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Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological and subjective measures

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Recommendations on backpack loading advice restricting the load to 10% of body weight and carrying the load high on the spine. The effects of increasing load (0%–5%–10%–15% of body weight) and changing the placement of the load on the spine, thoracic vs. lumbar placement, during standing and gait were analysed in 20 college-aged students by studying physiological, biomechanical and subjective data. Significant changes were: (1) increased thorax flexion; (2) reduced activity of M. erector spinae vs. increased activation of abdominals; (3) increased heart rate and Borg scores for the heaviest loads. A trend towards increased spinal flexion, reduced pelvic anteversion and rectus abdominis muscle activity was observed for the lumbar placement. The subjective scores indicate a preference for the lumbar placement. These findings suggest that carrying loads of 10% of body weight and above should be avoided, since these loads induce significant changes in electromyography, kinematics and subjective scores. Conclusions on the benefits of the thoracic placement for backpack loads could not be drawn based on the parameter set studied.

Keywords: Backpack; Load; Musculoskeletal adaptation; Subjective score

1. Introduction

Back pain in young people has been associated with heavily loaded backpacks (Negrini and Carabalona 2002, Sheir-Neiss et al. 2003, Korovessis et al. 2004). Backpacks exceeding 15% of body weight (BW) are carried by 30–54% of school children (Limon et al. 2004) and loads exceeding 30% of BW are carried by 34.8% of Italian school children (Negrini et al. 1999).

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The prevalence of back pain increases from under 10% in pre-teenagers to 50% in teenagers (Sheir-Neiss et al. 2003). Furthermore, researchers have found that the weight of school bags appears to influence the persistence of lower back pain (Szpalski et al. 2002). Children who experience back pain may be predisposed to suffering back pain in adult life (Grimmer and Williams 2000, Mackenzie et al. 2003, Steele et al. 2003). As a consequence, precautionary steps to reduce weight in school bags are necessary (Grimmer et al. 2002, Negrini and Carabalona 2002).

To prevent back pain, limitations of maximal backpack weight from 10–15% up to 20% of BW have been recommended: A load of 10% of BW was suggested by Li et al. (2003) for 10-year-old children, since no significant changes in trunk posture and respiratory variables were detected while walking on a treadmill with a backpack of 10% of BW. Additionally, it has been shown that trunk forward lean (Hong and Brueggemann 2000) and forward head position (Chansirinukor et al. 2001) increased for loads exceeding 10% of BW. Also based on trunk inclination, Hong and Cheung (2003) determined the permissible backpack load to be 15% of BW. Mackenzie et al. (2003) found a relationship between back pain and backpack load exceeding 15% to 20% of BW.

Previous studies have reported that not only the magnitude of load but also the position of the backpack might influence efficient posterior load carriage. Efficient load carriage has been associated with minimal energy expenditure and minimal spinal tissue stress. Spinal tissue stress is related to altered posture (i.e. posture that deviates from gravitational alignment; Grimmer et al. 2002). In the horizontal plane, positioning of the load close to the body’s centre of gravity has been reported to minimize energy expenditure (Cook and Neumann 1987). In the vertical plane, it remains unclear whether high or low positioning on the spine is optimal. Grimmer et al. (2002) found the greatest forward lean of the body with backpack centre at T7 in static condition and therefore recommend the low position. This contradicts the study of Bloom and Woodhull-McNeal (1987), who report a greater forward lean of the body and greater uncompensated torque at the hips while standing with the backpack centre lower and closer to the body.

In gait, vertical placement of the backpack is even more important. Bobet and Norman (1984) report that load placement above shoulder level produces higher moments around L5/S1 disc (centre of rotation) compared with lower load placement, due to the difference in rotational inertia of the load. Additionally, they found higher levels of upper trapezius and erector spinae activity in thoracic load placement.

However, in general, a high position of the load is typically recommended (Bloom and Woodhull-McNeal 1987, Orloff and Rapp 2004). Orloff and Rapp (2004) warn that the observed more upright position associated with the lumbar position of the load may be associated with increased curvature of the spine, since participants do not counterbalance the weight of the backpack with trunk flexion.

Whereas previous studies focused on a selection of either physiological or biomechanical parameters, this study is innovative since it focuses on changes in physiological (surface electromyography (EMG) of seven muscles, heart rate), biomechanical (joint angles) as well as subjective (Borg scale, position preference) variables during standing and gait under different loading conditions. Changes in each of these variables will be referenced by the authors as strain variables or physical strain.

This study tests two hypotheses. The first hypothesis is that increased backpack load causes significant changes in the strain variables. It is expected from the recommendations from literature (Hong and Brueggemann 2000, Chansirinukor et al. 2001, Li et al. 2003, Chow et al. 2005) that a backpack load exceeding 10% of BW will cause significant changes in the strain variables. The second hypothesis is that physical strain differs
between carrying loads at the thoracic level compared to the lumbar level. It is expected from the recommendations in the literature (Bloom and Woodhull-McNeal 1987, Orloff and Rapp 2004, Stuempfle et al. 2004) that more physical strain can be observed for the lumbar position.

2. Methods

2.1. Participants

A total of 20 college-aged students (12 male, eight female) volunteered to participate in this study and gave their informed consents. Participants were healthy and had no acute back or neck complaints. Their mean age, stature and weight were 23.9 (SD 2.59) years, 175.63 (SD 7.14) cm and 69.41 (SD 7.68) kg, respectively. Due to missing kinematic data at the time of registration for one subject, kinematics and EMG results are only available for 19 participants.

2.2. Protocol

To investigate the effect of increased loading, four load conditions were selected: carrying an empty backpack (0% BW), carrying a backpack with 5%, 10% and 15% of the subject’s BW. A two-strap backpack (Samsonite, 400 Series Inventure; Ict Backpack 41 126 * 041, Samsonite Corporation). Care was taken to have a uniform vertical and horizontal load distribution, avoiding concentration of load.

To study position effects, two placements were selected: thoracic placement with the top of the backpack on the shoulder line; and lumbar placement with the bottom of the backpack carried just above the spina iliaca posterior superior. The mean difference between the two placements was 6.5 (SD 1.9) cm. The first ten participants began with thoracic placement of the backpack, the following ten with lumbar placement. Loading conditions were randomized. During standing and gait, each subject performed two trials for each loading condition and each backpack position. For the standing condition, each subject was instructed to stand still for 1 min, looking straight ahead. Data were collected for 1 s, before and after this minute. For the dynamic (walking) condition, measurements were valid if two consecutive force plate strides were obtained. The first dynamic measurement was followed by 5 min walking on a walking platform. Thereafter, a second dynamic measurement was taken and heart rate was recorded. Immediately after the second data capture, participants were asked to rate their feelings of discomfort on Borg’s category rating 10 scale (Borg 1982). Participants rested for 3 min between different load conditions. After the complete test protocol, participants were asked the preferred placement, lumbar or thoracic.

2.3. Data capture

2.3.1. Kinematics. Three dimensional trajectories of 41 markers were obtained with a 6 camera Vicon system (VICON 370, version 2.5; Oxford Metrics, Oxford, UK) with a sampling frequency of 120 Hz. A standardized marker placement protocol (Vicon) was used for the marker placement. Marker clusters were foreseen to account for extrapolation of markers hidden by the backpack. Joint angles were calculated by Vicon software using a modified Plug-In-Gait model.

For the standing condition, mean angle of head, neck, thorax, spine, pelvis, right and left hip were analysed based on the mean of the two static measurements (before and after
1 min). Head, thorax and pelvis angles are absolute angles of the segments with regard to the global reference coordinate system. The neck angle is the relative angle between head and thorax. The spine angle is the angle between thorax and pelvis, whereas the hip angle is defined by pelvis and femur. During gait, kinematics were normalized with regard to the duration of the gait cycle. The trial immediately following the 5 min walking was analysed. Mean angle and range of motion (ROM) of the same angles defined in stance were calculated.

Spatiotemporal variables analysed in this study are single support duration, double support duration, stance duration, swing duration, stride time and walking velocity.

2.3.2. Electromyography. Surface EMG data of seven muscle groups were collected using a portable integrated EMG-module (16 channels K-Laboratory EMG system, the Netherlands). The seven muscles included were: M. trapezius pars descendens (TRAP), M. sternocleidomastoideus (STCL), M. erector spinae longissimus (ES), M. rectus abdominis (RA), M. obliquus externus abdominis (AO), M. rectus femoris (RF) and M. biceps femoris (BiFe). Silver/silver pellet electrodes with a 0.5 cm active surface were placed on the muscles according to standard procedures advised by SENIAM (Hermens et al. 1999).

EMG-signals were recorded with a sampling frequency of 1.5 KHz. The EMG signal was high pass filtered with a cut-off frequency at 20 Hz and amplified. This raw signal of the EMG was rectified and subsequently low pass filtered (cut-off frequency at 25 Hz). For the standing condition, the mean value of the linear envelope was calculated for 1 s. For the walking condition, the mean linear envelopes of the left and right muscles were obtained during a left and right stride, respectively.

2.3.3. Subjective score and heart rate. Subjective feelings of discomfort were scored on Borg’s category rating scale (Borg 1982). Six body zones were included, where perceived discomfort could occur: neck, both shoulders (SH_L/R) and upper (UP), mid (MI) and lower (LO) back. The scale ranged from 0 (none) to 10 (very strong).

Subject’s preferences for the lumbar or thoracic backpack placement were recorded at the end of the test. Heart rate was recorded with a Polar wristwatch and chest belt.

2.4. Statistical analysis

A two-way ANOVA with a repeated measures design (df = 4) was used to analyse the heart rate, kinematics and EMG data. If significant ($p < 0.05$), a Tukey HSD post hoc test was used to determine specific differences between loading conditions and placement. Difference in Borg scores were analysed with the Friedman ANOVA test for non-parametric variables. If significant, a Wilcoxon matched pairs test was calculated to determine the difference between test conditions. Subjective classification was analysed with a Chi-square goodness-of-fit test (df = 1).

For clarity of the results section, probability scores were expressed relative to $p < 0.05$, $p < 0.01$ or $p < 0.001$.

3. Results

3.1. Standing

3.1.1. Kinematic analysis. Figure 1 presents the mean and standard errors of the mean of the absolute and relative angles for the different loading conditions and backpack placement.
There was no significant difference in head positions between the different loading conditions. A tendency towards increasing head extension from 0% BW to 5% BW and 10% BW is apparent. For 15% BW, there is a return to baseline values (0% BW).

Neck extension increased for 5% BW and 10% BW. Angles differed statistically significantly between 0% BW and 10% BW with the thoracic placement ($p = 0.01$).
Increased loading (10% BW and 15% BW) resulted in significantly increased flexion of the thorax compared to baseline level in both placements ($p < 0.001$).

There was no significant change in spine angle. However, there was a tendency towards extension for the thoracic placement, whereas for the lumbar placement there was a tendency towards flexion.

Increased pelvis anteversion increased significantly with loading condition (10% BW and 15% BW) for the thoracic placement compared to baseline values (0% BW, $p < 0.05$).

Hip flexion increased significantly for the thoracic placement for 10% BW ($p < 0.05$) and 15% BW ($p < 0.01$) compared with baseline values (0% BW).

Comparing the findings between the thoracic and lumbar placements, there was a trend towards increased spine angle extension, pelvis anteversion and hip flexion in the thoracic placement.

3.1.2. Muscle activity. With both backpack placements, there was a bilateral increase in muscle activity of RA and AO with increasing load (figure 2). There were significant differences for the AO in 15% BW vs. 0% BW ($p < 0.001$) and 5% BW ($p < 0.01$). In the thoracic placement, the right and left RA differed significantly for 15% BW compared to 0% BW and 5% BW ($p < 0.001$).

Furthermore, there was a bilateral decrease in muscle activity of the ES with increasing load for both placements (figure 2). For both placements, the right ES activity decreased significantly at 10% BW ($p < 0.05$) and 15% BW ($p < 0.001$), compared to 0% BW. For the left ES, this decrease was only significant for 15% BW compared to 0% BW ($p < 0.01$).

Amplitudes of muscle activity of TRAP, STCL, RF and BiFe were affected minimally by loading conditions.

Comparing thoracic and lumbar backpack placement, there was a trend towards increased activation of RA for the thoracic placement with increasing load (figure 2).

3.2. Gait

3.2.1. Spatiotemporal parameters. The mean values for single support duration, double support duration, stance duration and swing duration for condition A and the right stride were 39.1 (SEM 0.4)% , 21.2 (SEM 0.5)% , 60.3 (SEM 0.3)% and 39.7 (SEM 0.3)% of the gait cycle, respectively. For the same condition, stride time and walking velocity means were 1.02 (SEM 0.01) and 1.45 (SEM 0.03) m/s, respectively. Results were similar for the left stride. No significant differences in these parameters were observed for different loading conditions or placements.

3.2.2. Kinematic analysis. Figure 3 presents the mean angles and SEM of the head, neck, thorax, spine, pelvis and hips during two consecutive strides (right and left stride), for all loading conditions and placements.

For the head kinematics, no consistent trend could be observed between the different load conditions and backpack placement.

Neck extension increased slightly between 0% BW and 10% BW for both placements. The ROM of the neck was not significantly affected by loading condition.

The results showed an increase of thorax forward lean with increasing load for both placements and this was significant at 15% BW ($p < 0.01$). There was no significant difference in the thorax ROM.
Figure 2. The mean linear envelopes of M. rectus abdominis, M. obliquus externus abdominis and M. erector spinae with different backpack placement during standing for loading condition of 0% body weight (BW), 5% BW, 10% BW and 15% BW. *Indicates a significant difference with 0% BW (*p < 0.05; **p < 0.01; ***p < 0.001); †indicates a significant difference with 5% BW (†p < 0.05; ††p < 0.01; †††p < 0.001); ‡indicates a significant difference with 10% BW (‡p < 0.05; ‡‡p < 0.05; ‡‡‡p < 0.001). Vertical bars indicate SEM.
Figure 3. The mean angles of head, neck, thorax, spine, pelvis and hips for both strides with different backpack placements during gait for loading condition of 0% body weight (BW), 5% BW, 10% BW and 15% BW. Positive values indicate flexion/anteversion; negative values extension/retroversion. *Indicates a significant difference with 0% BW (*p < 0.05; **p < 0.01; ***p < 0.001); †indicates a significant difference with 5% BW (†p < 0.05; ††p < 0.01; †††p < 0.001). Vertical bars indicate SEM. Note that vertical scales vary.
Figure 4 shows the ROM for the spine and pelvis for placements and loading conditions. Only the angles with significant changes with increasing load are presented. ROM of the spine increased significantly in 5% BW, 10% BW and 15% BW compared to 0% BW for the lumbar backpack placement (figure 4).

A trend to increased anteversion of the pelvis with increasing load in the thoracic placement was found (figure 3). With the lumbar placement, no changes in pelvis angle were seen. The ROM of the pelvis did increase with increasing load for the lumbar placement, with significant difference for 5% BW ($p < 0.05$) and 15% BW compared to 0% BW ($p < 0.01$) (figure 4).

For both backpack placements, the hip was more flexed in 15% BW condition compared to 0% BW, although the difference was not significant (figure 3). For the ROM, no consistent trend could be observed with increasing load.

Differences between thoracic and lumbar backpack placement were most obvious (although not statistically significant) in the head, neck, thorax, spine and pelvis (figures 3–4). With the lumbar placement, there was increased extension of the head and neck, as well as increased flexion of the thorax and spine compared to the thoracic placement. Although increased pelvic anteversion was more prominent for the thoracic than the lumbar placement, a higher ROM of spine and pelvis was observed for the lumbar compared to thoracic placement.

3.2.3. Muscle activity. Figure 5 shows the mean linear envelopes from the gait (dynamic) data for the muscles most affected by the increasing loads. Muscle activities of TRAP, STCL, RF and BiFe were only minimally or not affected by increasing load. For both backpack placements, the mean activity of right and left RA and AO increased with increased loading especially for conditions 10% BW and 15% BW compared to 0% BW (figure 5). However, mean activity of the ES decreased with increased loading especially for 10% BW and 15% BW compared to 0% BW.

Figure 4. The range of motion (ROM) of spine and pelvis for both strides with different backpack placement during gait for loading condition of 0% body weight (BW), 5% BW, 10% BW and 15% BW. *Indicates a significant difference with 0% BW (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$); § indicates a significant difference with 10% BW (†$p < 0.05$; ††$p < 0.01$; †††$p < 0.001$). Vertical bars indicate SEM.
Figure 5. The mean linear envelopes of M. rectus abdominis, M. obliquus externus abdominis and M. erector spinae with different backpack placements during gait for loading condition of 0% body weight (BW), 5% BW, 10% BW and 15% BW. *Indicates a significant difference with 0% BW (*p < 0.05; **p < 0.01; ***p < 0.001); †indicates a significant difference with 10% BW (†p < 0.05; ††p < 0.01; †††p < 0.001); ‡indicates a significant difference with 15% BW (‡p < 0.05; ‡‡p < 0.01). Vertical bars indicate SEM. Note that vertical scales vary.
For the highest load conditions (10% BW and 15% BW), mean linear activity of the RA in the thoracic placement was higher than in the lumbar placement, although this was not statistically significant. For TRAP, STCL, RF and BiFe, there were no prominent differences in muscle activity between the thoracic and lumbar backpack placements.

3.2.4. Heart rate. The mean heart rate increased with increasing load (table 1). This was significant for thoracic and lumbar positions, starting from 5% BW ($p < 0.05$) to 15%

Table 1. Mean (min-max) heart rate and Borg scores (min-max) with different backpack placements (lumbar–thoracic) during gait for loading condition of 0% body weight (BW), 5% BW, 10% BW and 15% BW.

<table>
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<tr>
<th>Heart rate (beats/min)</th>
<th>0% BW</th>
<th>5% BW</th>
<th>10% BW</th>
<th>15% BW</th>
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<td>89.85**</td>
<td>90.75***</td>
<td>91.25***</td>
</tr>
<tr>
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<td>89.4*</td>
<td>91.35***</td>
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<th>Borg scores</th>
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<tr>
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<td>0.675**†</td>
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<tr>
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<td>0.875***††</td>
<td>1.525***†††</td>
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<tr>
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</tr>
<tr>
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<td>0.475</td>
<td>0.55†</td>
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</table>

Values were significantly different from 0% BW ($^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$).
Values were significantly different from 5% BW ($^{†}p < 0.05$; $^{††}p < 0.01$).
Values were significantly different from 10% BW ($^{‡}p < 0.05$).
BW ($p < 0.001$) compared to 0% BW. There were no differences between the thoracic and lumbar placements.

3.2.5. Subjective scores. The Borg scores for the neck, the shoulders and upper back increased with increasing load. This was significant for 10% BW and 15% BW compared to 0% BW and 5% BW for both placements (table 1).

Comparing thoracic with lumbar placements, there were slightly higher scores with the thoracic placement for the neck, mid back and lower back. However, these differences were not significant. Participants tended to prefer the lumbar (14 participants) over thoracic placement (six participants) ($p < 0.0736$).

4. Discussion

This paper evaluated recommendations for backpack weight and placement in standing and during gait, using a combination of physiological, biomechanical and subjective variables. The selection of these variables was based on previous backpack studies reported in literature. Whereas each of the previous reported studies focused on a selection of either physiological or biomechanical parameters, this study is innovative in that it combines data collection on all these parameters during standing and gait. In evaluating the effect of load, it was assumed that any loading of the back that caused significant changes in kinematics, EMG and subjective scores should be avoided, to minimize the risk of spinal pain.

The kinematic data collected in this study show evidence of specific coping strategies to increased loading conditions, similar to the ones previously reported in the literature.

Increased trunk flexion with increasing load (Grimmer et al. 2002) has been identified as adaptation to bring the centre of gravity of the body and backpack further forward to maintain balance. A significant trunk forward lean was reported for a load of 15% BW and above (Hong and Brueggemann 2000, Hong and Cheung 2003, Li et al. 2003). The present study reports significant increases in thorax flexion for loading conditions of 10% BW and above with lumbar placement of the backpack. In contrast to the latter authors, in this study, the trunk was modelled in three parts: thorax, spine and pelvis with inclusion of a lumbar joint. This approach differentiates between the pelvis and thorax orientation and allows a more precise location of angular changes. Consequently, it was observed that, with the thoracic placement, balance was maintained not only by increased thorax flexion, but also by increased pelvic anteversion and hip flexion. Likewise, significant changes in pelvic anteversion and hip flexion were observed while standing with loads from 10% of BW.

Forward head posture increased when carrying 15% BW was reported by Chansirinukor et al. (2001). In the present study, no changes in head and neck angles due to increased loading were observed during the standing or walking trials. Requesting the subject to look straight ahead in the static test may have influenced this. However, during the walking trials, no instructions were given to the subject that would interfere with natural postures of the head. The current results are similar to Pascoe et al. (1997), who found no changes in head angle.

Based on the analysis of the kinematic data, two conclusions can be drawn concerning backpack weight: (1) changes in cervical spine and head position were not observed to balance the effect of increased loading of the backpack; (2) the changes in thorax, pelvis and hip angle are adaptations to increased back loading.
It was assumed that the EMG-results would support the trends observed in the kinematic data. The minimal changes in activations of the cervical muscles are consistent with the limited changes in the cervical spine and head position. However, with increased loading, increased activation of postural muscles providing spinal stability (Granata et al. 2001), and especially the back extensor muscles, is expected due to the increased thorax flexion. However, for both placements, EMG results show a decrease of back extensor (ES) activity with an increase of abdominal muscle activation with increasing load. The lack of cocontraction of abdominal and back muscles is an important indication that the load is being carried passively, highlighting a possible danger to these structures.

The subjective Borg scores show discrepancies with the biomechanical data. Participants reported mainly marked discomfort from loads of 10% of BW upwards, in the neck, both shoulders and upper back, whereas the kinematics of neck and head remained rather unchanged. Furthermore, no or little discomfort was reported in the mid back or lower back, although the kinematics data showed most changes in that region. The complaints of discomfort are therefore most likely to be related to other causes than muscle strain or postural changes. A similar conclusion is found by Holewijn (1990), who reported the pressure under the straps to be the limiting factor for carrying time, even for relatively low loads. Analysis of the heart rate did not provide additional information. Heart rate increased with load, but showed no trend between the load conditions.

With regard to backpack placement, no significant differences were found in the kinematics during standing or gait. The observed trends in kinematic changes during standing with thoracic placement of the backpack, (increased extension of the spine, anteverision of pelvis and flexion of hips) confirm the recommendation of Grimmer et al. (2002) that backpacks should be positioned with the centre at waist or hip level, i.e. lumbar placement, in order to minimize compensations. During gait with varying load conditions, fewer changes in spine position are found for the thorax placement compared to the lumbar placement. Thorax placement could therefore be advantageous during gait for individuals suffering from lower back pain, since it influences alignment of the spine minimally. On the other hand, the subjective Borg scores show discrepancies within the observed trends in the kinematics. Whereas larger changes in kinematics were found for the lumbar placement, participants showed a preference for the lumbar placement. The pressure under the straps probably influenced the subjective. No clear trends were found in EMG with altered backpack placement.

Despite the small sample size of this study, significant changes in biomechanical, physiological and subjective parameters were detected with increasing load. The limited sample size does not allow further discrimination of sex-related responses to backpack loading. The standardization of backpack size (one size fits all) may have biased the observed changes. The relationship between the observed adaptations and the ratio of subject height (or trunk height) and backpack length should be explored in further studies. Furthermore, immediate extrapolation of these findings obtained in a population of college-aged students to school-aged children may not be valid and should be further exploited, especially when considering the different backpack:height ratio in a paediatric population. However, it is the authors’ feeling that the duration of the experiment (approximately 3 h) limits the feasibility of applying a similar protocol to children aged 10–12 years.

In conclusion, the analysis of kinematics, EMG and subjective scores showed significant changes from loads of 10% BW, therefore confirming the first hypothesis. This is, however, in contrast to the majority of literature, in which significant changes were only detected with a load exceeding 10% BW. Differences in the kinematic
modelling of the trunk can account for these differences. Based on these findings, it is recommended that backpack loads from 10% of BW upwards should be avoided.

Contrasting the second hypothesis, no significant differences were found between thoracic and lumbar positions. This finding is in contrast to other studies (Bobet and Norman 1984, Bloom and Woodhull-McNeal 1987, Grimmer et al. 2002). The limited change between the thoracic and lumbar placement in the present study might have been too small to reveal significant changes.

5. Conclusion

This study used kinematics, EMG, heart rate and subjective scores to evaluate existing recommendations for backpack load and placement in standing and walking. The data collected showed significant changes in kinematics, EMG and discomfort scores with loads above 10% of BW. It is therefore recommended that students should avoid backpack loads of 10% of BW or higher. There was a remarkable difference in postural adaptation between static and dynamic load conditions for the backpack placement. In gait, most postural changes were observed with the lumbar position, whereas while standing most postural changes occurred in the thoracic position. From the subjective scores, students preferred the lumbar backpack position. Thoracic or lumbar carrying placement therefore cannot be recommended based on the findings from this study.

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