: Applications to Practice* (2nd ed.). Upper Saddle River, NJ: Prentice Hall Health.

Preuss, R., Grenier, S., & McGill, S. (2003). The effect of test position on lumbar spine position sense. *Journal of Orthopaedic & Sports Physical Therapy, 33*(2), 73-78.

Reid, S. A., Stevenson, J. M., & Whiteside, R. A. (2004). Biomechanical assessment of lateral stiffness elements in the suspension system of a backpack. *Ergonomics, 47*(12), 1272-1281.

Revel, M., Andre-Deshays, C., & Minguet, M. (1991). Cervicocephalic kinesthetic sensibility in patients with cervical pain. *Archives of Physical Medicine and Rehabilitation, 72*(5), 288-291.

Revel, M., Minguet, M., Gregoy, P., Vaillant, J., & Manuel, J. L. (1994). Changes in cervicocephalic kinesthesia after a proprioceptive rehabilitation program in patients with neck pain: a randomized controlled study. *Archives of Physical Medicine and Rehabilitation, 75*(8), 895-899.

Rome, L. C., Flynn, L., & Yoo, T. D. (2006). Biomechanics: rubber bands reduce the cost of carrying loads. *Nature, 444*(7122), 1023-1024.

Sahlstrand, T., Ortengren, R., & Nachemson, A. (1978). Postural equilibrium in adolescent idiopathic scoliosis. *Acta Orthopaedica Scandinavica, 49*(4), 354-365.

Schmidt, R. A. (2005). *Motor control and learning: a behavioral emphasis* (4th ed.). Champaign, Ill: Human Kinetics.

Sheir-Neiss, G. I., Kruse, R. W., Rahman, T., Jacobson, L. P., & Pelli, J. A. (2003). The association of backpack use and back pain in adolescents. *Spine, 28*(9), 922-930.

Sherrington, C. S. (1947). *The Integrative Action of the Nervous System*: New Haven: Yale University Press.

Silfies, S. P., Cholewicki, J., & Radebold, A. (2003). The effects of visual input on postural control of the lumbar spine in unstable sitting. *Human Movement Science, 22*(3), 237-252.

Skinner, H. B., Wyatt, M. P., Hodgdon, J. A., Conard, D. W., & Barrack, R. L. (1986). Effect of Fatigue on Joint Position Sense of the Knee. *Journal of Orthopaedic Research, 4*(1), 112-118.

Smith, I. K. (2001). Some schooling on backpacks. *Time, 158*(10), 89.

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.

Swinkels, A., & Dolan, P. (1998). Regional assessment of joint position sense in the spine. *Spine, 23*(5), 590-597.

Taimela, S., Kankaanpaa, M., & Luoto, S. (1999). The effect of lumbar fatigue on the ability to sense a change in lumbar position. A controlled study. *Spine, 24*(13), 1322-1327.

Taimela, S., Kujala, U. M., Salminen, J. J., & Viljanen, T. (1997). The prevalence of low back pain among children and adolescents. A nationwide, cohort-based questionnaire survey in Finland. *Spine, 22*(10), 1132-1136.

Taylor, J. L., & McCloskey, D. I. (1988). Proprioception in the neck. *Experimental Brain Research, 70*(2), 351-360.

Taylor, J. L., & McCloskey, D. I. (1990). Proprioceptive sensation in rotation of the trunk. *Experimental Brain Research, 81*(2), 413-416.

Troussier, B., Davoine, P., De Gaudemaris, R., Fauconnier, J., & Phelip, X. (1994). Back pain in school children. A study among 1178 pupils. *Scandinavian Journal of Rehabilitation Medicine, 26*(3), 143-146.

Viry, P., Creveuil, C., & Marcelli, C. (1999). Nonspecific back pain in children. A search for associated factors in 14-year-old schoolchildren. *Revue du Rhumatisme (English Ed.), 66*(7-9), 381-388.

Walker, B. F. (2000). The prevalence of low back pain: a systematic review of the literature from 1966 to 1998. *Journal of Spinal Disorders, 13*(3), 205-217.

Wang, C. X. G., Chow, D. H. K., & Pope, M. H. (2007). *Biomechanical effect of load carriage on spine curvature and repositioning ability in adolescents*. Paper presented at the Proceedings of the Fifth Iasted International Conference on Biomechanics.

Weitz, E. M. (1981). The Lateral Bending Sign. *Spine, 6*(4), 388-397.

White, L. J., Frasure, H. E., White, P., White, B., & White, M. J. (2000). Weight of backpacks carried by elementary school children: students or sherpas? *Academic Emergency Medicine, 7*(10), 1168.

Whittfield, J. K., Legg, S. J., & Hedderley, D. I. (2001). The weight and use of schoolbags in New Zealand secondary schools. *Ergonomics, 44*(9), 819-824.

Wilder, D. G., Aleksiev, A. R., Magnusson, M. L., Pope, M. H., Spratt, K. F., & Goel, V. K. (1996). Muscular response to sudden load - A tool to evaluate fatigue and rehabilitation. *Spine, 21*(22), 2628-2639.

Wilson, S. E., & Granata, K. P. (2003). Reposition sense of lumbar curvature with flexed and asymmetric lifting postures. *Spine*, *28*(5), 513-518.

Winter, D. A. (2005). *Biomechanics and motor control of human movement* (3rd ed.). Hoboken, N.J.: John Wiley & Sons.

APPENDICES

Appendix 1 Consent Form

研究資料和同意書

研究題目：背囊重量對脊柱的生物力學影響

研究員

周鴻奇教授，Prof. Daniel Chow
香港理工大學醫療科技及資訊學系　電話：2766
王新光先生，Mr. Chris Wang
香港理工大學醫療科技及資訊學系　電話：2766

研究目的

到目前為止，青少年多揹著背囊式書包上學。究竟這種方式對青少年的健康會否構成不良影響尚未清楚，不過很多研究發現，過重的書包和錯誤的配戴方法都會對青少年的健康有不良的影響。這項研究目的在於測試書包重量和不同位置對脊椎的影響以及與腰背痛的關係，從而對書包的設計給予建議，以達到避免學童脊椎受損及可能引致的腰背痛。

程序

若您的孩子是本研究的自願參加者，您將需要簽署研究同意書表明您已聽取及明白研究人員對此調查的介紹及解釋。

您的孩子需要

1. 提供姓名、年齡、性別、高度和重量的資料。高度和體重分別用捲尺和電子體重計量度。
2. 提供有關背部疼痛、脊椎損傷和變形、肩膀痛、頸痛和肩傷的病歷。
3. 提供有關於日常使用書包的情況。
4. 在進行研究時可選擇穿著游泳衣或已預備的衣服，及可選擇額外多穿一件醫院袍。
5. 展露脊背作觀察及用雙面膠紙貼上六個感應器進行脊椎角度數據收集, 感應器分別置於枕骨，頸椎第七節，胸椎第七和十二節，腰椎第三節及薦骨第一節。

6. 舒適地站立在一對腳印上，保持頭部向前，眼望向距離兩米成水平位置的記號，雙手放鬆置於身體兩旁，保持這姿勢五秒以進行脊椎角度數據收集，重復六次以確定其姿勢的穩定性。
7. 於三個負重測試狀況下重複進行脊椎角度數據收集，三個負重測試包括：不用背負書包站立，另背負書包達體重 10%，15% 或 20% 及重心分別置於：胸椎第七節, 胸椎第十二節及腰椎第三節。每個負重測試狀況下重復站立動作。每次站立姿勢保持三秒以進行脊椎角度數據收集。每個動作重復六次以確定其姿勢的穩定性。整個測試所需時間不超過兩小時。每次進行脊椎角度數據收集相隔不超過半分鐘，每完成一個負重測試狀況，可休息三至五分鐘以防止肌肉疲勞，直至測試狀況完成。

潛在風險與不適

您的孩子於完成測試後可能出現輕微肌肉疲勞現象，另於貼上感應器後，亦可能引至輕微皮膚不適。

保密

您的孩子不會被顯露其身份的資料，所有資料將作研究分析之用。研究結果將公開發佈，但個人資料及身份將保密。所有資料均會被香港理工大學擁有。

受傷條款

這項研究已獲批准進行，不過如果參與者或其家長對實驗程序有任何疑問，可直接書面向香港理工大學研究倫理委員會查詢。

拒絕或退出研究

您的孩子參與本研究屬自願性質，您或您的孩子可隨時拒絕或退出本研究，將沒有任何懲罰或後果。

查詢有關研究資料

如果您對本研究仍有疑問或想進一步取得更多資料，可與王新光先生(電話 2766) 或周鴻奇教授(電話 2766)聯絡。

家長簽名：____________________ 日期:____________________

孩子姓名：____________________

孩子簽名：____________________ 見證人簽名：____________________

Research Project Informed Consent Form

Project Title: Biomechanical Effects of Load Carriage on Spine Curvature and Proprioception

Investigator:

Prof. Daniel H. K. Chow (Tel: 2766)
Department of Health Technology and Informatics
The Hong Kong Polytechnic University

Student:

Mr. Chris X. G. Wang (Tel: 2766)
Department of Health Technology and Informatics
The Hong Kong Polytechnic University

Objectives:

Low back pain is a common problem affecting people. At least 90% of school children were reported to use backpacks in the developed countries. The excessive loading due to daily backpack carriage was reported to increase the stress on body and has been associated with increased risk of back pain. However, the effects of backpack on the spine have not been clearly documented. In this study, the effects of backpack of different weights and carrying methods on spinal curvature and proprioception will be investigated.

Experiment procedures:

1. Personal information, including age, body height and body weight, will be collected.
2. The participant will be asked to exposure his/her back for clinical palpation and 6 sensors will be attached to the skin of his/her back using double side adhesive tape.
3. The participant will be instructed to carry a backpack with either one of the three weights, i.e. 10% body weight (BW), 15% BW or 20% BW, with the center of gravity located at one of the six locations, i.e. T7, T12 or L3 spine level either anteriorly or posteriorly as well as without carrying the backpack.
4. For each testing condition, the participant will stand upright and comfortably on a pair of footprints with his/her eyes looking at a marker 2 meters ahead for 5 seconds and a total of 6 trials of this upright standing test will be performed.
5. A three-minute rest will be provided between successive trials and the whole experiment will last for approximately 2 hours.

Terms and conditions:

The results of all the captured data from the subject may be published; however all the personal information will be kept confidential.

The participation in this study is entirely voluntary and the subject can refuse to participate or withdraw from the study at any time. The experiment will be stopped immediately whenever the participant shows any discomfort during the experiment.

For further information or queries, please contact Prof. Daniel Chow at Tel. 2766 (Email: Daniel.Chow@). If there is any complaint, please contact the Secretary of the University Human Research Ethics Committee at Tel. 2766 (Email: hreric@).

Consent

I, ___________________, have been explained the details of this study. I voluntarily consent to participate in this study. I have understood that I can withdraw from this study at any time without having to give a reason, and my withdrawal will not lead to any punishment or prejudice against me. I have understood that experiment operator will stop the experiment immediately if I show him/her any discomfort in any part of the experiment.

I am aware of any potential in joining this study. I also understand that my personal information will not be disclosed to people who are not related to this study and my name or photograph will not appear on any publications resulted from this study.

I also understand that I can contact the chief investigator, Prof. Daniel Chow at telephone 2766 , email address (Daniel.Chow@) for any questions about this study. If I have any complaint, I can contact Mr. Eric Chan, the Secretary of the University Human Research Ethics Committee at telephone 2766 and email address (hreric@).

Signature of participant: ___________________ Date: _________________

Name (print): ___________________

Signature of Parent/Guidance: ___________________ Date: _________________

Name (print): ___________________

Signature of Witness: ___________________ Date: _________________

Name (print): ___________________

Appendix 2 The Participants' Information

Table A2.1 The participants' information

Subject number	Test group	Gender	Age (year)	Body height (cm)	Body weight (kg)
1	10%BW	Male	11	144	32.2
2	10%BW	Male	12	159	51
3	10%BW	Male	12	146	37.7
4	10%BW	Male	13	158	45.8
5	10%BW	Male	13	159	54.5
6	10%BW	Male	15	158	46.2
7	10%BW	Male	15	159	49
8	10%BW	Female	11	144	48.5
9	10%BW	Female	11	141	43
10	10%BW	Female	11	148	52
11	10%BW	Female	11	141	34.2
12	10%BW	Female	12	162	46.4
13	10%BW	Female	12	156	45.5
14	10%BW	Female	13	155	48.6
15	10%BW	Female	13	156	39
16	10%BW	Female	14	156	50
17	10%BW	Female	15	158	46
18	10%BW	Female	15	152	44.5
19	10%BW	Female	15	151	48.6
20	10%BW	Female	15	163	53.5
21	10%BW	Female	15	155	50
22	10%BW	Female	15	157	51
23	10%BW	Female	15	162	52
24	15%BW	Male	11	146	38
25	15%BW	Male	11	142	36.2
26	15%BW	Male	11	149	42.2
27	15%BW	Male	11	152	46.4
28	15%BW	Male	11	149	44.5
29	15%BW	Male	11	144	31.3
30	15%BW	Male	11	161	50.6
31	15%BW	Male	11	140	33.4
32	15%BW	Male	11	140	38.5
33	15%BW	Male	12	165	51.5
34	15%BW	Male	12	157	44.7
35	15%BW	Male	12	150	41.4
36	15%BW	Male	12	152	54.4

Table A2.1 (Cont'd) The participants' information

37	15%BW	Male	12	157	51.5
38	15%BW	Male	13	164	60
39	15%BW	Male	13	152	35
40	15%BW	Female	11	139	31.3
41	15%BW	Female	11	146	34.9
42	15%BW	Female	11	139	36.8
43	15%BW	Female	11	148	35
44	15%BW	Female	11	135	32.2
45	15%BW	Female	11	140	33.5
46	15%BW	Female	12	157	39.7
47	15%BW	Female	12	151	38.1
48	15%BW	Female	14	150	36
49	15%BW	Female	14	158	46.6
50	15%BW	Female	14	151	48.4
51	15%BW	Female	15	154	47.1
52	15%BW	Female	15	165	52
53	20%BW	Male	12	146	40.7
54	20%BW	Male	12	158	39.2
55	20%BW	Male	12	152	34.6
56	20%BW	Male	12	154	41.1
57	20%BW	Male	12	168	55
58	20%BW	Male	12	161	44
59	20%BW	Male	13	150	37.9
60	20%BW	Male	13	158	36.5
61	20%BW	Male	14	167	53.1
62	20%BW	Female	14	147	41.1
63	20%BW	Female	15	150	41.8

Appendix 3 Data of Error Estimation for the Accelerometers

Table A3.1 Error estimation for Accelerometer 1 for input range ±90º

Input Inclination (º)	Output Voltage (V)	Sine of input inclination	Output after linear regression	Inverse sine of output after 3 regions linear regression (º)	Difference between the input inclination and output angle (º)	RMS Error (º)
A	V	sin(A)	kV+b	$\sin^{-1}(kV+b)$	$\sin^{-1}(kV+b)-A$	
-90	2.1651	-1.0000	-0.9996	-88.3	1.70	
-88	2.1653	-0.9994	-0.9987	-87.0	0.96	
-86	2.1656	-0.9976	-0.9976	-86.1	-0.07	
-84	2.1663	-0.9945	-0.9949	-84.2	-0.22	
-82	2.1674	-0.9903	-0.9907	-82.2	-0.16	
-80	2.1688	-0.9848	-0.9851	-80.1	-0.09	
-78	2.1703	-0.9781	-0.9790	-78.2	-0.24	
-76	2.1723	-0.9703	-0.9712	-76.2	-0.21	
-74	2.1749	-0.9613	-0.9608	-73.9	0.09	
-72	2.1774	-0.9511	-0.9507	-71.9	0.07	
-70	2.1844	-0.9397	-0.9365	-69.5	0.53	
-60	2.2071	-0.8660	-0.8637	-59.7	0.26	
-50	2.2376	-0.7660	-0.7658	-50.0	0.02	
-40	2.2756	-0.6428	-0.6438	-40.1	-0.07	
-30	2.3199	-0.5000	-0.5015	-30.1	-0.10	
-20	2.3689	-0.3420	-0.3445	-20.1	-0.15	
-10	2.4219	-0.1736	-0.1745	-10.0	-0.05	
0	2.4756	0.0000	-0.0019	-0.1	-0.11	**0.5**
10	2.5299	0.1736	0.1723	9.9	-0.08	
20	2.5826	0.3420	0.3413	20.0	-0.04	
30	2.6320	0.5000	0.4998	30.0	-0.01	
40	2.6764	0.6428	0.6424	40.0	-0.03	
50	2.7155	0.7660	0.7678	50.2	0.16	
60	2.7466	0.8660	0.8675	60.2	0.17	
70	2.7694	0.9397	0.9408	70.2	0.19	
72	2.7713	0.9511	0.9504	71.9	-0.12	
74	2.7748	0.9613	0.9616	74.1	0.06	
76	2.7778	0.9703	0.9712	76.2	0.20	
78	2.7800	0.9781	0.9780	77.9	-0.05	
80	2.7819	0.9848	0.9840	79.7	-0.26	
82	2.7838	0.9903	0.9902	82.0	-0.02	
84	2.7851	0.9945	0.9941	83.8	-0.20	
86	2.7860	0.9976	0.9971	85.6	-0.38	
88	2.7867	0.9994	0.9993	87.8	-0.17	
90	2.7871	1.0000	1.0005	91.8	1.80	

Table A3.2 Error estimation for Accelerometer 2 for input range ±90º

Input Inclination (º)	Output Voltage (V)	Sine of input inclination	Output after linear regression	Inverse sine of output after 3 regions linear regression (º)	Difference between the input inclination and output angle (º)	RMS Error (º)
A	V	sin(A)	kV+b	$\sin^{-1}$(kV+b)	$\sin^{-1}$(kV+b)-A	
-90	2.1710	-1.0000	-1.0009	-92.5	-2.46	0.6
-88	2.1713	-0.9994	-1.0000	-89.7	-1.72	
-86	2.1720	-0.9976	-0.9979	-86.3	-0.30	
-84	2.1736	-0.9945	-0.9932	-83.3	0.69	
-82	2.1748	-0.9903	-0.9898	-81.8	0.20	
-80	2.1766	-0.9848	-0.9842	-79.8	0.20	
-78	2.1787	-0.9781	-0.9781	-78.0	0.00	
-76	2.1813	-0.9703	-0.9705	-76.0	-0.05	
-74	2.1842	-0.9613	-0.9620	-74.2	-0.16	
-72	2.1879	-0.9511	-0.9509	-72.0	0.02	
-70	2.1927	-0.9397	-0.9425	-70.5	-0.47	
-60	2.2160	-0.8660	-0.8676	-60.2	-0.18	
-50	2.2474	-0.7660	-0.7673	-50.1	-0.11	
-40	2.2862	-0.6428	-0.6432	-40.0	-0.03	
-30	2.3312	-0.5000	-0.4993	-30.0	0.05	
-20	2.3806	-0.3420	-0.3411	-19.9	0.06	
-10	2.4340	-0.1736	-0.1702	-9.8	0.20	
0	2.4879	0.0000	0.0025	0.1	0.14	
10	2.5423	0.1736	0.1764	10.2	0.16	
20	2.5948	0.3420	0.3444	20.1	0.14	
30	2.6439	0.5000	0.5016	30.1	0.11	
40	2.6880	0.6428	0.6426	40.0	-0.02	
50	2.7267	0.7660	0.7664	50.0	0.04	
60	2.7571	0.8660	0.8638	59.7	-0.25	
70	2.7793	0.9397	0.9351	69.2	-0.76	
72	2.7818	0.9511	0.9518	72.1	0.13	
74	2.7847	0.9613	0.9611	74.0	-0.03	
76	2.7875	0.9703	0.9701	76.0	-0.04	
78	2.7900	0.9781	0.9779	77.9	-0.06	
80	2.7920	0.9848	0.9844	79.9	-0.14	
82	2.7938	0.9903	0.9902	82.0	-0.01	
84	2.7952	0.9945	0.9949	84.2	0.18	
86	2.7962	0.9976	0.9980	86.4	0.40	
88	2.7967	0.9994	0.9996	88.3	0.32	
90	2.7968	1.0000	1.0001	90.9	0.89	

Table A3.3 Error estimation for Accelerometer 3 for input range ±90º

Input Inclination (º)	**Output Voltage (V)**	**Sine of input inclination**	**Output after linear regression**	**Inverse sine of output after 3 regions linear regression (º)**	**Difference between the input inclination and output angle (º)**	**RMS Error (º)**
A	V	sin(A)	kV+b	$\sin^{-1}$(kV+b)	$\sin^{-1}$(kV+b)-A	
-90	2.1644	-1.0000	-1.0005	-91.9	-1.89	
-88	2.1649	-0.9994	-0.9991	-87.6	0.41	
-86	2.1652	-0.9976	-0.9981	-86.5	-0.48	
-84	2.1667	-0.9945	-0.9934	-83.4	0.57	
-82	2.1679	-0.9903	-0.9896	-81.7	0.29	
-80	2.1695	-0.9848	-0.9848	-80.0	0.01	
-78	2.1715	-0.9781	-0.9786	-78.1	-0.14	
-76	2.1739	-0.9703	-0.9712	-76.2	-0.20	
-74	2.1772	-0.9613	-0.9608	-73.9	0.10	
-72	2.1804	-0.9511	-0.9509	-72.0	0.02	
-70	2.1841	-0.9397	-0.9385	-69.8	0.20	
-60	2.2071	-0.8660	-0.8650	-59.9	0.11	
-50	2.2378	-0.7660	-0.7665	-50.0	-0.04	
-40	2.2761	-0.6428	-0.6439	-40.1	-0.08	
-30	2.3207	-0.5000	-0.5008	-30.1	-0.06	
-20	2.3698	-0.3420	-0.3434	-20.1	-0.08	
-10	2.4229	-0.1736	-0.1733	-10.0	0.02	
0	2.4768	0.0000	-0.0005	0.0	-0.03	**0.5**
10	2.5311	0.1736	0.1735	10.0	-0.01	
20	2.5836	0.3420	0.3419	20.0	0.00	
30	2.6328	0.5000	0.4997	30.0	-0.02	
40	2.6772	0.6428	0.6419	39.9	-0.06	
50	2.7163	0.7660	0.7673	50.1	0.11	
60	2.7472	0.8660	0.8662	60.0	0.03	
70	2.7700	0.9397	0.9393	69.9	-0.06	
72	2.7721	0.9511	0.9505	71.9	-0.10	
74	2.7748	0.9613	0.9609	73.9	-0.08	
76	2.7774	0.9703	0.9708	76.1	0.11	
78	2.7793	0.9781	0.9780	78.0	-0.05	
80	2.7814	0.9848	0.9860	80.4	0.39	
82	2.7825	0.9903	0.9900	81.9	-0.10	
84	2.7838	0.9945	0.9947	84.1	0.11	
86	2.7845	0.9976	0.9974	85.9	-0.15	
88	2.7848	0.9994	0.9986	87.0	-1.00	
90	2.7850	1.0000	0.9994	88.0	-1.99	

Table A3.4 Error estimation for Accelerometer 4 for input range ±90º

Input Inclination (º)	Output Voltage (V)	Sine of input inclination	Output after linear regression	Inverse sine of output after 3 regions linear regression (º)	Difference between the input inclination and output angle (º)	RMS Error (º)
A	V	sin(A)	kV+b	$\sin^{-1}(kV+b)$	$\sin^{-1}(kV+b)-A$	
-90	2.1738963	-1.0000	-0.9991	-87.6	2.38	0.6
-88	2.1737586	-0.9994	-0.9996	-88.4	-0.44	
-86	2.1745217	-0.9976	-0.9969	-85.5	0.52	
-84	2.175199	-0.9945	-0.9945	-84.0	0.03	
-82	2.1760922	-0.9903	-0.9913	-82.4	-0.42	
-80	2.1775569	-0.9848	-0.9860	-80.4	-0.40	
-78	2.179856	-0.9781	-0.9778	-77.9	0.11	
-76	2.1818023	-0.9703	-0.9708	-76.1	-0.11	
-74	2.1845375	-0.9613	-0.9610	-73.9	0.06	
-72	2.187347	-0.9511	-0.9509	-72.0	0.03	
-70	2.1963	-0.9397	-0.9379	-69.7	0.31	
-60	2.2189	-0.8660	-0.8649	-59.9	0.13	
-50	2.2495	-0.7660	-0.7663	-50.0	-0.02	
-40	2.2875	-0.6428	-0.6438	-40.1	-0.07	
-30	2.3318	-0.5000	-0.5009	-30.1	-0.06	
-20	2.3807	-0.3420	-0.3433	-20.1	-0.08	
-10	2.4334	-0.1736	-0.1731	-10.0	0.03	
0	2.4870	0.0000	-0.0006	0.0	-0.03	
10	2.5409	0.1736	0.1735	10.0	-0.01	
20	2.5932	0.3420	0.3422	20.0	0.01	
30	2.6422	0.5000	0.4999	30.0	0.00	
40	2.6863	0.6428	0.6422	40.0	-0.04	
50	2.7251	0.7660	0.7674	50.1	0.12	
60	2.7559	0.8660	0.8667	60.1	0.08	
70	2.7785	0.9397	0.9396	70.0	-0.02	
72	2.7790705	0.9511	0.9520	72.2	0.17	
74	2.7820357	0.9613	0.9616	74.1	0.07	
76	2.784473	0.9703	0.9695	75.8	-0.19	
78	2.7869221	0.9781	0.9774	77.8	-0.21	
80	2.7893397	0.9848	0.9852	80.1	0.14	
82	2.7907799	0.9903	0.9899	81.8	-0.16	
84	2.7923397	0.9945	0.9949	84.2	0.23	
86	2.793086	0.9976	0.9973	85.8	-0.18	
88	2.7938721	0.9994	0.9999	89.1	1.14	
90	2.7941115	1.0000	1.0007	92.1	2.09	
80	2.7925	0.9848	0.9847	80.0	-0.03	
90	2.7972	1.0000	1.0001	91.0	0.98	

Table A3.5 Error estimation for Accelerometer 5 for input range ±90º

Input Inclination (º)	Output Voltage (V)	Sine of input inclination	Output after linear regression	Inverse sine of output after 3 regions linear regression (º)	Difference between the input inclination and output angle (º)	RMS Error (º)
A	V	sin(A)	kV+b	$\sin^{-1}(kV+b)$	$\sin^{-1}(kV+b)-A$	
-90	2.1651	-1.0000	-1.0005	-91.8	-1.85	
-88	2.1655	-0.9994	-0.9997	-88.5	-0.49	
-86	2.1663	-0.9976	-0.9972	-85.7	0.26	
-84	2.1674	-0.9945	-0.9943	-83.9	0.10	
-82	2.1688	-0.9903	-0.9903	-82.0	-0.03	
-80	2.1713	-0.9848	-0.9835	-79.6	0.42	
-78	2.1735	-0.9781	-0.9771	-77.7	0.28	
-76	2.1755	-0.9703	-0.9718	-76.4	-0.36	
-74	2.1786	-0.9613	-0.9631	-74.4	-0.38	
-72	2.1833	-0.9511	-0.9499	-71.8	0.22	
-70	2.1845	-0.9397	-0.9434	-70.6	-0.64	
-60	2.2080	-0.8660	-0.8681	-60.2	-0.24	
-50	2.2393	-0.7660	-0.7677	-50.1	-0.15	
-40	2.2781	-0.6428	-0.6433	-40.0	-0.04	
-30	2.3230	-0.5000	-0.4990	-29.9	0.06	
-20	2.3724	-0.3420	-0.3407	-19.9	0.08	
-10	2.4256	-0.1736	-0.1700	-9.8	0.21	
0	2.4796	0.0000	0.0032	0.2	0.18	**0.7**
10	2.5338	0.1736	0.1772	10.2	0.21	
20	2.5862	0.3420	0.3454	20.2	0.21	
30	2.6350	0.5000	0.5020	30.1	0.13	
40	2.6789	0.6428	0.6428	40.0	0.00	
50	2.7173	0.7660	0.7660	50.0	-0.01	
60	2.7475	0.8660	0.8629	59.6	-0.35	
70	2.7696	0.9397	0.9339	69.0	-0.95	
72	2.7739	0.9511	0.9524	72.3	0.25	
74	2.7763	0.9613	0.9618	74.1	0.11	
76	2.7783	0.9703	0.9692	75.8	-0.25	
78	2.7801	0.9781	0.9762	77.5	-0.53	
80	2.7824	0.9848	0.9847	80.0	-0.04	
82	2.7834	0.9903	0.9883	81.2	-0.77	
84	2.7850	0.9945	0.9945	84.0	0.00	
86	2.7859	0.9976	0.9978	86.2	0.23	
88	2.7863	0.9994	0.9996	88.4	0.44	
90	2.7868	1.0000	1.0015	93.2	3.15	

Table A3.6 Error estimation for Accelerometer 6 for input range ±90º

Input Inclination (º)	Output Voltage (V)	Sine of input inclination	Output after linear regression	Inverse sine of output after 3 regions linear regression (º)	Difference between the input inclination and output angle (º)	RMS Error (º)
A	V	sin(A)	kV+b	$\sin^{-1}(kV+b)$	$\sin^{-1}(kV+b)-A$	
-90	2.1628	-1.0000	-1.0000	-89.8	0.23	0.4
-88	2.1631	-0.9994	-0.9988	-87.2	0.79	
-86	2.1634	-0.9976	-0.9979	-86.3	-0.27	
-84	2.1642	-0.9945	-0.9945	-84.0	0.00	
-82	2.1654	-0.9903	-0.9896	-81.7	0.26	
-80	2.1665	-0.9848	-0.9853	-80.2	-0.18	
-78	2.1681	-0.9781	-0.9792	-78.3	-0.29	
-76	2.1700	-0.9703	-0.9713	-76.2	-0.24	
-74	2.1726	-0.9613	-0.9611	-74.0	0.04	
-72	2.1753	-0.9511	-0.9505	-71.9	0.11	
-70	2.1845	-0.9397	-0.9392	-69.9	0.08	
-60	2.2076	-0.8660	-0.8653	-59.9	0.08	
-50	2.2385	-0.7660	-0.7667	-50.1	-0.06	
-40	2.2771	-0.6428	-0.6437	-40.1	-0.07	
-30	2.3219	-0.5000	-0.5005	-30.0	-0.04	
-20	2.3713	-0.3420	-0.3431	-20.1	-0.06	
-10	2.4247	-0.1736	-0.1728	-10.0	0.05	
0	2.4789	0.0000	0.0003	0.0	0.02	
10	2.5335	0.1736	0.1743	10.0	0.04	
20	2.5861	0.3420	0.3425	20.0	0.03	
30	2.6356	0.5000	0.5002	30.0	0.01	
40	2.6800	0.6428	0.6421	39.9	-0.05	
50	2.7193	0.7660	0.7673	50.1	0.11	
60	2.7502	0.8660	0.8659	60.0	-0.02	
70	2.7729	0.9397	0.9384	69.8	-0.22	
72	2.7780	0.9511	0.9513	72.0	0.04	
74	2.7808	0.9613	0.9605	73.8	-0.15	
76	2.7837	0.9703	0.9699	75.9	-0.08	
78	2.7862	0.9781	0.9783	78.0	0.04	
80	2.7884	0.9848	0.9853	80.2	0.17	
82	2.7899	0.9903	0.9901	81.9	-0.06	
84	2.7913	0.9945	0.9949	84.2	0.18	
86	2.7922	0.9976	0.9978	86.2	0.20	
88	2.7925	0.9994	0.9987	87.1	-0.95	
90	2.7927	1.0000	0.9994	88.1	-1.93	

Appendix 4 Data of Error Estimation for the Accelerometers in Dynamic Situation

Table A4.1 Mean and standard deviation of the inclination in upright stance

Subject number	Accelerometer	1	2	3	4	5	6
	Location	OC	C7	T7	T12	L3	S1
1	Mean	-10.4º	26.8º	-2.5º	-3.3º	19.3º	15.1º
	SD	0.4º	0.2º	0.2º	0.2º	0.1º	0.1º
2	Mean	-20.2º	24.9º	5.4º	-4.8º	16.6º	8.4º
	SD	0.4º	0.1º	0.1º	0.1º	0.1º	0.2º
3	Mean	-30.2º	33.5º	-2.3º	-6.2º	21.6º	17.4º
	SD	0.9º	0.2º	0.2º	0.2º	0.1º	0.1º
4	Mean	-11.0º	41.7º	9.7º	-8.3º	21.0º	18.5º
	SD	0.3º	0.2º	0.1º	0.2º	0.1º	0.1º
5	Mean	-1.4º	35.8º	7.5º	-10.9º	29.4º	19.2º
	SD	0.5º	0.3º	0.2º	0.3º	0.1º	0.2º
6	Mean	-4.5º	41.4º	9.1º	-8.0º	19.6º	28.4º
	SD	0.6º	0.4º	0.4º	0.3º	0.1º	0.1º
Mean of SD		**0.5º**	**0.2º**	**0.2º**	**0.2º**	**0.1º**	**0.1º**
Standard deviation of SD		**0.21º**	**0.10º**	**0.11º**	**0.08º**	**0.00º**	**0.05º**

Appendix 5 Determination of Backpack Centre of Gravity

Vertical direction

The backpack centre of gravity (CG) was dependent on two factors, i.e. the number of dead weights and the location of dead weights. Two kinds of dead weights with different mass were used in this study, i.e. 0.5 kg per unit and 1 kg per unit. The backpack CG location was adjusted by moving the dead weights upward and downward along the inside frame.

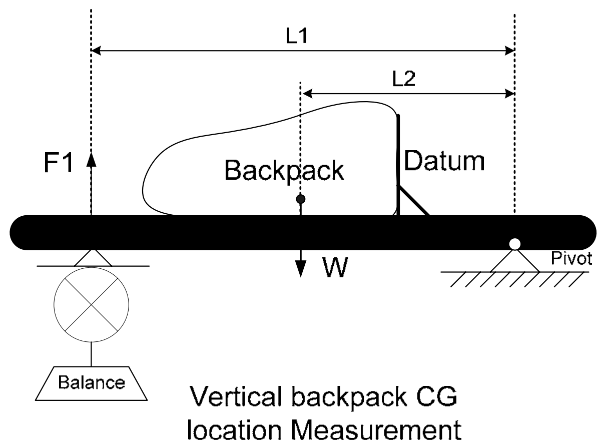


Figure A5.1 The lever system for determining the CG location of the backpack in vertical direction

In order to determine the relationship between the dead weights location relative to the bottom of the backpack ($H_{Deadweights}$) and the backpack CG location ($H_{BackpackCG}$), a linear regression method was used for each backpack weight. The dead weights were put at 4 heights relative to the bottom of the backpack, i.e. 8cm, 14cm, 24cm and 34cm. The backpack CG location was calculated for these 4 locations using the lever system (Figure A5.1). The proportional constant (a) and offset (b) were determined to convert $H_{BackpackCG}$ to $H_{Deadweights}$ in vertical direction (Equation A5.1). The linear regression was repeated for each backpack weight to calculate the parameters a and b (Table A5.1).

$$H_{Deadweights} = a \times H_{BackpackCG} + b \qquad \text{A5.1}$$

Table A5.1 The parameters used for the adjustment of backpack CG in vertical direction

Amounts of dead weights (kg)	a	b	r^2
1	2.2297	-26.2854	0.9933
1.5	2.0141	-23.9215	1.0000
2	1.6920	-16.4398	0.9950
2.5	1.6477	-15.1157	0.9998
3	1.5681	-14.7466	0.9998
3.5	1.4773	-13.1158	0.9999
4	1.4486	-12.5148	0.9996
4.5	1.3139	-9.8028	1.0000
5	1.2877	-9.2829	0.9991
5.5	1.2716	-9.1298	0.9995
6	1.2362	-8.3337	0.9994
6.5	1.2032	-8.3012	0.9998
7	1.1909	-8.2414	0.9999
7.5	1.1822	-8.1487	0.9996

a: the proportional constant
b: offset
r^2: correlation coefficient

By changing the location of dead weights, the backpack CG can be adjusted. For each subject, the backpack CG was determined by measuring the height of spine level relative to the backpack bottom when carrying on the backpack. The height of the dead weights location was then determined. For example, to prepare a backpack of 15% body weight with the backpack CG located at T12 spine level, 3 steps should be completed. Firstly, the number of dead weights (N) was determined by calculating the 15% of body weight. Second, the backpack CG location ($H_{BackpackCG}$) was decided by measuring the distance between the subject's T12 spine level and the bottom of the backpack. Finally, the parameters a and b was checked from the **Error! Reference source not found.** according to the amounts of dead weights, the location of the dead weights ($H_{Deadweights}$) was then calculated using the equation A4.1.

Anteroposterior direction

The backpack CG in anteroposterior direction should be independent to the vertical location of dead weights. To determine the backpack CG in anteroposterior direction, the dead weights were located at around the middle height of the backpack. For each backpack weight, the backpack CG in anteroposterior direction was calculated using the lever system (Figure A5.2). The backpack CG location was estimated to be in the range from 4.4 to 6.2 cm relative to the back cover of backpack (Table A5.2).

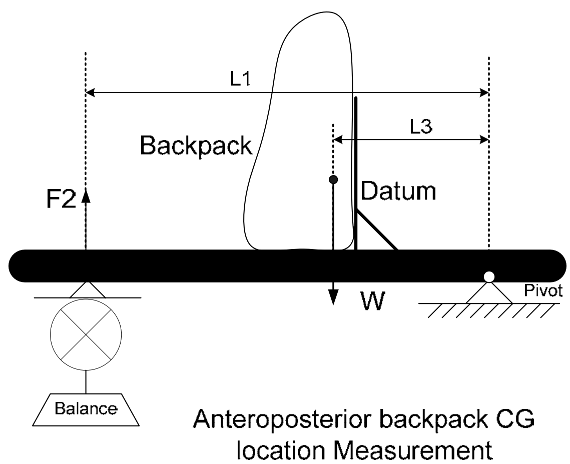


Figure A5.2 The lever system for determining the CG location of the backpack in anteroposterior direction

Table A5.2 Backpack CG location in anteroposterior direction

Amounts of dead weights (kg)	Balance Reading (g)	Backpack Weight (g)	CG Location (Relative to back) (cm)
1	920	2935	4.40
1.5	1155	3485	4.94
2	1350	4035	5.04
2.5	1540	4585	5.08
3	1800	5135	5.22
3.5	2040	5685	5.34
4	2235	6235	5.47
4.5	2465	6785	5.55
5	2700	7335	5.72
5.5	2910	7885	5.90
6	3115	8435	6.03
6.5	3325	8985	6.10
7	3535	9535	6.12
7.5	3750	10085	6.16
Average			5.50
Standard Deviation			0.53

Appendix 6 The Raw Data of the Inclinations at Each Spine Level in Upright Stance

Table A6.1 Raw data of the inclinations at OC

No.	Backpack weight	Gender	Inclination (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	-25.7	-24.1	-22.9	-22.7	-23.0	-25.9	-23.3
2	10%BW	Male	-19.6	-17.7	-14.8	-15.0	-14.2	-13.9	-10.9
3	10%BW	Male	-32.4	-30.4	-28.4	-32.6	-30.3	-28.3	-24.6
4	10%BW	Male	-22.6	-23.5	-23.3	-26.4	-20.1	-19.8	-17.2
5	10%BW	Male	-11.2	-7.8	-15.3	-8.8	-12.5	-7.8	-11.2
6	10%BW	Male	-5.5	-15.4	-8.6	-10.5	-6.7	-10.6	-14.2
7	10%BW	Male	-13.9	-14.3	-25.2	-13.2	-25.9	-17.6	-24.5
8	10%BW	Female	-7.6	-1.3	-3.3	-5.0	-4.0	-8.4	-4.2
9	10%BW	Female	-18.9	-21.9	-24.9	-17.6	-14.8	-20.2	-20.1
10	10%BW	Female	-27.2	-28.9	-28.9	-28.9	-31.4	-30.0	-29.0
11	10%BW	Female	-22.2	-21.2	-23.0	-19.7	-17.6	-18.6	-21.8
12	10%BW	Female	-30.4	-30.7	-30.3	-28.2	-26.5	-31.0	-29.0
13	10%BW	Female	-12.4	-4.6	-13.1	-12.1	-11.7	-11.4	-13.0
14	10%BW	Female	-23.3	-25.1	-25.1	-25.0	-29.9	-25.1	-24.4
15	10%BW	Female	-24.7	-29.0	-23.3	-23.2	-19.7	-23.8	-24.0
16	10%BW	Female	-21.6	-24.2	-22.7	-25.5	-25.8	-22.5	-27.7
17	10%BW	Female	-17.7	-24.3	-18.0	-23.0	-24.2	-24.3	-22.8
18	10%BW	Female	-25.6	-33.1	-26.4	-28.3	-28.6	-32.8	-33.6
19	10%BW	Female	-35.9	-36.8	-36.4	-36.0	-34.5	-34.0	-41.3
20	10%BW	Female	-17.9	-30.9	-25.5	-32.0	-28.1	-29.1	-23.2
21	10%BW	Female	-19.9	-22.5	-28.3	-22.7	-20.8	-19.9	-25.7
22	10%BW	Female	-35.3	-27.5	-29.1	-26.7	-33.1	-29.2	-32.2
23	10%BW	Female	-29.5	-21.3	-24.0	-27.6	-30.0	-28.5	-27.5
24	15%BW	Male	-18.0	-19.9	-21.4	-22.9	-19.1	-23.0	-20.3
25	15%BW	Male	-11.5	-14.0	-14.6	-16.9	-15.4	-17.5	-15.9
26	15%BW	Male	-15.6	-17.8	-20.6	-20.2	-19.5	-19.0	-20.4
27	15%BW	Male	-29.3	-37.0	-34.9	-31.7	-32.6	-28.8	-34.2
28	15%BW	Male	-13.4	-25.5	-27.6	-23.0	-26.3	-22.2	-25.1
29	15%BW	Male	-36.7	-35.9	-37.3	-33.9	-35.9	-31.4	-26.9
30	15%BW	Male	-38.3	-42.7	-40.3	-39.1	-37.4	-32.9	-37.2
31	15%BW	Male	-19.4	-17.2	-19.3	-17.2	-19.6	-23.6	-23.7
32	15%BW	Male	-32.5	-36.4	-43.4	-35.7	-35.5	-40.6	-37.3
33	15%BW	Male	-8.5	-12.8	-15.5	-11.9	-7.7	-8.2	-10.5
34	15%BW	Male	-23.9	-24.5	-22.9	-24.6	-22.0	-20.9	-20.5
35	15%BW	Male	-44.6	-45.7	-46.0	-48.9	-49.2	-45.0	-46.9
36	15%BW	Male	-28.2	-27.7	-23.9	-27.5	-29.0	-29.4	-24.6
37	15%BW	Male	-45.1	-41.2	-45.3	-40.6	-44.1	-41.8	-47.3

Table A6.1 (Cont'd) Raw data of the inclinations at OC

38	15%BW	Male	-30.1	-20.6	-28.9	-24.7	-30.5	-30.3	-30.6
39	15%BW	Male	-20.0	-22.0	-20.0	-34.1	-31.9	-22.7	-26.9
40	15%BW	Female	-31.8	-32.3	-31.3	-30.2	-31.8	-31.9	-35.7
41	15%BW	Female	-14.1	-14.1	-16.0	-14.0	-14.1	-18.9	-18.7
42	15%BW	Female	-20.6	-25.8	-26.0	-24.0	-24.0	-22.3	-25.6
43	15%BW	Female	-13.5	-16.0	-13.9	-17.1	-17.5	-16.0	-14.4
44	15%BW	Female	-12.2	-12.7	-10.1	-9.9	-11.5	-11.4	-10.5
45	15%BW	Female	-29.1	-27.8	-27.7	-28.9	-31.8	-33.0	-31.4
46	15%BW	Female	-0.8	-3.4	-7.0	0.2	-0.5	-2.6	-0.6
47	15%BW	Female	-11.4	-12.9	-14.3	-19.6	-12.4	-13.6	-10.5
48	15%BW	Female	-10.8	-20.2	-26.1	-18.5	-18.8	-14.6	-15.1
49	15%BW	Female	-21.4	-29.5	-26.0	-28.4	-27.3	-25.3	-27.5
50	15%BW	Female	-28.2	-28.8	-29.4	-28.7	-28.6	-26.6	-25.3
51	15%BW	Female	-18.5	-25.3	-29.1	-28.3	-26.0	-24.2	-24.1
52	15%BW	Female	-6.9	-10.4	-15.7	-9.3	-10.4	-13.4	-14.7
53	20%BW	Male	-16.6	-17.2	-7.4	-16.6	-11.2	-11.4	-16.6
54	20%BW	Male	-14.5	-17.1	-18.0	-12.6	-19.9	-17.2	-13.6
55	20%BW	Male	-12.1	-21.0	-20.1	-13.8	-19.6	-15.7	-17.5
56	20%BW	Male	-20.8	-17.2	-24.4	-20.5	-17.9	-17.4	-20.2
57	20%BW	Male	-15.8	-20.6	-16.9	-18.8	-12.7	-12.6	-10.4
58	20%BW	Male	-14.8	-14.6	-11.6	-14.3	-13.8	-10.8	-14.3
59	20%BW	Male	-30.0	-29.1	-24.3	-10.6	-9.2	-17.2	-16.0
60	20%BW	Male	-13.8	-23.7	-18.5	-18.7	-17.6	-12.3	-15.2
61	20%BW	Male	-5.5	-6.4	-8.5	-6.8	-6.4	3.2	0.2
62	20%BW	Female	-13.0	-7.5	-17.8	-1.8	-15.0	-13.1	-17.9
63	20%BW	Female	-39.1	-36.5	-35.8	-38.8	-35.0	-36.7	-33.3

Refer to Table 3.1 for the abbreviations

Table A6.2 Raw data of the inclinations at C7

No.	Backpack weight	Gender	Inclination (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	22.6	22.2	21.3	21.1	29.5	28.2	29.7
2	10%BW	Male	31.9	29.7	27.7	28.4	35.7	35.0	36.6
3	10%BW	Male	39.5	34.9	31.1	31.5	42.5	47.2	41.1
4	10%BW	Male	23.4	23.5	16.4	19.1	26.1	29.9	30.2
5	10%BW	Male	19.9	16.8	14.6	19.5	26.4	31.3	29.7
6	10%BW	Male	26.0	21.3	23.2	23.8	27.8	26.9	28.9
7	10%BW	Male	21.5	17.8	18.7	15.1	27.8	26.9	28.7
8	10%BW	Female	32.4	31.2	31.4	28.7	40.1	39.6	40.9
9	10%BW	Female	30.5	29.3	30.5	29.0	36.6	38.1	35.5
10	10%BW	Female	16.5	16.0	17.8	12.6	17.8	24.2	20.4
11	10%BW	Female	24.0	23.2	21.9	23.2	37.2	37.8	39.8
12	10%BW	Female	20.9	21.2	19.1	23.1	26.6	26.3	27.2
13	10%BW	Female	30.2	30.8	31.8	30.4	38.5	39.7	39.8
14	10%BW	Female	21.0	17.2	18.4	17.3	24.4	22.6	23.7
15	10%BW	Female	15.0	11.7	11.9	12.0	16.7	17.8	18.3
16	10%BW	Female	47.4	46.2	43.7	53.6	49.9	47.2	52.1
17	10%BW	Female	22.5	23.3	21.8	21.7	26.4	27.8	25.2
18	10%BW	Female	33.1	23.7	24.1	28.2	38.1	32.7	37.5
19	10%BW	Female	36.8	39.3	37.7	39.3	42.6	45.8	44.6
20	10%BW	Female	42.4	42.5	39.1	43.3	44.0	44.1	45.1
21	10%BW	Female	34.7	32.0	31.5	30.3	38.9	37.6	37.1
22	10%BW	Female	24.5	21.8	24.5	26.2	30.3	32.4	29.7
23	10%BW	Female	33.9	26.9	24.0	29.2	38.4	38.4	35.7
24	15%BW	Male	21.2	21.4	18.9	19.5	30.6	35.0	27.9
25	15%BW	Male	28.0	27.6	27.7	29.3	33.9	34.8	33.6
26	15%BW	Male	29.0	29.7	31.7	28.7	32.1	35.1	32.3
27	15%BW	Male	36.4	34.9	33.0	35.5	56.2	54.9	57.0
28	15%BW	Male	36.1	31.4	32.0	35.5	40.0	40.3	45.2
29	15%BW	Male	33.8	31.1	31.4	31.3	37.7	37.5	41.9
30	15%BW	Male	18.2	24.1	24.5	26.9	29.7	33.2	30.4
31	15%BW	Male	15.9	15.0	5.5	10.8	24.7	23.6	23.5
32	15%BW	Male	35.7	22.7	26.7	26.0	44.2	37.8	41.4
33	15%BW	Male	33.8	39.6	40.8	41.0	50.0	53.6	48.8
34	15%BW	Male	20.6	25.9	21.8	27.6	33.4	35.6	39.5
35	15%BW	Male	19.7	18.2	16.6	22.8	28.6	29.2	29.0
36	15%BW	Male	15.1	13.3	14.0	10.4	26.2	25.9	28.6
37	15%BW	Male	17.2	27.4	19.9	18.2	29.2	33.9	36.8
38	15%BW	Male	20.6	25.9	21.7	24.0	29.1	35.7	37.8
39	15%BW	Male	27.6	34.8	36.1	29.5	36.2	38.0	38.4
40	15%BW	Female	23.7	25.4	19.5	20.3	30.8	29.6	31.3

Table A6.2 (Cont'd) Raw data of the inclinations at C7

41	15%BW	Female	31.3	27.3	26.7	25.2	33.2	32.8	33.5
42	15%BW	Female	29.1	25.8	25.8	23.5	37.1	37.4	38.7
43	15%BW	Female	14.2	12.8	8.6	10.7	20.6	19.5	21.5
44	15%BW	Female	26.2	18.3	19.9	20.1	34.8	36.2	36.6
45	15%BW	Female	29.8	25.6	22.8	22.0	30.1	29.1	33.7
46	15%BW	Female	8.0	6.0	2.8	5.2	20.5	19.0	17.4
47	15%BW	Female	26.5	30.9	22.3	26.0	29.2	35.5	34.4
48	15%BW	Female	45.9	44.0	40.1	49.4	56.0	54.9	50.7
49	15%BW	Female	23.8	26.4	20.7	17.9	37.2	34.0	34.8
50	15%BW	Female	18.2	16.6	11.4	14.4	34.9	32.6	37.7
51	15%BW	Female	14.3	14.8	7.7	12.1	30.3	36.5	32.8
52	15%BW	Female	29.1	28.9	26.6	29.1	36.5	37.4	33.7
53	20%BW	Male	26.7	27.4	24.3	30.9	43.0	40.5	37.9
54	20%BW	Male	15.2	20.2	15.6	13.3	18.6	24.1	26.0
55	20%BW	Male	32.4	28.8	29.0	26.1	36.8	35.3	37.2
56	20%BW	Male	20.3	13.5	12.7	13.4	38.2	35.0	39.5
57	20%BW	Male	21.1	25.5	18.1	22.1	33.1	37.5	33.6
58	20%BW	Male	24.3	26.9	27.1	27.5	33.5	34.4	31.7
59	20%BW	Male	25.0	27.0	27.6	29.2	34.5	38.8	39.6
60	20%BW	Male	26.8	11.6	12.2	13.3	29.6	27.5	26.4
61	20%BW	Male	11.9	11.2	7.9	4.8	12.2	24.1	19.2
62	20%BW	Female	39.0	33.3	32.7	37.3	40.5	40.4	39.4
63	20%BW	Female	23.4	25.7	23.0	19.3	31.3	33.5	26.3

Refer to Table 3.1 for the abbreviations

Table A6.3 Raw data of the inclinations at T7

No.	Backpack weight	Gender	Inclination (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	2.4	-0.1	-2.9	2.0	3.4	3.1	4.8
2	10%BW	Male	0.6	-1.9	-2.7	-3.6	2.6	5.5	2.8
3	10%BW	Male	0.5	-9.7	-11.3	-8.4	2.3	6.5	4.5
4	10%BW	Male	0.2	-1.1	-6.8	-7.1	5.7	10.1	11.1
5	10%BW	Male	2.0	-7.6	-8.2	-4.5	9.7	12.6	11.7
6	10%BW	Male	0.0	-6.7	-3.6	-2.4	5.0	7.2	8.7
7	10%BW	Male	4.4	-2.5	-2.1	-3.9	11.7	12.3	13.7
8	10%BW	Female	3.6	-5.4	-6.0	-6.3	6.0	7.5	7.9
9	10%BW	Female	-6.1	-10.9	-9.3	-12.5	-1.3	-3.0	-4.2
10	10%BW	Female	-5.4	-11.1	1.2	-11.9	-0.4	0.5	-0.4
11	10%BW	Female	-8.1	-10.0	-11.7	-8.4	0.9	5.5	3.7
12	10%BW	Female	4.6	0.2	0.6	2.2	11.3	14.0	13.8
13	10%BW	Female	-4.9	-7.4	-7.9	-8.1	5.0	3.6	3.7
14	10%BW	Female	-1.0	-8.0	-8.7	-7.2	6.0	7.5	6.2
15	10%BW	Female	4.4	-2.7	-3.1	-2.8	8.4	10.4	8.3
16	10%BW	Female	-8.9	-14.9	-16.4	-13.5	1.3	1.4	0.2
17	10%BW	Female	5.8	1.7	0.9	0.5	10.1	10.3	9.7
18	10%BW	Female	-3.8	-12.0	-11.9	-10.0	3.3	3.0	4.2
19	10%BW	Female	5.0	6.4	2.7	9.6	7.3	8.1	10.3
20	10%BW	Female	2.4	-0.4	0.4	0.5	0.2	2.3	5.0
21	10%BW	Female	6.0	6.3	4.1	4.2	12.8	11.0	10.9
22	10%BW	Female	-4.7	-8.7	-6.6	-6.4	1.7	5.1	3.0
23	10%BW	Female	-3.0	-10.3	-12.3	-9.3	-2.5	-2.1	-2.5
24	15%BW	Male	-12.8	-15.4	-16.8	-17.2	-6.1	-1.1	-2.1
25	15%BW	Male	-3.8	-7.0	-5.7	-5.9	4.9	3.4	4.5
26	15%BW	Male	-5.8	-11.8	-16.1	-15.4	0.3	1.8	1.3
27	15%BW	Male	-5.8	-11.5	-11.9	-7.0	5.2	3.0	5.3
28	15%BW	Male	0.4	-9.3	-13.3	-5.2	12.0	14.4	8.6
29	15%BW	Male	-3.4	-9.2	-8.6	-7.8	9.2	10.8	12.4
30	15%BW	Male	-7.7	-6.6	-6.4	-0.9	7.7	-1.9	-2.6
31	15%BW	Male	-10.8	-11.0	-17.8	-15.0	1.4	1.2	-0.2
32	15%BW	Male	2.9	-14.3	-10.0	-13.8	9.0	11.9	8.5
33	15%BW	Male	-2.6	2.2	1.6	3.6	12.3	13.7	13.6
34	15%BW	Male	-3.5	-1.0	-6.7	-0.7	7.3	6.8	9.2
35	15%BW	Male	5.0	4.4	-0.2	7.4	14.6	22.1	15.7
36	15%BW	Male	0.2	-0.3	-1.1	-3.5	14.7	15.7	16.4
37	15%BW	Male	-10.6	-0.8	-8.5	-9.9	1.1	6.0	9.6
38	15%BW	Male	-0.8	3.1	-4.4	0.2	2.4	10.7	14.7
39	15%BW	Male	-2.1	-1.3	0.4	-6.3	13.8	12.7	16.8
40	15%BW	Female	-9.9	-10.4	-16.8	-14.3	-3.8	-3.8	-2.4

Table A6.3 (Cont'd) Raw data of the inclinations at T7

41	15%BW	Female	5.8	0.2	-1.5	-3.2	2.4	4.6	5.1
42	15%BW	Female	5.7	-1.2	-1.2	-1.6	13.7	15.5	14.9
43	15%BW	Female	-2.3	-11.7	-13.4	-10.8	7.0	5.6	7.2
44	15%BW	Female	-0.7	-6.5	-3.4	-5.8	4.5	8.2	7.7
45	15%BW	Female	-7.2	-13.5	-15.8	-16.3	-6.6	-8.0	-5.3
46	15%BW	Female	-14.5	-21.6	-22.5	-22.4	-2.3	-5.5	-4.7
47	15%BW	Female	-14.8	-16.9	-23.0	-17.6	-6.7	-4.6	-8.0
48	15%BW	Female	-0.5	-4.2	-8.0	-3.7	12.4	11.3	10.7
49	15%BW	Female	-17.8	-24.8	-29.8	-34.9	-5.9	-4.0	-4.4
50	15%BW	Female	-0.5	-7.5	-10.4	-10.2	9.7	10.0	12.6
51	15%BW	Female	-10.7	-12.9	-24.3	-19.6	-6.0	3.6	3.5
52	15%BW	Female	-3.0	-8.1	-7.3	-7.3	4.5	11.8	5.4
53	20%BW	Male	-10.0	-9.1	-20.0	-3.7	1.7	1.4	1.2
54	20%BW	Male	-3.5	-5.6	-7.7	-10.7	5.7	3.3	5.3
55	20%BW	Male	-13.0	-15.1	-16.5	-13.6	-4.7	-2.7	-2.0
56	20%BW	Male	-16.1	-27.6	-33.0	-31.1	-0.9	-3.2	3.4
57	20%BW	Male	-3.6	-2.7	-13.1	-7.5	9.2	12.2	10.2
58	20%BW	Male	-10.5	-19.3	-19.9	-21.3	-2.6	-4.3	-5.3
59	20%BW	Male	0.5	-0.9	-2.8	-5.9	7.5	12.3	11.1
60	20%BW	Male	4.2	-8.6	-10.6	-7.5	12.7	9.9	8.3
61	20%BW	Male	-6.8	-6.0	-8.6	-4.9	-4.6	6.2	2.4
62	20%BW	Female	11.8	0.2	7.6	6.9	10.6	11.7	11.1
63	20%BW	Female	8.6	6.0	2.2	5.7	13.0	20.4	17.9

Refer to Table 3.1 for the abbreviations

Table A6.4 Raw data of the inclinations at T12

No.	Backpack weight	Gender	Inclination (°)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	-13.4	-19.5	-19.8	-14.3	-8.2	-10.8	-11.0
2	10%BW	Male	-11.8	-11.4	-11.5	-14.2	-9.5	-7.9	-9.2
3	10%BW	Male	-11.5	-19.2	-16.5	-13.0	-8.6	-7.1	-8.0
4	10%BW	Male	-18.9	-19.7	-16.4	-23.2	-10.9	-10.3	-11.4
5	10%BW	Male	-12.4	-24.9	-23.5	-23.4	-4.4	-6.0	-4.8
6	10%BW	Male	-10.4	-14.3	-8.0	-10.3	-4.4	-0.8	1.0
7	10%BW	Male	-8.5	-17.9	-13.6	-16.3	-0.7	-2.9	-2.6
8	10%BW	Female	-21.0	-26.3	-25.1	-21.6	-12.6	-10.4	-13.9
9	10%BW	Female	-16.9	-16.1	-15.3	-16.2	-6.0	-4.8	-5.9
10	10%BW	Female	-6.8	-17.4	-0.8	-11.9	-0.6	-0.8	-1.2
11	10%BW	Female	-19.6	-19.4	-22.6	-18.6	-11.0	-11.9	-8.6
12	10%BW	Female	-10.3	-11.1	-10.9	-16.8	-3.5	-4.7	-6.9
13	10%BW	Female	-18.7	-25.8	-24.3	-27.0	-12.1	-10.5	-9.9
14	10%BW	Female	-13.8	-23.0	-19.2	-20.4	-8.4	-8.8	-9.0
15	10%BW	Female	-12.3	-17.8	-17.3	-18.3	-9.8	-9.0	-8.5
16	10%BW	Female	-15.4	-24.6	-22.5	-20.3	-6.0	-6.4	-8.1
17	10%BW	Female	-11.6	-13.6	-13.0	-12.2	-8.7	-9.6	-8.5
18	10%BW	Female	-14.8	-23.2	-24.5	-24.1	-8.9	-7.8	-7.0
19	10%BW	Female	-17.4	-12.1	-20.8	-7.2	-14.2	-15.7	-12.2
20	10%BW	Female	-16.9	-23.7	-13.9	-20.5	-16.6	-13.7	-12.6
21	10%BW	Female	-11.9	-10.4	-13.6	-15.1	-5.3	-7.6	-6.5
22	10%BW	Female	-15.4	-25.8	-21.2	-21.5	-10.2	-8.5	-8.6
23	10%BW	Female	-16.8	-27.6	-28.6	-24.4	-12.7	-14.7	-15.4
24	15%BW	Male	-18.8	-19.5	-18.8	-18.9	-11.5	-12.7	-10.9
25	15%BW	Male	-16.2	-19.9	-18.7	-18.8	-8.2	-8.7	-9.6
26	15%BW	Male	-11.4	-14.3	-20.1	-16.1	-8.7	-8.6	-8.9
27	15%BW	Male	-18.0	-23.6	-21.6	-24.6	-9.1	-9.2	-10.3
28	15%BW	Male	-9.3	-18.5	-16.1	-12.9	-4.3	-1.7	-5.5
29	15%BW	Male	-17.4	-28.5	-23.9	-23.7	-6.6	-5.6	-8.9
30	15%BW	Male	-10.9	-11.2	-14.8	-13.5	2.1	-4.4	-4.0
31	15%BW	Male	-11.7	-19.7	-23.2	-22.6	-4.0	-4.8	-3.1
32	15%BW	Male	-13.5	-18.8	-18.3	-20.8	-7.7	-5.0	-7.0
33	15%BW	Male	-25.0	-24.3	-26.3	-22.2	-17.3	-16.1	-14.8
34	15%BW	Male	-11.4	-13.6	-17.8	-14.2	-11.4	-9.2	-9.2
35	15%BW	Male	-12.5	-17.4	-19.7	-17.7	-3.3	0.9	-3.4
36	15%BW	Male	-12.5	-17.6	-17.3	-19.7	0.8	0.9	1.1
37	15%BW	Male	-20.1	-15.5	-26.8	-25.2	-7.9	-9.8	-8.3
38	15%BW	Male	-21.4	-20.9	-22.6	-15.0	-8.6	-8.7	-8.0
39	15%BW	Male	-14.9	-21.7	-19.8	-24.8	-7.6	-6.5	-7.3
40	15%BW	Female	-10.3	-19.6	-20.9	-20.1	-4.2	-4.1	-2.1

Table A6.4 (Cont'd) Raw data of the inclinations at T12

41	15%BW	Female	-9.9	-17.2	-16.7	-17.8	-2.5	-5.1	-5.6
42	15%BW	Female	-19.3	-25.7	-25.7	-25.5	-3.3	-5.9	-5.5
43	15%BW	Female	-10.4	-22.7	-21.5	-20.9	-7.6	-6.2	-5.4
44	15%BW	Female	-22.7	-28.8	-28.1	-26.5	-12.2	-10.2	-10.4
45	15%BW	Female	-20.9	-25.6	-24.0	-24.6	-12.2	-15.1	-15.4
46	15%BW	Female	-17.5	-32.0	-26.8	-27.5	-6.2	-7.4	-9.9
47	15%BW	Female	-23.0	-25.2	-35.3	-34.9	-11.0	-12.0	-13.7
48	15%BW	Female	-17.0	-15.8	-18.8	-13.8	-3.1	-3.9	-4.8
49	15%BW	Female	-18.0	-25.8	-34.4	-32.3	-9.7	-9.5	-1.9
50	15%BW	Female	-22.1	-26.4	-29.1	-23.9	-5.5	-5.3	-7.9
51	15%BW	Female	-24.6	-25.8	-41.0	-34.7	-11.5	-12.8	-12.9
52	15%BW	Female	-19.7	-24.3	-21.2	-19.0	-14.4	-12.5	-12.6
53	20%BW	Male	-20.2	-22.0	-29.6	-15.8	-9.5	-8.8	-4.5
54	20%BW	Male	-6.0	-10.4	-7.9	-13.0	4.0	2.0	1.6
55	20%BW	Male	-17.4	-17.9	-18.7	-19.0	-8.4	-7.7	-7.1
56	20%BW	Male	-16.3	-31.0	-36.7	-32.9	-2.3	-7.2	-0.6
57	20%BW	Male	-20.9	-22.4	-28.3	-23.6	-8.6	-5.8	-7.6
58	20%BW	Male	-19.4	-22.4	-27.8	-23.3	-3.9	-6.0	-7.8
59	20%BW	Male	-12.8	-15.8	-16.2	-23.1	-11.4	-5.6	-7.2
60	20%BW	Male	-7.4	-12.6	-13.0	-9.6	1.3	4.2	-0.2
61	20%BW	Male	-16.1	-12.4	-12.5	-8.3	-7.8	-4.7	-6.3
62	20%BW	Female	-12.0	-19.6	-12.9	-10.8	-4.6	-8.2	-8.5
63	20%BW	Female	-15.8	-13.2	-16.0	-16.9	-5.1	-3.5	-4.9

Refer to Table 3.1 for the abbreviations

Table A6.5 Raw data of the inclinations at L3

No.	Backpack weight	Gender	Inclination (°)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	5.9	-5.5	3.7	0.4	13.4	23.0	6.9
2	10%BW	Male	-1.3	-4.7	-5.4	-9.3	-1.7	2.4	3.4
3	10%BW	Male	3.5	4.2	5.1	5.8	3.4	7.7	8.1
4	10%BW	Male	8.3	4.8	8.3	7.3	8.9	8.2	6.6
5	10%BW	Male	4.3	4.9	6.8	6.7	5.9	4.4	4.9
6	10%BW	Male	-0.2	1.5	3.1	2.4	3.2	1.0	1.8
7	10%BW	Male	1.6	0.7	3.0	2.1	8.3	7.6	7.3
8	10%BW	Female	-16.1	-10.1	-10.2	-16.9	-12.9	-7.8	-11.9
9	10%BW	Female	9.7	7.4	5.7	1.4	12.6	15.6	17.8
10	10%BW	Female	9.3	4.5	17.4	3.0	13.0	11.9	20.7
11	10%BW	Female	2.0	-7.2	-7.2	-4.9	15.3	3.9	4.6
12	10%BW	Female	9.1	7.4	4.6	7.2	8.5	12.2	3.1
13	10%BW	Female	-9.1	-6.2	0.4	-1.5	2.4	0.0	4.4
14	10%BW	Female	6.2	5.0	5.7	5.8	6.6	3.7	5.4
15	10%BW	Female	3.6	8.0	8.3	7.0	7.3	7.8	7.9
16	10%BW	Female	4.1	2.1	3.2	-1.3	7.8	6.3	5.9
17	10%BW	Female	-1.0	2.7	1.0	1.6	0.8	2.4	0.7
18	10%BW	Female	5.8	5.7	4.6	6.6	6.6	6.2	4.8
19	10%BW	Female	-1.6	-0.9	-1.6	0.1	-0.2	0.4	-1.2
20	10%BW	Female	3.5	0.7	5.1	2.2	5.1	5.1	3.0
21	10%BW	Female	7.6	4.1	3.2	3.5	5.9	4.2	5.0
22	10%BW	Female	12.5	9.7	9.5	8.1	13.2	12.7	13.3
23	10%BW	Female	8.1	10.0	14.5	5.9	14.2	18.2	16.6
24	15%BW	Male	14.4	7.3	9.8	8.9	18.7	20.3	18.8
25	15%BW	Male	2.5	-4.8	-2.2	0.0	9.3	14.0	9.3
26	15%BW	Male	11.2	7.8	5.7	8.3	19.0	15.9	12.4
27	15%BW	Male	13.0	8.9	10.5	10.2	15.7	16.6	16.5
28	15%BW	Male	0.2	-1.3	2.6	-3.4	5.5	3.1	2.7
29	15%BW	Male	18.0	2.1	-0.6	13.8	28.1	30.1	22.6
30	15%BW	Male	6.5	-1.0	0.6	-0.3	10.4	10.2	15.7
31	15%BW	Male	11.9	-4.4	2.7	1.5	14.4	16.2	17.1
32	15%BW	Male	0.5	4.7	3.9	3.6	9.8	4.9	7.4
33	15%BW	Male	12.4	9.1	5.3	9.0	14.5	17.4	12.2
34	15%BW	Male	-4.7	-10.6	-6.0	-6.4	-7.1	2.5	-2.7
35	15%BW	Male	-7.0	-9.2	-2.9	-2.8	4.2	-9.0	8.3
36	15%BW	Male	-4.2	-4.4	-4.6	-3.7	2.2	1.5	-3.1
37	15%BW	Male	14.8	11.4	14.4	14.3	20.3	22.2	22.2
38	15%BW	Male	2.2	-5.0	-4.5	-1.0	13.6	6.7	6.6
39	15%BW	Male	9.1	6.3	6.7	5.3	9.3	10.0	7.4
40	15%BW	Female	0.6	0.7	-2.5	-1.9	-1.4	3.3	5.0

Table A6.5 (Cont'd) Raw data of the inclinations at L3

41	15%BW	Female	14.5	12.4	14.5	14.0	20.3	18.7	18.7
42	15%BW	Female	-11.2	-18.1	-18.0	-15.5	-10.5	-14.3	-6.8
43	15%BW	Female	15.7	14.9	18.1	15.6	13.1	11.7	14.9
44	15%BW	Female	12.7	3.9	5.1	5.8	18.3	17.8	20.1
45	15%BW	Female	10.5	5.0	10.0	6.1	16.3	17.1	15.1
46	15%BW	Female	11.7	-6.1	3.6	-1.4	19.2	20.7	21.2
47	15%BW	Female	12.3	-2.2	5.0	3.8	30.3	20.8	27.8
48	15%BW	Female	10.3	7.7	20.0	20.1	21.7	20.8	10.3
49	15%BW	Female	4.7	-10.7	-8.7	-8.0	8.2	7.1	8.6
50	15%BW	Female	-5.3	-6.8	-17.9	-20.3	1.1	3.9	-2.5
51	15%BW	Female	-12.9	-16.7	-18.4	-17.7	-4.8	-7.2	-12.2
52	15%BW	Female	6.9	4.0	5.0	6.8	7.9	7.8	6.7
53	20%BW	Male	16.6	14.1	20.4	9.4	24.7	24.9	25.9
54	20%BW	Male	6.9	11.1	9.9	16.4	8.7	7.2	9.3
55	20%BW	Male	4.1	8.7	8.7	-1.9	16.5	13.4	19.3
56	20%BW	Male	3.7	-15.9	-10.8	-13.5	4.0	-3.2	6.7
57	20%BW	Male	14.3	4.2	8.6	5.2	16.6	14.9	15.7
58	20%BW	Male	7.6	2.5	2.0	1.9	6.0	7.1	6.8
59	20%BW	Male	4.2	-3.7	-3.2	2.6	-4.2	1.0	1.3
60	20%BW	Male	9.2	7.8	11.6	10.6	2.9	12.5	8.0
61	20%BW	Male	9.0	7.1	8.0	8.4	11.3	7.5	10.0
62	20%BW	Female	4.3	4.0	5.8	4.7	8.2	6.0	6.2
63	20%BW	Female	3.7	0.8	2.3	1.8	2.5	4.8	4.3

Refer to Table 3.1 for the abbreviations

Table A6.6 Raw data of the inclinations at S1

No.	Backpack weight	Gender	Inclination (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	31.9	31.3	32.8	32.5	37.0	37.0	36.7
2	10%BW	Male	12.7	18.6	21.2	16.7	13.7	14.1	11.0
3	10%BW	Male	19.4	12.1	18.9	14.9	15.4	9.2	13.5
4	10%BW	Male	27.0	22.1	23.9	27.9	28.9	21.0	19.4
5	10%BW	Male	11.4	7.3	12.1	10.2	12.2	3.9	9.2
6	10%BW	Male	11.3	7.7	11.9	11.0	11.6	6.6	8.3
7	10%BW	Male	18.5	16.7	14.1	18.3	16.7	15.4	16.5
8	10%BW	Female	22.2	16.3	17.7	21.5	19.8	22.1	21.0
9	10%BW	Female	11.8	5.4	7.8	6.7	5.8	5.9	9.2
10	10%BW	Female	30.6	27.0	38.5	28.0	33.4	35.7	34.1
11	10%BW	Female	13.0	4.9	8.5	6.3	16.1	12.0	11.6
12	10%BW	Female	24.4	25.5	24.2	22.7	24.3	23.9	27.0
13	10%BW	Female	2.2	1.5	3.1	3.1	5.2	4.4	6.4
14	10%BW	Female	27.7	24.3	26.4	20.6	23.7	17.5	22.1
15	10%BW	Female	9.5	8.8	9.7	9.8	3.7	-0.5	2.4
16	10%BW	Female	18.2	12.0	14.1	16.5	18.5	16.6	16.5
17	10%BW	Female	10.2	13.4	13.8	14.2	8.4	9.3	9.1
18	10%BW	Female	17.6	16.2	17.1	16.8	10.0	2.7	14.0
19	10%BW	Female	11.4	13.9	10.8	13.9	14.9	11.6	14.8
20	10%BW	Female	27.8	22.5	29.1	26.9	16.5	6.5	24.8
21	10%BW	Female	5.5	16.2	18.6	17.0	19.8	16.2	13.4
22	10%BW	Female	22.1	16.7	21.3	13.9	2.1	-2.8	7.1
23	10%BW	Female	18.2	16.9	17.9	18.4	15.7	9.4	18.3
24	15%BW	Male	23.7	17.2	18.1	17.2	23.2	21.1	22.4
25	15%BW	Male	24.5	23.9	23.8	23.7	29.9	32.1	27.1
26	15%BW	Male	12.7	14.8	11.9	14.5	17.7	14.1	12.9
27	15%BW	Male	24.1	20.9	22.1	20.7	21.5	18.9	19.0
28	15%BW	Male	20.8	17.2	17.7	16.8	14.3	13.5	15.0
29	15%BW	Male	24.9	13.1	11.8	10.8	13.5	13.4	19.2
30	15%BW	Male	35.6	28.3	28.6	28.6	31.8	36.9	39.2
31	15%BW	Male	38.9	28.6	30.6	29.6	37.4	40.9	40.8
32	15%BW	Male	6.4	8.0	9.9	5.1	6.5	4.7	9.6
33	15%BW	Male	16.3	12.1	10.8	12.5	13.0	12.1	10.9
34	15%BW	Male	26.0	21.6	22.6	24.1	25.9	29.1	27.2
35	15%BW	Male	14.1	9.0	8.4	6.3	15.9	9.2	16.0
36	15%BW	Male	28.6	23.6	23.7	24.1	23.7	27.4	25.1
37	15%BW	Male	26.8	14.3	16.4	17.4	29.8	30.4	27.7
38	15%BW	Male	20.9	17.7	17.3	18.4	25.5	20.5	20.6
39	15%BW	Male	15.5	2.1	0.6	4.5	13.4	12.7	10.3
40	15%BW	Female	17.2	13.4	12.9	13.5	15.9	22.2	22.3

Table A6.6 (Cont'd) Raw data of the inclinations at S1

41	15%BW	Female	16.3	17.8	18.8	16.6	16.7	14.5	15.6
42	15%BW	Female	23.8	16.2	16.2	16.8	23.3	21.3	26.2
43	15%BW	Female	13.7	11.7	17.4	15.2	6.4	7.4	7.4
44	15%BW	Female	30.6	27.0	26.7	27.3	36.2	35.1	37.8
45	15%BW	Female	23.2	16.9	17.5	20.4	16.0	17.0	16.6
46	15%BW	Female	32.4	21.0	25.1	22.3	41.4	42.7	44.1
47	15%BW	Female	7.8	-3.9	0.9	-3.0	15.9	10.4	16.1
48	15%BW	Female	16.5	14.8	16.2	17.8	16.6	14.2	17.2
49	15%BW	Female	36.6	22.7	28.9	28.2	38.4	34.6	34.3
50	15%BW	Female	40.1	28.7	30.2	29.0	40.5	41.5	44.6
51	15%BW	Female	24.6	18.2	20.2	21.2	26.9	22.6	20.3
52	15%BW	Female	3.6	18.6	16.1	13.3	-4.9	-9.4	1.4
53	20%BW	Male	15.6	8.2	6.7	9.1	11.5	11.5	7.5
54	20%BW	Male	19.4	11.7	13.2	12.8	23.7	23.0	21.5
55	20%BW	Male	15.0	7.0	6.8	11.6	23.0	21.8	22.7
56	20%BW	Male	20.6	11.9	13.5	11.0	24.4	23.2	24.4
57	20%BW	Male	21.9	12.8	15.0	15.5	21.6	20.4	21.7
58	20%BW	Male	19.3	17.3	17.1	13.1	10.9	10.4	10.4
59	20%BW	Male	24.7	20.2	19.8	16.1	30.4	17.8	19.9
60	20%BW	Male	16.0	16.4	19.3	18.1	23.5	30.4	29.1
61	20%BW	Male	22.5	26.1	25.0	26.0	22.8	28.8	24.1
62	20%BW	Female	20.2	16.7	19.8	38.5	38.8	36.2	34.2
63	20%BW	Female	27.7	23.1	21.8	18.5	15.0	10.2	20.7

Refer to Table 3.1 for the abbreviations

Appendix 7 The Raw Data of the Repositioning Errors at Each Spine Level in Upright Stance

Table A7.1 Raw data of the repositioning errors at OC-C7 in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	2.3	2.1	2.8	4.0	4.8	3.0	2.9
2	10%BW	Male	1.6	3.1	3.1	2.4	2.5	2.6	3.8
3	10%BW	Male	3.9	7.1	8.6	9.6	7.2	8.2	3.3
4	10%BW	Male	3.8	6.2	5.1	3.1	4.1	3.4	4.0
5	10%BW	Male	1.2	2.9	3.5	8.9	3.0	3.7	1.8
6	10%BW	Male	4.6	3.3	4.0	2.6	2.4	2.2	4.0
7	10%BW	Male	2.7	1.6	5.4	1.7	2.4	1.2	2.1
8	10%BW	Female	3.4	2.0	3.2	1.8	2.3	2.9	3.4
9	10%BW	Female	3.3	3.3	2.7	5.4	5.1	4.8	4.8
10	10%BW	Female	2.3	3.7	3.6	1.8	2.5	1.9	1.8
11	10%BW	Female	2.4	4.1	3.4	5.4	4.0	2.7	3.5
12	10%BW	Female	1.5	1.1	1.8	1.5	3.5	1.6	2.1
13	10%BW	Female	2.6	3.1	3.2	2.3	2.4	2.6	2.1
14	10%BW	Female	1.4	2.3	1.2	1.1	5.5	1.4	1.6
15	10%BW	Female	2.6	4.3	5.8	6.1	3.4	5.2	4.4
16	10%BW	Female	2.7	3.8	5.3	4.7	3.2	3.5	3.3
17	10%BW	Female	2.3	2.3	4.2	3.4	1.2	1.2	2.1
18	10%BW	Female	2.7	5.4	5.3	3.7	6.5	5.2	4.6
19	10%BW	Female	3.5	5.4	2.3	4.4	5.3	3.3	1.4
20	10%BW	Female	4.3	2.5	5.5	4.7	3.7	3.7	1.8
21	10%BW	Female	3.2	4.0	5.4	2.5	2.6	2.5	1.4
22	10%BW	Female	3.7	3.3	2.3	4.4	5.2	5.4	4.5
23	10%BW	Female	4.8	8.5	4.2	5.3	3.0	2.1	3.1
24	15%BW	Male	2.3	3.1	3.1	1.5	2.4	3.1	1.9
25	15%BW	Male	2.0	2.6	3.8	2.1	2.3	5.1	3.9
26	15%BW	Male	2.7	3.2	3.2	2.9	4.3	2.3	1.1
27	15%BW	Male	2.3	4.9	4.8	2.6	5.5	4.7	2.8
28	15%BW	Male	3.2	2.2	3.5	4.2	1.5	2.7	2.2
29	15%BW	Male	4.7	6.1	6.1	6.7	6.0	4.4	6.6
30	15%BW	Male	1.9	3.7	2.8	4.5	4.4	4.4	6.8
31	15%BW	Male	4.2	8.1	8.9	5.8	4.6	6.1	3.7
32	15%BW	Male	4.2	3.5	1.3	2.8	7.2	3.8	2.7
33	15%BW	Male	3.0	4.3	4.1	3.3	6.4	4.3	4.1
34	15%BW	Male	1.9	4.1	5.5	3.0	2.9	4.9	3.6
35	15%BW	Male	4.7	4.3	3.3	2.0	1.0	1.6	2.4
36	15%BW	Male	3.6	4.5	6.4	5.0	1.7	2.6	6.4
37	15%BW	Male	5.3	6.1	5.2	6.3	3.8	5.9	1.2

Table A7.1 (Cont'd) Raw data of the repositioning errors at OC-C7 in upright stance

38	15%BW	Male	2.2	3.4	3.8	2.7	1.8	1.4	1.6
39	15%BW	Male	2.1	7.8	9.1	6.2	6.5	7.2	8.4
40	15%BW	Female	1.8	3.7	0.6	4.8	3.1	1.5	6.5
41	15%BW	Female	1.9	2.0	1.7	1.5	4.7	2.1	1.5
42	15%BW	Female	2.8	2.5	2.4	2.9	3.1	2.7	3.8
43	15%BW	Female	2.1	3.5	2.0	2.7	2.8	3.5	2.8
44	15%BW	Female	3.8	1.2	1.8	1.0	1.6	2.6	1.4
45	15%BW	Female	1.7	2.0	2.1	1.6	3.7	4.5	2.6
46	15%BW	Female	2.8	2.9	4.8	4.5	1.6	2.8	5.3
47	15%BW	Female	2.2	2.9	5.8	8.5	6.9	0.9	5.6
48	15%BW	Female	3.1	5.5	5.8	7.5	5.7	7.8	7.5
49	15%BW	Female	1.5	1.0	3.3	3.0	3.5	2.4	1.9
50	15%BW	Female	2.1	3.3	1.8	2.0	4.0	4.5	3.2
51	15%BW	Female	2.4	3.6	2.9	2.0	3.2	6.7	5.3
52	15%BW	Female	2.2	3.0	5.0	4.4	1.3	1.9	9.0
53	20%BW	Male	3.2	1.7	2.1	5.2	1.7	3.7	4.9
54	20%BW	Male	2.1	3.7	4.8	4.4	2.7	2.1	3.3
55	20%BW	Male	1.2	1.5	2.5	1.4	0.8	2.2	1.6
56	20%BW	Male	2.9	5.7	7.3	5.2	4.2	3.7	4.7
57	20%BW	Male	2.1	3.5	1.1	2.7	1.6	1.8	2.9
58	20%BW	Male	2.2	2.9	2.4	1.9	3.6	2.0	1.6
59	20%BW	Male	5.1	4.9	4.1	3.9	1.8	5.1	6.1
60	20%BW	Male	3.3	2.1	3.9	2.4	4.4	5.7	2.4
61	20%BW	Male	2.2	2.3	3.4	1.9	5.0	1.2	2.0
62	20%BW	Female	3.5	5.4	6.0	3.4	5.0	4.6	4.7
63	20%BW	Female	2.2	2.8	3.3	1.8	2.7	3.3	1.9

Refer to Table 3.1 for the abbreviations

Table A7.2 Raw data of the repositioning errors at C7-T7 in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	0.3	1.0	0.5	0.6	1.0	1.2	1.2
2	10%BW	Male	0.7	1.2	1.5	1.5	0.6	1.5	1.4
3	10%BW	Male	2.1	1.7	1.5	2.2	2.0	3.3	1.4
4	10%BW	Male	2.4	2.5	3.2	0.8	3.4	1.3	2.3
5	10%BW	Male	0.7	3.0	1.5	5.4	0.8	2.6	1.1
6	10%BW	Male	1.3	1.0	1.4	1.2	1.4	2.2	2.4
7	10%BW	Male	0.6	0.8	0.8	0.9	1.0	2.0	1.0
8	10%BW	Female	1.1	1.8	1.5	1.0	3.2	2.4	0.8
9	10%BW	Female	1.1	1.0	2.0	2.0	2.5	2.4	2.1
10	10%BW	Female	0.4	1.2	5.3	2.1	1.9	1.9	1.2
11	10%BW	Female	0.8	0.7	1.0	1.0	1.3	2.2	1.4
12	10%BW	Female	0.7	0.9	0.9	0.5	1.4	1.0	1.7
13	10%BW	Female	1.5	1.1	1.1	1.6	1.4	1.7	1.3
14	10%BW	Female	0.6	0.9	1.4	1.0	1.8	1.0	1.2
15	10%BW	Female	1.6	2.1	1.4	1.8	2.2	1.0	3.2
16	10%BW	Female	1.3	2.8	0.9	2.5	2.3	1.8	1.2
17	10%BW	Female	0.5	2.0	1.0	1.2	0.8	0.9	0.6
18	10%BW	Female	1.9	3.0	0.7	1.1	1.7	1.4	2.7
19	10%BW	Female	0.5	2.2	0.6	1.6	1.6	1.3	0.8
20	10%BW	Female	1.4	0.9	1.5	1.8	4.1	4.2	1.4
21	10%BW	Female	0.7	1.6	0.7	1.1	1.0	1.0	1.1
22	10%BW	Female	1.7	2.3	1.1	1.9	1.1	1.1	1.1
23	10%BW	Female	0.9	1.6	0.7	1.6	1.6	0.4	1.3
24	15%BW	Male	0.7	1.4	0.6	1.0	1.5	0.6	2.0
25	15%BW	Male	0.5	0.7	1.3	1.2	1.9	0.9	1.5
26	15%BW	Male	1.4	1.8	1.2	1.7	3.3	0.8	1.7
27	15%BW	Male	1.5	1.9	0.7	0.5	1.0	1.4	1.1
28	15%BW	Male	1.4	0.8	1.5	1.3	1.8	2.4	1.5
29	15%BW	Male	1.7	0.9	1.5	1.0	2.4	3.2	2.9
30	15%BW	Male	2.1	3.5	1.4	2.3	0.9	2.1	1.6
31	15%BW	Male	2.0	7.1	4.3	1.7	2.0	2.3	2.3
32	15%BW	Male	1.3	2.6	0.7	0.7	1.9	2.9	2.5
33	15%BW	Male	1.3	1.4	1.1	1.0	0.8	0.6	2.7
34	15%BW	Male	0.6	1.4	1.7	1.1	1.7	1.9	2.3
35	15%BW	Male	1.8	1.8	0.8	0.7	0.6	0.9	0.9
36	15%BW	Male	0.8	0.7	1.0	0.6	1.4	1.0	0.8
37	15%BW	Male	1.4	1.1	1.0	1.2	1.9	1.9	1.3
38	15%BW	Male	0.5	0.3	0.6	0.6	1.3	0.4	0.4
39	15%BW	Male	0.8	0.4	0.9	1.8	0.9	0.7	1.5
40	15%BW	Female	1.9	1.9	1.2	0.8	2.5	2.9	3.4

Table A7.2 (Cont'd) Raw data of the repositioning errors at C7-T7 in upright stance

41	15%BW	Female	0.4	0.5	0.8	0.6	0.8	1.2	0.7
42	15%BW	Female	2.0	2.0	2.0	2.5	1.8	3.5	1.4
43	15%BW	Female	1.4	4.2	2.5	1.8	0.7	1.4	1.4
44	15%BW	Female	0.9	0.8	2.9	1.3	1.2	1.0	1.1
45	15%BW	Female	1.4	0.9	1.6	1.0	1.9	1.4	1.3
46	15%BW	Female	1.7	1.2	3.3	2.3	2.0	3.0	1.8
47	15%BW	Female	1.4	1.4	1.6	4.6	3.0	2.1	2.0
48	15%BW	Female	1.0	0.6	1.3	0.8	1.0	1.0	1.4
49	15%BW	Female	1.3	0.5	0.5	0.7	2.8	3.6	1.9
50	15%BW	Female	0.5	0.5	0.5	0.3	0.8	0.7	0.5
51	15%BW	Female	0.8	2.9	2.0	2.2	1.2	0.6	0.9
52	15%BW	Female	0.7	0.5	0.9	0.7	1.1	2.0	2.8
53	20%BW	Male	1.3	1.0	0.7	1.3	2.1	2.2	1.9
54	20%BW	Male	0.3	1.3	1.0	1.3	1.5	1.1	0.9
55	20%BW	Male	1.5	2.8	1.0	1.9	1.3	1.4	2.4
56	20%BW	Male	2.7	2.8	3.4	4.7	2.7	1.4	0.9
57	20%BW	Male	0.6	1.8	0.6	1.8	0.9	0.7	1.2
58	20%BW	Male	2.1	2.8	2.0	3.1	3.3	2.3	3.1
59	20%BW	Male	1.3	2.4	3.4	4.9	3.2	1.6	3.4
60	20%BW	Male	0.9	0.6	1.0	1.7	0.9	4.0	2.5
61	20%BW	Male	1.6	0.9	1.7	1.0	1.5	5.6	3.3
62	20%BW	Female	1.7	3.0	2.3	1.4	1.7	1.6	1.5
63	20%BW	Female	1.6	1.8	0.8	2.0	1.3	1.5	1.5

Refer to Table 3.1 for the abbreviations

Table A7.3 Raw data of the repositioning errors at T7-T12 in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	1.2	0.7	0.8	1.5	1.2	2.1	1.6
2	10%BW	Male	1.7	0.8	1.2	0.6	2.1	1.9	2.0
3	10%BW	Male	1.6	3.3	4.8	4.1	2.1	0.6	1.9
4	10%BW	Male	1.9	2.6	7.4	1.7	2.7	2.9	2.8
5	10%BW	Male	0.8	3.2	0.9	4.0	0.5	1.1	0.5
6	10%BW	Male	1.9	1.9	1.5	1.6	2.2	1.4	0.6
7	10%BW	Male	1.7	2.4	1.7	1.9	1.7	1.0	2.2
8	10%BW	Female	0.8	0.8	1.6	0.6	1.2	1.3	0.9
9	10%BW	Female	0.3	0.8	1.7	1.3	3.0	1.7	1.6
10	10%BW	Female	1.0	1.7	1.8	2.5	1.2	2.7	1.7
11	10%BW	Female	0.5	0.5	1.4	1.2	2.4	2.0	0.5
12	10%BW	Female	1.6	3.0	1.3	1.4	1.6	0.8	1.1
13	10%BW	Female	1.2	1.4	0.8	1.8	2.4	0.8	1.2
14	10%BW	Female	0.7	0.7	0.3	0.6	1.0	1.3	0.6
15	10%BW	Female	1.9	1.8	2.0	2.5	1.3	1.3	2.5
16	10%BW	Female	1.9	1.8	2.1	3.1	1.7	0.8	2.5
17	10%BW	Female	0.7	0.7	0.6	0.6	0.7	0.6	0.7
18	10%BW	Female	0.4	0.8	0.4	0.6	1.0	1.9	1.1
19	10%BW	Female	1.7	1.0	1.2	0.6	1.1	0.9	0.9
20	10%BW	Female	2.2	1.0	0.3	1.2	1.4	3.0	1.3
21	10%BW	Female	1.0	2.7	0.9	0.9	0.9	0.9	1.0
22	10%BW	Female	2.0	2.2	1.8	2.0	1.7	1.0	1.0
23	10%BW	Female	1.8	1.1	0.7	0.8	2.1	1.7	2.7
24	15%BW	Male	1.6	0.5	0.9	1.3	1.6	1.2	3.6
25	15%BW	Male	1.1	2.0	1.7	1.3	3.3	2.2	1.8
26	15%BW	Male	0.9	0.9	1.1	2.0	1.3	0.8	0.2
27	15%BW	Male	0.9	0.8	1.3	0.8	1.6	1.5	1.1
28	15%BW	Male	0.6	1.7	0.9	1.2	2.7	2.1	2.8
29	15%BW	Male	2.5	5.1	2.2	3.9	3.9	2.0	5.4
30	15%BW	Male	1.3	2.1	1.6	1.6	3.9	2.8	2.6
31	15%BW	Male	1.1	3.2	4.6	2.6	6.5	8.0	6.2
32	15%BW	Male	1.8	2.1	2.3	2.5	0.8	0.8	1.2
33	15%BW	Male	2.8	2.4	1.0	2.0	0.8	1.1	1.6
34	15%BW	Male	0.4	0.9	2.8	1.8	2.3	2.6	0.9
35	15%BW	Male	0.6	2.1	1.2	1.2	0.2	1.0	0.9
36	15%BW	Male	1.2	1.5	1.7	0.7	0.8	0.2	0.1
37	15%BW	Male	2.1	0.6	2.3	2.3	2.1	4.0	1.5
38	15%BW	Male	0.7	0.9	1.9	2.0	1.7	1.2	0.5
39	15%BW	Male	1.8	2.2	1.8	3.0	2.4	2.5	3.3
40	15%BW	Female	2.0	1.2	2.1	3.0	2.9	1.2	2.2

Table A7.3 (Cont'd) Raw data of the repositioning errors at T7-T12 in upright stance

41	15%BW	Female	0.5	0.6	1.5	1.2	2.1	1.5	0.5
42	15%BW	Female	1.2	1.0	0.9	1.0	1.9	0.9	1.7
43	15%BW	Female	2.0	3.8	3.0	2.2	3.2	3.3	3.4
44	15%BW	Female	2.2	1.4	0.6	2.5	1.0	1.7	1.3
45	15%BW	Female	1.5	1.2	2.2	0.9	2.3	1.4	1.3
46	15%BW	Female	3.0	2.7	6.1	1.1	2.3	1.8	1.6
47	15%BW	Female	2.7	0.7	2.6	4.6	1.0	4.2	1.8
48	15%BW	Female	1.0	0.5	1.3	1.2	1.2	2.2	1.4
49	15%BW	Female	1.2	1.0	2.9	4.3	2.3	0.8	5.4
50	15%BW	Female	1.4	1.5	0.9	1.3	1.4	4.1	0.5
51	15%BW	Female	1.2	2.3	2.8	4.8	0.9	0.5	0.8
52	15%BW	Female	1.3	0.7	0.7	1.0	0.7	0.4	2.2
53	20%BW	Male	1.5	0.9	1.9	1.9	2.5	2.2	1.9
54	20%BW	Male	0.8	0.5	0.9	1.1	1.7	0.7	1.5
55	20%BW	Male	1.4	2.2	1.6	0.6	2.0	0.7	2.4
56	20%BW	Male	1.6	2.6	1.5	1.1	1.3	3.0	2.3
57	20%BW	Male	0.3	0.8	2.6	1.7	0.9	0.3	0.3
58	20%BW	Male	2.3	1.0	1.9	1.6	5.5	5.5	4.0
59	20%BW	Male	0.8	2.3	1.4	1.1	0.3	0.3	0.4
60	20%BW	Male	2.2	1.8	1.0	1.2	4.3	5.4	3.7
61	20%BW	Male	1.2	0.8	1.1	1.8	1.2	2.1	2.6
62	20%BW	Female	0.8	2.5	1.0	1.0	2.0	1.4	1.5
63	20%BW	Female	1.6	3.5	1.4	1.7	2.7	1.0	0.7

Refer to Table 3.1 for the abbreviations

Table A7.4 Raw data of the repositioning errors at T12-L3 in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	2.5	1.4	1.7	1.1	4.6	6.4	2.6
2	10%BW	Male	1.1	0.7	1.6	0.7	2.7	3.2	2.7
3	10%BW	Male	0.9	1.3	1.2	1.6	1.9	1.9	2.1
4	10%BW	Male	2.2	1.4	2.4	1.5	3.1	2.0	1.4
5	10%BW	Male	0.8	2.3	2.6	7.7	1.9	2.1	1.1
6	10%BW	Male	1.5	2.1	2.3	2.8	2.2	1.8	2.4
7	10%BW	Male	1.0	1.2	1.2	1.5	0.6	1.3	0.6
8	10%BW	Female	1.5	1.4	1.8	0.5	1.4	1.1	2.4
9	10%BW	Female	1.7	5.9	1.8	2.4	1.3	3.2	0.7
10	10%BW	Female	4.3	1.0	3.5	2.8	1.1	4.0	1.3
11	10%BW	Female	2.2	2.3	1.0	3.7	5.2	2.9	2.1
12	10%BW	Female	1.6	3.4	1.2	2.1	1.9	2.3	1.4
13	10%BW	Female	2.1	2.6	1.0	2.0	2.6	1.2	1.9
14	10%BW	Female	0.8	1.1	0.8	1.5	1.3	1.7	1.2
15	10%BW	Female	3.6	1.3	1.9	2.7	1.0	1.7	1.6
16	10%BW	Female	2.7	2.4	1.9	4.2	2.3	0.8	2.8
17	10%BW	Female	1.1	0.6	0.7	0.9	1.0	0.9	0.9
18	10%BW	Female	2.1	4.1	2.4	1.4	2.5	1.4	2.6
19	10%BW	Female	1.2	1.7	1.3	2.4	0.9	1.7	1.1
20	10%BW	Female	0.8	2.2	2.3	2.1	5.3	6.1	1.9
21	10%BW	Female	2.2	5.2	3.0	2.6	1.7	1.2	1.6
22	10%BW	Female	2.8	4.2	1.6	0.9	2.3	1.6	1.6
23	10%BW	Female	1.5	1.3	2.8	1.0	3.5	2.6	5.9
24	15%BW	Male	1.8	0.3	1.1	1.9	1.5	1.8	2.5
25	15%BW	Male	1.5	1.9	0.7	0.6	4.5	2.2	3.5
26	15%BW	Male	0.9	1.1	1.0	1.5	2.9	1.8	2.8
27	15%BW	Male	1.0	1.5	2.4	1.4	2.6	3.7	2.1
28	15%BW	Male	2.3	1.9	1.0	2.8	2.3	0.7	2.2
29	15%BW	Male	3.0	3.4	4.2	4.8	4.8	1.9	3.5
30	15%BW	Male	3.4	7.0	1.9	3.6	5.2	2.6	2.9
31	15%BW	Male	1.7	7.5	9.6	5.6	3.6	8.0	7.0
32	15%BW	Male	1.6	0.7	0.9	1.1	2.0	1.9	2.1
33	15%BW	Male	0.4	2.2	1.5	2.0	3.7	4.4	2.0
34	15%BW	Male	0.8	2.8	0.6	1.1	7.3	9.9	4.1
35	15%BW	Male	3.4	4.7	1.6	1.4	3.3	4.0	0.8
36	15%BW	Male	1.8	1.7	1.9	1.9	1.4	3.3	1.9
37	15%BW	Male	2.8	3.7	4.6	4.7	4.7	6.6	3.8
38	15%BW	Male	1.9	0.9	1.6	2.0	0.7	1.8	1.4
39	15%BW	Male	2.8	3.4	4.4	2.8	3.0	2.0	2.4
40	15%BW	Female	2.6	1.8	1.4	1.2	5.0	4.8	2.4

Table A7.4 (Cont'd) Raw data of the repositioning errors at T12-L3 in upright stance

41	15%BW	Female	0.9	1.2	2.1	1.2	1.5	0.4	0.8
42	15%BW	Female	1.9	0.4	0.4	1.4	0.8	3.0	3.2
43	15%BW	Female	3.8	7.4	2.8	2.8	3.3	1.1	3.1
44	15%BW	Female	1.2	2.5	2.5	4.3	1.8	2.9	1.0
45	15%BW	Female	2.0	1.1	1.4	1.9	2.3	1.3	0.7
46	15%BW	Female	2.0	3.4	7.6	4.2	1.6	1.0	1.4
47	15%BW	Female	1.5	4.3	3.7	8.4	5.3	3.7	3.9
48	15%BW	Female	1.0	0.9	2.1	1.4	1.9	2.1	2.4
49	15%BW	Female	2.3	1.6	2.0	3.7	2.8	2.4	5.3
50	15%BW	Female	1.0	4.1	2.0	1.5	3.6	2.4	2.1
51	15%BW	Female	1.3	3.5	4.2	4.6	1.4	3.5	3.1
52	15%BW	Female	1.5	1.0	1.5	1.4	1.0	1.4	2.7
53	20%BW	Male	2.1	1.4	2.4	1.3	3.1	5.3	4.7
54	20%BW	Male	1.0	1.6	3.0	1.1	1.3	2.6	3.3
55	20%BW	Male	2.3	1.4	1.5	1.7	4.9	3.6	2.3
56	20%BW	Male	1.8	1.3	3.2	2.9	2.9	2.8	3.3
57	20%BW	Male	3.1	0.8	3.2	1.1	1.0	2.8	2.5
58	20%BW	Male	1.8	2.0	2.3	1.7	4.1	3.0	3.1
59	20%BW	Male	1.6	3.5	4.1	2.9	1.6	2.8	2.8
60	20%BW	Male	1.4	1.7	1.7	1.4	2.5	2.0	5.5
61	20%BW	Male	1.7	2.8	2.0	1.5	1.6	1.3	2.7
62	20%BW	Female	2.0	2.4	2.9	2.3	2.9	2.8	2.0
63	20%BW	Female	1.6	2.8	2.0	3.3	3.9	2.7	3.2

Refer to Table 3.1 for the abbreviations

Table A7.5 Raw data of the repositioning errors at L3-S1 in upright stance

No.	Backpack weight	Gender	Repositioning Error (°)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	1.3	1.9	1.0	1.0	2.5	4.0	1.7
2	10%BW	Male	0.8	1.0	0.6	0.4	1.5	2.6	2.8
3	10%BW	Male	0.3	0.9	0.5	0.5	3.2	1.0	0.9
4	10%BW	Male	1.1	0.9	1.9	1.3	1.6	0.6	0.6
5	10%BW	Male	0.6	1.9	1.9	2.7	1.9	4.6	1.4
6	10%BW	Male	2.8	1.3	0.9	2.3	2.6	3.7	2.7
7	10%BW	Male	1.0	0.7	1.4	0.8	0.7	1.3	0.5
8	10%BW	Female	1.6	0.8	1.1	1.2	1.1	1.5	0.6
9	10%BW	Female	1.1	5.5	1.0	0.9	1.5	2.9	1.5
10	10%BW	Female	1.1	0.9	1.6	1.5	1.2	2.1	0.4
11	10%BW	Female	1.2	2.7	1.8	1.0	5.7	3.3	0.9
12	10%BW	Female	2.1	2.5	1.6	1.1	2.2	1.0	3.9
13	10%BW	Female	1.0	2.3	1.4	1.9	1.5	2.1	1.5
14	10%BW	Female	0.6	0.7	0.6	0.5	0.6	0.9	1.5
15	10%BW	Female	1.0	0.7	0.8	0.9	0.6	1.5	1.2
16	10%BW	Female	2.1	1.3	0.7	3.9	1.8	1.7	1.9
17	10%BW	Female	0.8	1.7	1.5	1.2	1.3	0.9	0.5
18	10%BW	Female	1.8	1.6	1.5	1.0	1.9	1.4	1.2
19	10%BW	Female	1.7	0.5	0.8	0.8	1.2	1.2	0.6
20	10%BW	Female	0.6	1.7	1.9	1.5	1.9	4.5	2.5
21	10%BW	Female	0.9	2.5	0.6	0.5	1.5	1.5	1.8
22	10%BW	Female	1.0	1.0	1.1	0.4	1.4	1.9	2.7
23	10%BW	Female	1.8	3.1	1.8	1.2	2.9	1.9	1.7
24	15%BW	Male	0.9	1.4	0.7	1.5	0.7	1.1	1.8
25	15%BW	Male	0.8	1.1	2.0	1.1	2.6	0.9	1.6
26	15%BW	Male	0.3	0.8	0.5	0.5	1.0	1.4	1.8
27	15%BW	Male	0.8	0.5	1.0	0.9	1.7	1.0	1.5
28	15%BW	Male	2.9	1.6	1.1	2.9	0.5	1.1	1.1
29	15%BW	Male	1.3	0.8	3.8	3.8	2.5	3.4	3.5
30	15%BW	Male	0.5	0.6	0.8	0.8	1.0	1.0	1.4
31	15%BW	Male	0.2	0.7	2.1	0.9	0.4	4.1	1.5
32	15%BW	Male	1.7	1.5	2.5	0.4	2.9	1.8	1.5
33	15%BW	Male	1.2	1.4	0.6	1.6	2.3	1.4	2.7
34	15%BW	Male	0.5	0.7	0.5	0.9	3.7	3.0	0.7
35	15%BW	Male	1.8	3.8	0.5	0.6	2.0	3.5	0.9
36	15%BW	Male	1.0	1.1	0.4	0.9	1.2	1.4	1.2
37	15%BW	Male	1.0	0.7	0.9	1.2	2.1	2.2	2.4
38	15%BW	Male	0.4	0.4	0.6	0.6	0.9	1.9	1.4
39	15%BW	Male	1.7	1.4	1.9	3.0	3.5	1.9	5.0
40	15%BW	Female	0.6	0.6	0.2	0.3	1.3	2.1	0.9

Table A7.5 (Cont'd) Raw data of the repositioning errors at L3-S1 in upright stance

41	15%BW	Female	0.6	0.4	0.8	0.4	1.2	0.7	1.2
42	15%BW	Female	0.8	0.4	0.4	0.4	1.2	1.0	0.5
43	15%BW	Female	2.8	4.4	3.6	3.0	2.6	1.9	2.7
44	15%BW	Female	0.9	0.3	0.4	0.3	0.3	0.4	0.3
45	15%BW	Female	0.9	0.7	0.9	2.6	0.5	1.3	0.8
46	15%BW	Female	1.2	0.7	2.7	0.6	2.1	2.8	1.9
47	15%BW	Female	0.5	2.1	0.6	1.2	1.0	0.7	2.1
48	15%BW	Female	1.0	1.4	1.5	1.1	1.6	0.6	1.9
49	15%BW	Female	0.5	0.9	0.9	0.4	1.8	1.8	3.6
50	15%BW	Female	1.6	1.0	1.6	2.9	2.5	3.1	2.5
51	15%BW	Female	0.6	2.2	1.7	0.7	1.3	0.6	1.4
52	15%BW	Female	0.9	2.6	2.4	6.0	1.9	2.2	1.9
53	20%BW	Male	0.9	0.5	0.5	1.3	2.9	1.4	1.3
54	20%BW	Male	0.7	1.6	1.6	1.0	1.6	1.6	2.0
55	20%BW	Male	0.7	0.6	0.4	1.0	4.2	3.1	2.5
56	20%BW	Male	1.1	1.2	1.1	1.1	1.7	1.2	2.0
57	20%BW	Male	0.5	2.6	0.8	1.5	0.4	1.2	0.9
58	20%BW	Male	0.2	0.5	0.7	0.7	4.8	2.1	3.6
59	20%BW	Male	1.6	2.6	2.8	2.1	1.5	2.3	2.6
60	20%BW	Male	1.8	0.6	0.8	1.5	4.4	1.3	3.3
61	20%BW	Male	0.9	0.7	0.5	1.3	2.1	5.7	3.5
62	20%BW	Female	0.5	1.0	1.0	2.6	2.2	2.5	2.2
63	20%BW	Female	1.4	0.4	1.1	0.7	1.7	2.1	0.6

Refer to Table 3.1 for the abbreviations

Table A7.6 Raw data of the repositioning errors at S1-Vertical in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	0.9	0.8	1.0	0.7	2.2	2.6	0.6
2	10%BW	Male	0.8	1.0	0.5	1.4	1.3	3.0	2.6
3	10%BW	Male	0.7	1.6	1.2	1.3	5.4	1.3	1.4
4	10%BW	Male	1.9	1.4	3.2	1.4	2.3	2.0	1.3
5	10%BW	Male	0.9	3.4	2.9	4.3	2.7	5.5	2.1
6	10%BW	Male	3.8	1.5	1.2	3.2	2.6	4.1	3.2
7	10%BW	Male	0.8	0.5	1.5	0.9	0.5	2.0	0.8
8	10%BW	Female	0.6	1.3	0.9	1.3	1.3	2.4	1.5
9	10%BW	Female	1.3	0.9	1.2	1.3	1.3	3.3	0.8
10	10%BW	Female	1.8	1.2	1.4	2.0	1.7	1.9	0.9
11	10%BW	Female	1.1	1.7	0.6	2.3	4.7	2.1	2.1
12	10%BW	Female	1.8	1.3	1.2	1.5	2.5	1.1	3.1
13	10%BW	Female	1.8	2.1	1.6	2.8	2.5	1.5	1.8
14	10%BW	Female	0.9	0.8	0.6	0.4	0.8	1.3	1.6
15	10%BW	Female	1.5	0.8	0.7	1.0	0.6	1.7	2.0
16	10%BW	Female	1.5	1.4	0.8	3.0	2.8	2.6	2.3
17	10%BW	Female	0.6	1.8	1.6	1.6	1.0	0.9	0.4
18	10%BW	Female	1.0	1.3	1.2	0.9	1.9	1.3	1.3
19	10%BW	Female	1.3	1.3	0.5	1.5	1.3	0.8	1.0
20	10%BW	Female	1.8	1.5	1.7	1.5	2.8	5.2	3.0
21	10%BW	Female	1.4	3.7	1.2	1.0	1.6	1.1	2.0
22	10%BW	Female	1.1	1.4	1.1	1.0	1.4	1.4	2.6
23	10%BW	Female	2.5	3.1	2.5	1.0	1.6	1.2	2.0
24	15%BW	Male	0.4	0.8	0.8	1.3	1.0	0.4	1.5
25	15%BW	Male	2.3	1.7	1.9	1.2	3.4	1.7	2.2
26	15%BW	Male	0.4	1.2	0.9	0.8	1.1	1.1	0.7
27	15%BW	Male	0.7	0.4	1.4	0.5	2.0	2.8	1.7
28	15%BW	Male	0.5	0.8	0.8	0.9	1.8	1.7	2.1
29	15%BW	Male	1.5	1.7	1.7	2.8	2.7	2.7	3.0
30	15%BW	Male	1.2	0.8	1.5	1.7	1.2	2.5	1.4
31	15%BW	Male	0.7	1.0	1.3	2.1	3.4	7.8	5.3
32	15%BW	Male	2.1	2.7	1.8	3.4	3.1	1.5	1.6
33	15%BW	Male	1.1	1.3	1.6	1.0	0.9	1.5	0.6
34	15%BW	Male	0.5	1.3	0.7	1.3	2.7	5.5	2.5
35	15%BW	Male	1.1	1.1	1.2	0.8	1.6	2.5	1.1
36	15%BW	Male	0.8	1.2	1.6	1.3	1.2	1.0	1.3
37	15%BW	Male	2.3	1.4	1.7	1.4	4.3	6.1	4.3
38	15%BW	Male	0.5	0.4	0.8	0.9	0.5	0.7	0.3
39	15%BW	Male	2.8	1.9	2.3	4.2	5.4	3.5	7.2
40	15%BW	Female	1.3	1.9	1.1	1.5	1.8	1.6	1.8

Table A7.6 (Cont'd) Raw data of the repositioning errors at S1-Vertical in upright stance

41	15%BW	Female	1.4	1.6	1.0	0.6	2.2	0.6	2.0
42	15%BW	Female	0.6	1.1	1.0	1.3	0.6	1.9	2.2
43	15%BW	Female	1.1	2.0	2.5	3.3	1.2	1.3	2.9
44	15%BW	Female	0.8	1.2	0.4	1.0	1.6	2.2	1.4
45	15%BW	Female	1.3	0.7	1.4	1.3	2.2	2.9	1.3
46	15%BW	Female	2.7	0.9	1.7	1.5	1.2	2.4	2.4
47	15%BW	Female	1.1	0.9	2.8	3.6	2.7	2.3	2.0
48	15%BW	Female	0.7	2.0	1.4	0.6	1.8	1.8	2.0
49	15%BW	Female	1.1	1.0	0.9	0.8	1.4	2.0	3.1
50	15%BW	Female	1.7	1.4	1.0	1.5	4.2	2.2	2.2
51	15%BW	Female	1.8	1.2	1.3	1.7	1.0	1.9	2.3
52	15%BW	Female	1.1	2.5	2.5	6.4	1.5	2.8	0.9
53	20%BW	Male	1.1	1.3	0.5	1.7	1.6	4.0	3.0
54	20%BW	Male	0.7	1.7	1.2	0.7	1.4	0.4	1.8
55	20%BW	Male	1.3	2.4	1.1	0.9	0.7	2.1	2.6
56	20%BW	Male	1.8	1.3	2.4	1.4	3.0	5.0	4.9
57	20%BW	Male	0.8	0.6	1.1	1.5	1.9	1.5	1.6
58	20%BW	Male	1.6	1.0	1.1	1.5	1.0	1.5	1.9
59	20%BW	Male	1.9	2.4	2.7	2.4	2.1	2.4	2.3
60	20%BW	Male	1.8	2.0	1.4	2.8	3.8	1.9	2.9
61	20%BW	Male	0.8	0.6	1.0	1.8	3.5	4.8	4.3
62	20%BW	Female	1.2	0.8	1.4	1.3	2.0	2.2	2.3
63	20%BW	Female	0.4	0.6	1.7	0.8	1.5	2.4	0.5

Refer to Table 3.1 for the abbreviations

Table A7.7 Raw data of the repositioning errors at C7-T12 in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	AT7	AT12	AL3	PT7	PT12	PL3
1	10%BW	Male	1.4	1.6	1.1	2.0	1.7	1.6	1.3
2	10%BW	Male	2.0	1.6	1.2	1.7	1.9	1.6	0.8
3	10%BW	Male	2.3	3.3	4.6	5.2	4.2	3.2	2.3
4	10%BW	Male	4.0	3.8	8.0	1.6	6.0	3.9	3.6
5	10%BW	Male	1.2	6.0	1.8	9.2	1.0	2.8	1.1
6	10%BW	Male	2.1	2.0	1.7	1.6	1.1	2.3	2.0
7	10%BW	Male	1.9	2.7	1.4	2.4	2.1	2.9	2.9
8	10%BW	Female	1.7	2.1	2.6	0.9	3.0	1.5	1.3
9	10%BW	Female	0.9	1.6	2.8	1.8	4.1	2.9	3.1
10	10%BW	Female	1.2	2.5	4.7	4.0	2.2	3.1	1.6
11	10%BW	Female	1.2	1.0	2.2	0.7	1.8	2.1	1.1
12	10%BW	Female	2.0	3.6	1.9	1.8	2.5	1.6	2.8
13	10%BW	Female	2.7	2.0	1.9	3.2	2.1	1.9	1.2
14	10%BW	Female	1.1	1.5	1.1	1.1	2.0	1.3	1.5
15	10%BW	Female	2.4	2.6	3.1	3.8	2.9	1.0	4.9
16	10%BW	Female	4.0	3.7	1.9	3.5	3.5	1.3	2.9
17	10%BW	Female	0.9	1.7	1.5	0.8	1.4	1.3	1.1
18	10%BW	Female	2.1	2.8	1.0	1.7	2.0	3.1	3.7
19	10%BW	Female	2.1	2.5	1.6	1.5	2.1	1.0	0.8
20	10%BW	Female	3.2	1.9	1.7	2.8	4.5	7.1	1.7
21	10%BW	Female	1.6	3.0	1.6	1.6	0.7	1.4	0.7
22	10%BW	Female	3.1	4.3	2.8	3.6	1.8	1.8	1.6
23	10%BW	Female	1.9	2.2	1.3	1.9	2.9	1.9	3.5
24	15%BW	Male	2.3	1.5	1.2	2.0	2.6	1.6	3.7
25	15%BW	Male	1.4	1.7	1.4	1.6	1.9	1.9	1.4
26	15%BW	Male	1.5	1.6	1.9	2.6	4.0	1.0	1.7
27	15%BW	Male	1.5	2.1	1.4	0.7	2.0	1.9	1.1
28	15%BW	Male	2.0	2.4	2.1	2.4	1.3	2.3	2.4
29	15%BW	Male	2.4	5.5	2.2	4.6	5.0	3.9	7.6
30	15%BW	Male	3.2	6.1	2.8	1.9	7.6	2.6	3.5
31	15%BW	Male	1.9	5.2	8.6	3.0	5.0	5.9	4.6
32	15%BW	Male	2.5	4.2	2.1	2.7	1.9	2.4	2.4
33	15%BW	Male	4.0	1.6	1.7	2.2	1.3	1.4	3.9
34	15%BW	Male	0.9	1.7	4.2	2.5	2.0	4.2	2.1
35	15%BW	Male	1.7	1.8	2.0	1.1	0.6	1.4	0.7
36	15%BW	Male	0.9	1.7	1.4	0.5	1.0	1.1	0.8
37	15%BW	Male	2.0	1.5	2.5	2.5	1.5	2.7	1.9
38	15%BW	Male	0.7	0.9	1.8	2.2	0.6	1.1	0.6
39	15%BW	Male	3.6	2.3	1.6	3.3	3.2	2.9	2.8
40	15%BW	Female	4.6	2.8	2.5	3.8	5.2	3.4	3.5

Table A7.7 (Cont'd) Raw data of the repositioning errors at C7-T12 in upright stance

41	15%BW	Female	0.6	0.9	1.6	0.9	2.5	1.4	0.8
42	15%BW	Female	2.7	2.7	2.6	3.4	2.8	2.9	2.2
43	15%BW	Female	5.0	5.4	2.9	1.8	3.1	2.1	3.2
44	15%BW	Female	2.0	1.4	3.3	3.5	0.8	1.9	2.1
45	15%BW	Female	2.2	1.5	3.2	1.6	3.0	1.1	2.2
46	15%BW	Female	3.7	3.4	5.6	2.3	3.5	3.9	2.4
47	15%BW	Female	3.8	1.6	3.7	7.0	3.3	5.2	3.4
48	15%BW	Female	0.4	0.9	2.5	1.4	1.3	2.8	0.8
49	15%BW	Female	1.3	1.0	3.1	4.7	3.5	3.7	7.2
50	15%BW	Female	2.2	4.8	0.9	1.1	2.1	4.2	0.5
51	15%BW	Female	1.3	4.6	4.4	6.9	1.3	0.6	1.0
52	15%BW	Female	1.3	0.7	0.6	0.5	1.5	1.9	3.0
53	20%BW	Male	2.5	1.1	1.7	2.2	1.6	2.7	3.2
54	20%BW	Male	0.6	1.0	1.4	1.9	2.9	1.0	1.8
55	20%BW	Male	1.9	4.5	2.1	2.1	3.1	1.3	4.4
56	20%BW	Male	4.4	3.4	5.3	4.6	3.2	3.0	1.9
57	20%BW	Male	0.6	1.6	2.3	2.0	0.9	0.8	1.3
58	20%BW	Male	2.9	3.2	3.7	4.4	5.7	7.4	3.6
59	20%BW	Male	1.6	1.3	4.1	5.6	3.3	1.6	3.6
60	20%BW	Male	1.8	1.8	1.9	1.8	4.1	3.1	2.6
61	20%BW	Male	3.1	3.4	2.6	2.1	1.9	5.4	4.4
62	20%BW	Female	2.3	2.1	3.0	1.2	3.4	1.8	1.6
63	20%BW	Female	1.8	2.3	1.2	3.2	2.2	1.6	1.5

Refer to Table 3.1 for the abbreviations

Table A7.8 Raw data of the repositioning errors at T12-S1 in upright stance

No.	Backpack weight	Gender	Repositioning Error (º)						
			NoBP	**AT7**	**AT12**	**AL3**	**PT7**	**PT12**	**PL3**
1	10%BW	Male	1.6	1.6	1.9	2.0	3.9	3.5	1.3
2	10%BW	Male	1.9	1.4	1.7	1.0	3.0	5.1	2.7
3	10%BW	Male	1.1	1.1	1.5	1.4	3.8	2.8	2.7
4	10%BW	Male	2.0	1.5	5.4	1.7	4.1	2.1	1.9
5	10%BW	Male	1.2	3.1	5.4	5.7	3.7	5.3	1.9
6	10%BW	Male	4.1	3.4	2.3	4.4	4.1	5.3	5.0
7	10%BW	Male	1.8	1.8	2.1	1.8	1.0	2.4	0.8
8	10%BW	Female	0.5	1.2	1.5	1.2	1.7	1.7	1.9
9	10%BW	Female	1.5	1.2	2.1	1.8	1.4	4.7	1.3
10	10%BW	Female	5.0	0.6	2.3	2.6	1.0	2.7	1.4
11	10%BW	Female	1.5	3.5	1.3	3.8	4.7	4.8	2.4
12	10%BW	Female	3.0	4.2	1.3	1.8	3.9	1.6	4.5
13	10%BW	Female	1.7	2.4	2.0	1.1	2.7	2.1	2.3
14	10%BW	Female	0.6	1.1	0.9	1.3	1.0	2.4	1.1
15	10%BW	Female	1.2	1.8	2.1	2.1	1.0	1.3	1.5
16	10%BW	Female	1.9	1.4	1.7	1.6	4.1	2.2	4.3
17	10%BW	Female	0.9	2.1	1.5	0.8	1.3	0.5	0.7
18	10%BW	Female	1.1	3.4	1.8	0.6	2.6	1.2	2.8
19	10%BW	Female	2.5	1.7	1.3	2.7	1.1	0.9	1.2
20	10%BW	Female	0.7	2.0	1.4	3.1	3.9	4.2	3.6
21	10%BW	Female	2.5	3.3	3.0	2.7	1.7	1.1	1.7
22	10%BW	Female	1.9	3.9	1.0	1.0	2.7	1.9	2.3
23	10%BW	Female	2.8	2.3	4.0	0.8	2.3	2.2	4.7
24	15%BW	Male	1.4	1.7	1.3	1.5	1.3	0.9	3.8
25	15%BW	Male	1.3	1.5	2.0	1.6	2.6	1.7	2.6
26	15%BW	Male	0.8	1.9	1.0	1.6	2.9	1.8	1.1
27	15%BW	Male	0.7	1.7	3.2	1.6	2.3	4.4	2.4
28	15%BW	Male	1.2	1.3	1.7	0.7	2.2	0.9	1.2
29	15%BW	Male	1.8	2.7	2.8	2.2	2.5	2.4	1.5
30	15%BW	Male	3.7	5.0	2.5	3.4	5.5	2.3	2.7
31	15%BW	Male	1.7	5.0	4.0	4.8	3.6	7.6	6.4
32	15%BW	Male	1.6	1.9	2.5	1.2	4.3	0.4	1.5
33	15%BW	Male	1.1	1.1	1.8	1.8	2.6	3.8	1.5
34	15%BW	Male	0.9	3.4	0.8	1.6	3.9	7.0	3.8
35	15%BW	Male	2.7	3.2	1.4	1.4	2.2	3.3	1.1
36	15%BW	Male	1.5	2.5	2.1	2.4	2.1	2.3	2.1
37	15%BW	Male	3.5	3.9	4.8	5.0	5.1	6.2	6.7
38	15%BW	Male	2.0	0.9	2.1	2.1	1.3	0.4	0.8
39	15%BW	Male	3.5	4.4	5.8	4.7	6.3	3.2	7.1
40	15%BW	Female	2.3	1.3	1.5	1.0	4.4	3.6	1.9

Table A7.8 (Cont'd) Raw data of the repositioning errors at T12-S1 in upright stance

41	15%BW	Female	1.2	1.4	2.7	1.2	2.5	1.0	1.4
42	15%BW	Female	1.4	0.5	0.5	1.5	0.7	3.3	3.0
43	15%BW	Female	4.8	2.4	1.6	3.4	2.1	1.7	2.5
44	15%BW	Female	1.0	2.5	2.6	4.3	1.8	2.6	1.2
45	15%BW	Female	2.1	0.5	1.2	1.2	2.5	2.1	1.0
46	15%BW	Female	2.5	3.8	7.6	4.6	3.1	2.9	3.1
47	15%BW	Female	1.6	2.5	4.1	3.6	4.7	3.3	1.9
48	15%BW	Female	0.6	1.4	2.1	2.2	1.5	1.9	2.0
49	15%BW	Female	2.8	2.2	2.4	3.7	3.1	4.1	4.9
50	15%BW	Female	2.5	1.8	1.9	2.5	5.9	3.6	2.4
51	15%BW	Female	1.7	3.4	2.1	5.1	0.5	3.1	3.6
52	15%BW	Female	0.9	3.4	1.8	3.8	1.2	3.3	2.5
53	20%BW	Male	1.8	1.6	2.4	2.4	2.8	4.8	3.7
54	20%BW	Male	0.8	1.1	1.9	1.1	2.4	2.1	1.9
55	20%BW	Male	2.3	1.7	1.3	3.2	3.5	4.3	4.1
56	20%BW	Male	3.5	2.7	3.7	3.0	4.2	4.7	3.9
57	20%BW	Male	2.7	3.1	2.7	1.6	1.1	2.0	3.0
58	20%BW	Male	2.9	2.4	2.8	1.1	4.7	3.4	3.3
59	20%BW	Male	1.6	4.1	3.1	2.3	2.9	3.5	2.9
60	20%BW	Male	1.0	2.0	1.7	2.7	3.4	1.0	2.7
61	20%BW	Male	1.2	3.4	2.3	2.9	2.1	3.4	5.1
62	20%BW	Female	2.1	3.1	3.2	3.2	4.7	3.2	3.7
63	20%BW	Female	1.8	2.8	1.5	2.9	4.0	4.6	2.9

Refer to Table 3.1 for the abbreviations