CHANGES IN UPPER BODY AND ARM KINEMATICS WHILE CARRYING SYMMETRICAL AND ASSYMETRICAL BACKPACK LOADS

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The effects of different backpack carrying techniques on posture were investigated in 10 adolescent females. Subjects walked with no load, while carrying 20% bodyweight (BW) in a backpack with both shoulder straps, and with 20% BW in a pack secured by one shoulder strap. Positions of skin markers attached to the trunk, pelvis, and upper extremities were recorded by a motion capture system. Mean angular positions and range of motion (ROM) for the trunk, pelvis, and shoulder were calculated. Results indicated that carrying 20% BW on both shoulders caused a significant increase in forward trunk inclination, a decrease in pelvic rotation, and changes in shoulder elevation and swing, relative to unloaded gait. When the backpack was supported by a single shoulder, numerous additional changes in posture were observed.

KEY WORDS: backpack, kinematics, gait, adolescent.

INTRODUCTION: Daily backpack carrying is associated with frequent symptoms of back pain in school children (Negrini & Carabalona, 2002). Previous research indicates that backpack loads of 20% bodyweight (BW) caused significant biomechanical changes in adolescents, including an increase in the duration of the double support phase of gait (Hong & Brueggemann, 2000; Hong & Li, 2001), forward inclination of the trunk (Hong & Brueggemann, 2000; Hong & Li, 2001, Pascoe et al., 1997), and a decrease in peak knee flexion (Hong & Li, 2001) and sagittal trunk range of motion (Hong & Brueggemann, 2000, Li & Hong, 2001). Though Grimmer and Williams (2000) found that 33% of children used only one shoulder strap for backpack carriage, research on assymetrical load carrying in children is limited. Pascoe et al. (1997) found that carrying a backpack with one shoulder strap resulted in an increase in lateral deviation of the trunk and elevation of the load-bearing shoulder, relative to symmetrical load carrying and unloaded gait. Postural strain caused by prolonged deviation of the trunk is considered a potential cause of back pain (Brown, 1976). However, trans-planar changes in trunk posture during backpack carrying are not clearly understood and the interaction between trunk and pelvis motion has yet to be examined. Further evaluation of assymetrical load carrying is of interest, as many new school bags have only one shoulder strap. Thus, the present study was conducted to evaluate shoulder, trunk, and pelvis kinematics in children while carrying 20% BW with one or both shoulder straps.

METHODS: Ten female adolescents aged 13-15 years were included in this study, due to gender-specific associations between symptoms of back pain and backpack load (Grimmer & Williams, 2000). Reflective markers were attached to the skin overlying the feet, pelvis, trunk, shoulders, and elbows. Subjects walked down a 10 m runway, at a self-determined pace, while carrying each of three randomized loads: no backpack (BW), 20% BW carried in a backpack with both shoulder straps (BOTH), and 20% BW carried in a backpack with the right shoulder strap only (ONE). The positions of the markers were captured using an 8-camera Motion Analysis System (Motion Analysis Corp., Santa Rosa CA), with a sampling rate of 60 Hz. A global coordinate system (GCS), established during system calibration, was used to define three anatomical planes of motion. Segmental kinematics were calculated by projecting the segment axis, defined by two markers, onto the appropriate plane. Eight kinematic parameters were calculated. Trunk motion was measured in all three anatomical planes, relative to the GCS. Pelvis motion was measured in the coronal and transverse planes only, as the presence of the backpack on the dorsal surface of the pelvis prevented measurement of sagittal plane motion. Right and left shoulder elevation were measured in the coronal plane, relative to the position of the trunk. Right and left shoulder swing, measured in the sagittal plane, were also calculated relative to the trunk. For each load condition, data from three complete gait cycles (interval between successive right foot strikes) were used for analysis. Mean angle and range of motion (ROM, calculated as the difference between maximum and minimum values) were computed for each kinematic parameter. A multivariate ANOVA was used to compare differences in mean angle, for each kinematic parameter, between load conditions. A second multivariate ANOVA was used to compare differences in ROM. In the presence of a significant main effect, Tukey's post hoc comparisons were used to evaluate significant mean differences between load conditions. The overall significance level for this study was 0.05. However, a Bonferroni correction was applied, such that a p-value of less than 0.025 was considered statistically significant.

RESULTS: Figure 1 displays mean kinematics for the trunk (top row) and pelvis (bottom row), expressed as a percentage of the gait cycle. In the coronal plane, no differences in mean angle or ROM were observed between BW and BOTH. Significant differences for ONE included increased lateral deviation of the trunk away from the load-bearing shoulder (p = .000) and increased right tilting of the pelvis (p = .000), compared to BW. In the transverse plane, pelvic ROM was significantly decreased for BOTH (p = .004) and ONE (p = .001), relative to BW. Additionally, the trunk had a significantly greater mean angle for ONE than for BW (p = .000), indicating increased left rotation. Transverse pelvis angle for ONE was also increased toward the load-bearing side (right), relative to BW (p = .007). In the sagittal plane, increased forward inclination of the trunk was observed for BOTH (p = .000) and ONE (p = .000), relative to BW.

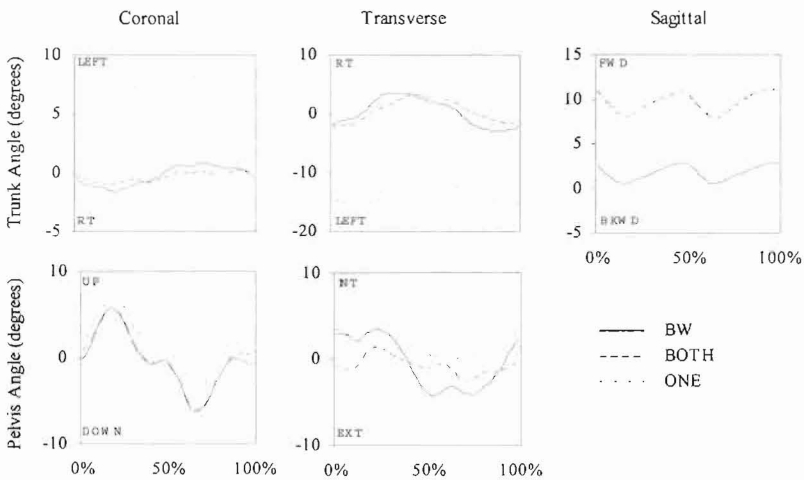

Figure 1. Kinematics of the trunk (top row) and pelvis (bottom row), expressed as a percentage of time of the gait cycle.

Elevation and swing of the left and right shoulders are displayed in Figure 2, expressed as a percentage of the gait cycle. No differences in shoulder elevation for mean angle or ROM were observed in the left shoulder. In contrast, mean elevation angle of the right shoulder was significantly greater in BOTH (p = .002) and ONE (p = .000), relative to BW. Mean shoulder swing angle was greater for BOTH then for BW, in the right (p = .023) and left (p = .000) shoulders. Right shoulder swing ROM was significantly decreased for ONE, relative to BW (p = .000) and BOTH (p = .004).

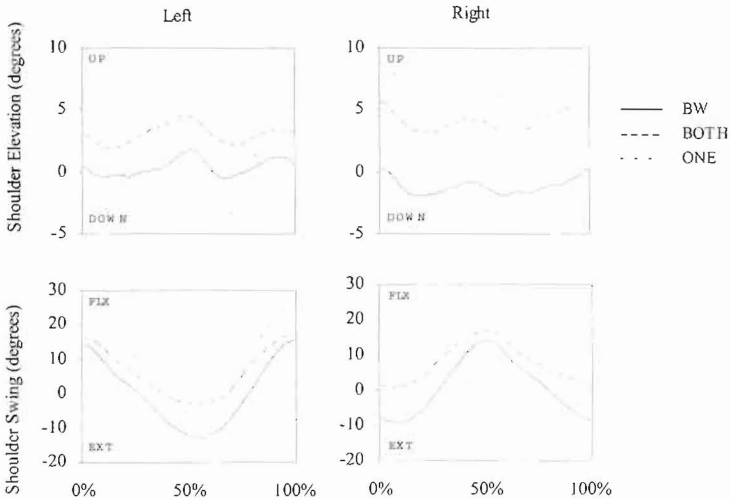

Figure 2. Left and right shoulder elevation (top row) and shoulder swing (bottom row), expressed as a percentage of time of the gait cycle.

DISCUSSION AND CONCLUSIONS: *Backpack carrying with both shoulder straps:* Significant changes in posture, relative to unloaded walking, included increased forward trunk inclination and decreased rotational ROM of the pelvis. The former of these responses has been previously observed in boys (Hong & Brueggemann, 2000; Hong & Li, 2001, Li & Hong, 2001), though the magnitude appears to be more pronounced in females. Pelvic rotation was reduced by nearly 40%, indicating possible impairment of its normal function in aiding to reduce the amplitude of the vertical COM excursion of the body (Murray, 1967). An increase in fore-aft trunk ROM was not observed in this study, though it was previously observed in boys under the same load condition (Hong & Brueggemann, 2000, Li & Hong, 2001; Pascoe et al., 1997). In contrast, a slight increase in ROM was observed, relative to unloaded walking. This difference may either be gender related, or the cause of different measurement methods between studies. In the present study, the superior aspect of the sagittal trunk segment was identified with a marker on C7, whereas previous studies used a mid-point between the shoulder markers. The latter of these may have resulted in overestimation of trunk motion, due to elevation and depression of the shoulders relative to the trunk (Figure 2). Double strap carriage also resulted in significant elevation of the right shoulder and comparable, though not statistically significant, elevation of the left shoulder. The statistical discrepancy between right and left sides may be explained by high inter-subject variability for this parameter. Nonetheless, the observed 3-4° elevation of each shoulder suggests that there may be increased strain on the local shoulder musculature, which has been found to be a limiting factor in backpack load tolerance (Holewijn, 1990). Finally, the right and left shoulders maintained a position of increased flexion during double strap carrying, relative to unloaded walking. This was attributed to an increase in peak flexion to compensate for loss of extension beyond 0° (Figure 2), due to the shoulder straps. Thus, increased activation of the shoulder flexors may be necessary to maintain normal swing ROM. In summary, it is evident that carrying 20% BW in a backpack with both shoulder straps affects the normal biomechanics of the trunk, pelvis, and shoulder, particularly in the young female. *Backpack carrying with one shoulder strap:* Load carriage using this technique induced a trans-planar adjustment in trunk posture relative to unloaded gait, including forward inclination, left lateral bending, and left rotation. Mean coronal trunk angle was shifted nearly 10° to the left relative to unloaded gait, a greater magnitude than was previously observed in boys (Pascoe et al., 1997).

During unloaded gait, the trunk deviates laterally to maintain the COM of the body over the supporting leg (Thurston & Harris, 1983). However, it is apparent that normal trunk position was compromised to counteract the external load moment, which was acting to pull the trunk downward and to the right. This effect propagated to the right hemi-pelvis, which tilted upward throughout the gait cycle. Similarly, the marked leftward rotation of the trunk was accompanied by right rotation of the pelvis, to allow for forward progression during walking. The load-bearing shoulder was significantly elevated, relative to its position during unloaded walking. Support of the entire mass of the pack on the right shoulder also inhibited its swing function, as indicated by the marked decrease in ROM (Figure 2). In summary, carrying the backpack on one shoulder induces a postural compensation by the trunk and shoulders in an attempt to center the load over the hips. Prolonged changes in alignment of the trunk and pelvis, as observed when carrying 20% BW with one shoulder, may place the adolescent at risk for injury. This may be of particular concern for female teenagers with a lower relative lean body mass than their male peers.

REFERENCES:

Brown, J.R. (1976). Manual Lifting and related fields: an annotated bibliography. (Ontarion Ministry of Labour, Labour Safety Council.).

Grimmer, K., Williams, M. (2000). Gender-age environmental associates of low back pain. *Applied Ergonomics*, **31**, 343-60.

Holewijn, M. (1990). Physiological strain due to load carrying. *Journal of European Physiology*, **61**, 237-45.

Hong, Y., Brueggemann, G.P. (2000). Changes of gait pattern in 10 year old children carrying increasing loads on a treadmill. *Gait and Posture*, **11**, 254-59.

Hong, Y., Li, J.X. Movement kinematics of treadmill walking under load carriage in 6-year-old children – A preliminary report. *XIX International Symposium on Biomechanics in Sports*, San Francisco, CA, June 20-26, 2001.

Li, J.X., Hong, Y. Changes of trunk position and breathing pattern in children walking under conditions of load carriage. *XIX International Symposium on Biomechanics in Sports*, San Francisco, CA, June 20-26, 2001.

Murray, M.P. (1967). Gait as a total pattern of movement. *American Journal of Physical Medicine*, **46**, 290-33.

Negrini, S., Carabalona, R. (2002). Backpacks on! Schoolchildren's perception of load, associations with back pain and factors determining load. *Spine*, **27**, 187-95.

Pascoe, D.D., Pascoe, D.E., Wang, Y.T., & Shim, D. (1997). Influence of carrying book bags on gait cycle and posture of youths. *Ergonomics*, **40**, 631-41.

Thurston, A.J., & Harris, J.D. (1983). Normal kinematics of the lumbar spine and pelvis. *Spine*, **8**, 199-205.