The influence of two backpack loads on children's spinal kinematics

CDD. 20.ed. 612.76
796.023

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Abstract

This study aimed to analyze the effect of backpack load carriage over the spine. The studies that have investigated load carriage using backpacks have analyzed the lower limb dynamics and have not focused on the spine. In addition, the strategies applied by children may differ from adults as the relative weight differs between adolescents and adults. Methods: Ten schoolboys (13.9 ± 0.6 years-old; 1.53 ± 0.05 m; 44.9 ± 3.3 kg) volunteered to participate after their parents sign an informed consent form. Participants walked in a treadmill during approximately 15 minutes carrying a specially built backpack with a load that corresponded to 0.10 and 20% BW. A number of landmarks were placed over the subjects back and allowed reconstruction of the spinal profiles in the sagittal and frontal planes. The relation between the segments formed between acromium markers and the posterior superior iliac crest markers was used as a spinal rotation index. The maximum, minimal, mean and range of motion of the thoracic and lumbar regions and the whole spine were analyzed. The gait cycle was applied to normalize the gait cycle. Results indicated differences between the two loads (10%BW and 20%BW). A number of changes in the spinal kinematics was found. In the saggital plane the range of movement was unaltered, although there was an increased in the flexion, which was interpreted as a compensatory strategy to counteract the effect of the load. These results are in line with the idea that the use of a backpack increases anterior leaning of the trunk, but are in disagreement with the notion that pronounced changes in the range of motion occur. Carrying a backpack did not produce a clear effect over the variables selected to identify thoracic and lumbar spine regions in the sagittal plane. Conclusion: Carrying a load that corresponded to 20%BW influences spinal kinematics in all planes of movements. These changes may impose an important change in posture and stress applied over the posterior aspect of the vertebral column. The slow walking speed used in the present study may have not induced large changes in the kinematics of the vertebral column as in other studies in which walking was performed in greater speeds. Thus, it is suggested that weight of the backpack is not the only factor that determines the movements of the vertebral column.

UNITERMS: Load carriage; Low back pain; Backpack.

Introdution

Changes in posture from load carriage have called attention of many researchers and ergonomists due to the functional problems of the vertebral column which are influenced by several factors such as the weight of the load, transport strategy, bag type and subjects' physical characteristics (FOWLER, RODACKI & RODACKI, 2006; GRIMMER, WILLIAMS & GILL, 2002; PASCOE, PASCOE & WANG, 1997; WONG & HONG, 1997).

Backpacks are widely used by adolescents to carry their personal and school materials (BRACKLEY & STEVENSON, 2004) and represent one of the most usual physical efforts related to weight handling performed by young subjects (FORJUOH & SCHUMANN, 2003;

MACKIE, LEGG, BEADLE & HEDDERLEY, 2003). This concern has been confirmed by recent clinical studies that have shown increased occurrence of back pain due to excessive/repeated load applied to immature spinal structures while carrying/handling weights (GRIMMER, WILLIAMS & GILL, 1999). In fact, the prevalence of back pain in adolescents has been reported to as high as 51% (PASCOE et al., 1997) and 65% (NEGRINI, CARABOLONA & DIPENG, 2002; NEGRINI, CARABOLONA & PINOCHI, 1998). Thus, It has been also considered a concern in many physical education teachers as some activities can be introduced to prevent or reduce these adverse effects.

Recently, KOROVESIS, KOUREAS e ZACHARATOS (2005) performed a quantitative postural analysis in students aged 12-18 years-old and showed that backpack carrying (asymmetrically placed) causes changes in upper trunk, shoulder and cervical lordosis. They recommended the use of symmetric backpacks. Unfortunately, most studies have focused on the lower limb dynamics (WANG, PASCOE & PERRY, 2001) and only a reduced number of studies about how the spine behaves during symmetric backpack load carriage have been conducted (HONG & BRUEGGEMANN, 2000; WONG & HONG, 1997). Probably, technical problems related to the visualization of the spinal landmarks have limited a more detailed kinematic assessment of vertebral column during the task.

VACHERON, POUMARAT, CHANDEZON and VANNEUVILLE (1999) performed a kinematic analysis of the spine in which they reported a reduced range of movement about the lumbar (S1-L3-T12) and thoracic (L3-T12-T7) segments of the spine. These adjustments were also accompanied by an increased range of motion of the cervical region (T7-C7). VACHERON et al. (1999) tested only one load condition (22.5 kg), which did not allow a more comprehensive understanding of how the load magnitude (i.e. expressed as a fraction of the body weight) influences and determines spinal postural adjustments during the task. In addition, rotational movements of the spine, a well-known risk factor for low back pain development (AU, COOK & MCGILL, 2001; CHAFFIN, ANDERSON & MARTIN, 2001), was not quantified. Finally, it s not known whether the postural adjustments performed by adults are also replicated by adolescents. This is particularly relevant because children and adolescents that experienced thoracic and lumbar pain have increased risk of back discomforts in adulthood (BURTON, CLARKE & MCCLUNE, 1996).

The aim of the present study was to identify the movements of the vertebral column of adolescents during backpack carriage using two loads (10 and 15% BW) in comparison to the pattern obtained in an unloaded condition (0% BW). The understanding of how adolescents respond to different loads may help to identify spinal loading mechanisms and provide evidence to design preventive measures. It is a particular concern for professionals involved in physical activity for children and adolescent subjects (such as physical education teachers) as this information are relevant to intervene in early stages of postural adjustments.

Methods

Ten schoolboys (13.9 ± 0.6 years-old; 1.53 ± 0.05 m; 44.9 ± 3.3 kg) agreed to volunteer in the present study after their parents sign an informed consent form. All procedures were approved by the University Ethical Committee. Participants were screened by a physician to identify postural (e.g. scoliosis, lordosis) and other health problems that could interfere in the performance of the task. In the first visit, the physical characteristics of the participants were assessed and a brief familiarization period of 10 minutes walking on the treadmill (Pro-Action, model Explorer) was allowed. During this visit, the comfortable volitional walking speed was identified (1.1 $m.s^{-1}$). In the second visit, subjects walked in the treadmill during approximately 15 minutes carrying a specially built backpack with a load that corresponded to 0.10 and 20% BW. A random order was followed in such a way that each experimental was performed during approximately five minutes of the task.

A backpack was specially built for the present study. The backpack consisted of a pair of lead bars firmly connected in the top. This setup left visible the central aspects of the entire spinal contour (i.e., the spinal processes). The lead bars were covered by a resistant cloth (jeans) to avoid direct contact of the bars with the subject's back. Two small pockets in the posterior aspect of the backpack allowed fine adjustments to the weight of the load. The backpack was reported as to similar as that usually carried by the participants, who reported no discomfort or pain during the task.

The centre of mass of the backpack was previously estimated and placed approximately around the eighth thoracic vertebrae (T8). This arrangement permitted the movements of a number of extruded marks (6 cm long and diameter of 1.5 cm and negligible weight) to be detected by two synchronized camcorders (JVC GR-SR 33, Japan) placed approximately 3 m behind the treadmill (angled at ~ 45° with the respect to the progression line). A third camcorder was placed at the foot level in the sagittal plane (~ 1 m away from treadmill's edge) to determine gait cycle. All camcorders sampled at 60 Hz and images were stored in a tape and transferred on to a personal computer using an analog-digital board (Pinnacle, Linx), which reduced the sampling frequency to 30 Hz. One subject wearing the backpack during the experiment is shown in FIGURE 1.

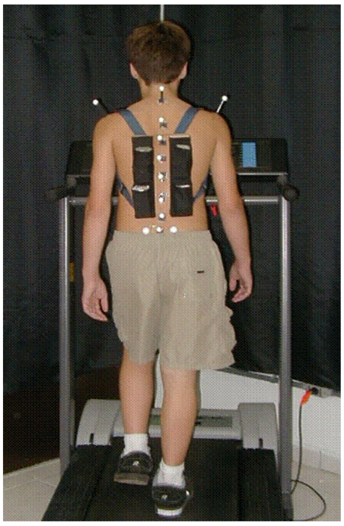

FIGURE 1 - One participant being evaluated during one of the load conditions that replicated walking with a backpack.

FIGURE 1 also shows where the markers were positioned on subjects' back (spinal process of the seventh cervical vertebrae (C7), spinal process of the fourth (T4); seventh (T7), tenth (T10) and twelve thoracic vertebrae (T12); spinal process of second (L2) and fourth (L4) lumbar vertebrae and the spinal process of the second sacral vertebrae (S2)) to determine the movements of the vertebral column. The most prominent aspects of the acromium and the left and right superior posterior iliac spines were also marked to represent the shoulder and hip axis, respectively (SYCZEWSKA, OBERG & KARLSSON, 1999). The coordinates of these points were determined by manually digitizing all landmarks using a specific software (SIMI, Reality Motion Systems, version 6.0). Then, coordinates were filtered (Low-pass Buterworth 2nd order and a cutoff frequency of 6Hz; HONG & BRUEGGMANN, 2000), and used to calculate the thoracic and lumbar angles. The thoracic and lumbar angles were defined as the projection angle of a straight line between C7-T4 and T7-T10 and T12-L2 and L4-S2, respectively. This analysis was performed in the sagittal and frontal planes. The relation between the segments formed between acromium markers and the posterior superior iliac crest markers (transversal plane) was used as a spinal rotation index. Thus, the maximum, minimal, mean and the range of motion of these spinal angles were analyzed.

For analysis purposes, ten complete gait cycles (heel strike to heel strike) were collected between the 4th and 5th minute of the task for each experimental condition. However, only three cycles were further analyzed. The data series were normalized using a customized spline routine with respect to the gait cycle, which was set to 100% (WINTER, 1991). Then, normalized data of three cycles were used to calculate the ensemble average of each variable.

Gait in the unloaded condition was used as a baseline and, thus, deducted from each experimental loaded condition (10 and 20% BW) to represent individual variations. An experimental pilot study revealed that the error of the kinematic analysis was smaller than 1°. All variables were tested for normality with the K-S test and analyzed using descriptive (mean and standard deviation) and inferential statistics (Student t test for dependent samples). The significance level was set at $p < 0.05$. The statistical procedures were performed using the software Statistica (Statsoft, version 5).

Results

Results are presented in the movement planes and can be found in table 1. In the sagittal plane, the vertebral column (S2-C7) showed increased maximal and minimal angles (17.7% and 36.6%, respectively) during the 20%BW condition. The mean angles of the 20%BW also showed an increase of 26.5% when compared to the 10%BW condition. No changes were found in the range of motion between the two load conditions. The other two contours of the vertebral column (C7-T4/T7-T10 and T12-L2/L4-S2) were not affected by the load conditions. In the frontal plane, the maximum forward leaning angle of the spine was observed (1.27°), irrespective of the load magnitude. The minimum and the mean angles (T12-C7) increased when the heaviest condition (20%BW) was performed. When the variables were analyzed in the thoracic region (T12-C7), the maximum angle increased 2.36° and the minimum angle 2.55°. In average, the mean angle increased 2.61° when the load of 20%BW was applied. The lumbar segment (S2-T12) remained stable and no significant changes were detected. In the transversal plane, the range of movement increased by 34.6% in the 20%BW condition when compared to the 10%BW condition.

TABLE 1 - Mean (± sd) of the vertebral column variables in the sagittal, frontal and transversal planes of movement during two walking load conditions (10 and 20%BW).

Plane	Spinal region	Variables (deg)	10% BW	20% BW	p
Sagital plane	Vertebral column S2-C7	Maximal angle	7.74 ± 2.43	9.11 ± 2.71	0.00667
		Minimal angle	4.13 ± 1.98	5.64 ± 2.94	0.00057
		Range of movement	3.61 ± 1.50	3.46 ± 1.44	0.65739
		Mean angle	5.81 ± 2.00	7.35 ± 2.90	0.00517
	Thoracic segment C7-T4/T7-T-10	Maximal angle	3.53 ± 3.13	3.86 ± 4.71	0.7470
		Minimal angle	- 2.55 ± 2.39	- 1.38 ± 4.31	0.1170
		Range of movement	6.08 ± 2.47	5.23 ± 2.48	0.3126
		Mean angle	0.45 ± 2.69	1.12 ± 4.28	0.3700
	Lumbar segment T12-L2/L4-S12	Maximal angle	7.03 ± 6.73	5.48 ± 8.35	0.3481
		Minimal angle	- 10.73 ± 6.24	- 9.87 ± 9.70	0.5130
		Range of movement	17.76 ± 10.41	15.36 ± 11.37	0.1087
		Mean angle	- 2.29 ± 3.95	- 2.52 ± 6.60	0.8375
Frontal plane	Vertebral column S2-C7	Maximal angle	0.81 ± 1.74	2.08 ± 1.76	0.0039
		Minimal angle	- 1.84 ± 1.55	0.76 ± 1.76	0.0161
		Range of movement	2.65 ± 1.08	2.83 ± 1.06	0.5898
		Mean angle	- 0.54 ± 1.68	0.58 ± 1.62	0.0009
	Thoracic segment T12-C7	Maximal angle	7.68 ± 2.30	10.04 ± 2.61	0.0020
		Minimal angle	3.47 ± 2.56	6.02 ± 3.15	0.0001
		Range of movement	4.21 ± 2.55	4.02 ± 1.91	0.6450
		Mean angle	5.47 ± 2.03	8.08 ± 2.51	0.0005
	Lumbar segment S2-T12	Maximal angle	- 9.44 ± 5.14	- 8.14 ± 4.48	0.4385
		Minimal angle	- 3.52 ± 4.63	- 1.74 ± 4.49	0.3141
		Range of movement	- 5.92 ± 3.19	- 6.40 ± 4.16	0.4175
		Mean angle	- 6.53 ± 4.63	- 4.86 ± 4.23	0.3121
Transversal plane		Maximal angle	4.98 ± 1.54	6.78 ± 2.83	0.0814
		Minimal angle	0.50 ± 1.01	0.75± 1.62	0.7106
		Range of movement	4.48 ± 1.66	6.03 ± 2.65	0.0447
		Mean angle	2.46 ± 1.10	3.43 ± 1.82	0.2198

Discussion

The data profiles obtained in the present study are similar to those reported in the literature during overground walking (MURRAY, SPURR, SEPIC & GARDNER, 1985; WATERS, LUNSFORD & PERRY, 1988) and suggest that the participants are not different from general population. In addition, stride parameters (not presented here) were also comparable with other studies that examined adolescents and remained very robust between experimental conditions (i.e., 10 vs. 20%BW). The stride parameters stability obtained in both experimental conditions may be related to the constant walking speed imposed while walking in the treadmill. Thus, it is likely that a number of gait parameters may change during overground walking, as evidenced in other studies where participants were free to determine their own pace (e.g. FOWLER, RODACKI & RODACKI, 2006). Therefore, one must take into account such limitation while extrapolating the results of the present study to overground conditions.

The S2-C7 segment represents the long axis of the back and indicates the global movements of the vertebral column, as a whole. The range of movement of the vertebral column in the sagittal plane increased when the backpack was carried, irrespective of the load magnitude and gait cycle phase. Probably, this is a compensatory strategy to counteract the effect of the load, which tends to displace the participant's centre of mass away from mid-line (i.e., backwards). In general, the trunk movement amplitude change has been related to the magnitude of the load, i.e., greater loads cause more pronounced trunk movement alterations. Others (HONG & CHEUNG, 2003) have reported a reduced range of movement when carrying heavy loads (e.g. 20%BW) in comparison to unloaded conditions (0%BW) and are in disagreement with the results of the present study, which showed an increased range of motion when a load was added. It is likely that the relatively low volitional walking speed (0.9 $m.s^{-1}$) used in the present study have imposed a smaller effort to control the large moment of inertia of the trunk segment than that used by HONG and CHEUNG (2003), in which speed varied from 1.37 to 1.52 $m.s^{-1}$.

In greater walking speeds, the large moment of inertial of the trunk (further increased by the aggregated mass of the backpack) induces a greater muscular effort to control (accelerate and decelerate) the segment and may produce higher muscle fatigue levels. Other studies designed to manipulate the walking speed and muscle activation are required to test explore further these arguments. Thus, trunk range of movement control may be more related to the walking speed than to the backpack's weight. Therefore, it seems that the magnitude of the load is not the only risk factor to influence the movements of the vertebral column, but also the distance covered (HONG & CHEUNG, 2003) and walking speed in which the task is performed (VOGT, PFEIFER & BANZER, 2002).

The results of the present study disagreed with those reported by PASCOE et al. (1997), who showed no changes in trunk range of movement when carrying a load (17%BW), when compared to an unloaded condition. Our results presented no differences between load magnitudes (10 vs. 20%BW), and showed a similar mean range of movement increase of ~ 3.5° (ranging from 3.4° to 3.6°) in both experimental conditions. These results are in line with the idea that the use of a backpack increases anterior leaning of the trunk, but are in disagreement with the notion that pronounced changes in the range of motion occur.

The increased anterior leaning of the trunk segment was influenced by the load magnitude. Previous studies analyzing adolescents (HONG & CHEUNG, 2003) and adults (KINOSHITA, 1985; MARTIN & NELSON, 1986) have demonstrated that the forward inclination of the trunk increases when the load and/or the walking distance are increased. The forward inclination of the trunk segment may impose greater stress over the vertebral column and increase the risk of back problems. In fact, GOH, THAMBYAH and BOSE (1998) indicated increased peak lumbo-sacral forces during forward progression while walking with weight. Thus, forward leaning of the trunk may not result only in greater muscular strain but also in greater stress applied in ligaments and other soft structures of the spine, such as the intervertebral discs. It is well-known that trunk flexion tends to protrude the intervertebral discs towards the posterior aspect of the spine and may overload several structures that may cause back pain and disability. In addition, faulty postures are believed to be close related to back problems later in life (WIDHE, 2001). Some studies have proposed that the origin of back pain in adolescents is related to alterations in softy tissues (intervertebral discs, ligaments and trunk muscles) while carrying backpacks (KOROVESSIS, KOUREAS & ZACHARATOS, 2005). In schoolboys these concerns must be viewed with additional caution due to the immature nature of their structures, which are more prone to adaptation than that found in adults.

Carrying a backpack did not produce a clear effect over the variables selected to identify thoracic and lumbar spine regions in the sagittal plane. Other studies also failed to find a relation between changes in thoracic kyphosis, lumbar lordosis while carrying a backpack (KOROVESSIS, KOUREAS & ZACHARATOS, 2005). The analysis of the individual profiles of the selected variables revealed large variability between subjects (see TABLE 1). It is suggested the existence of individual compensatory strategies, which did not allow identifying a common pattern. Probably, the interactions between movements of the thoracic and lumbar segments may have played a confounding role. Indeed, some studies have pointed that evaluation of postural segments as independent parts is impossible, as any change in one place is ideally compensated by other adjustments (TUZUN, YORULMAZ, CINDAS & VATAN, 1999).

In the frontal plane, movements of the spine reflect the medial-lateral oscillation of the centre of mass during the gait cycle. The trunk segment showed greater lateral leaning when carrying the heaviest load (20%BW) when compared to the other condition (10%BW). However, the mean variation was very small (~0.5°) and is within the error measurement margin. In addition, such a small variation has no mechanical or clinical significance and must be considered as negligible. It is interesting to note that most changes in the frontal plane occurred in the thoracic region of the vertebral column (maximum, minimum and mean angles). These changes may be an attempt to reduce the lateral oscillations of the trunk that occur in response to the dynamics of the lower limb and pelvis segments during locomotion.

A greater range of vertebral column rotation (torsion), as measured by the angle formed between the shoulder and pelvis axis, was detected while carrying heavier loads (i.e., 20%BW). These results are in contrast with that found by LA FIANDRA, HOLT, WAGENAAR and OBUSEK (2003), who reported reduced trunk rotation in response to backpack loading.

Greater rotation of the long axis of the spine are described as a risk factor of low back disorders as the ability of the vertebral column to resist to rotation is small in comparison with other loads (e.g., compressive forces) that may cause stress over some structures that are not well designed to absorb and transmit the stresses applied in the vertebral column.

Conclusion

The present study identified small changes in vertebral column kinematics in all planes of movements. The range of movement remained stable, but the trunk segment showed an increased forward inclination to compensate the effect of the backpack that tends to shift the centre of mass away from the midline. These changes may impose an important change in posture and stress applied over the posterior aspect of the vertebral column. The slow walking speed used in the present study may have not induced large changes in the kinematics of the vertebral column as in other studies in which walking was performed in greater speeds. Thus, it is suggested that weight of the backpack is not the only factor that determines the movements of the vertebral column. The small, but significant changes in spinal alignment may not be the only factor that influences the development of low back pain. The greater rotation of the spine that occurred when the load was increased was interpreted as a risk factor while carrying heavy loads (e.g. 20% BW).

Resumo

A influência de duas mochilas sobre a cinemática da coluna de crianças

Este estudo visou analisar o efeito do carregamento de cargas por meio de mochilas sobre a coluna. Os estudos que investigaram o carregamento de cargas utilizando mochilas têm analisado a dinâmica de membros inferiores e não tem focado a coluna vertebral. Em adição, as estratégias aplicadas por crianças podem diferir visto que as cargas relativas podem diferir entre adolescentes e adultos. Métodos: dez escolares (13,9 ± 0,6 anos; 1,53 ± 0,05 m; 44,9 ± 3,3 kg) foram voluntários para participar do estudo após seus pais consentirem e assinarem um formulário livre e esclarecido. Os participantes caminharam em uma esteira. Durante aproximadamente 15 minutos carregando uma mochila especialmente feita que correspondia a 0,10 e 20% do peso corporal. Um número de marcas corporais foi colocada nas costas dos sujeitos que permitiram a reconstrução dos perfis da coluna nos planos sagital e frontal. A relação entre os segmentos formados pelas marcas entre os acrômios e as cristas ilíacas foi usada como um índice de rotação da coluna. Os valores máximos, mínimos, médios e as amplitudes de movimento das regiões torácica e lombar e a coluna toda foram analisados. O ciclo da marcha foi normalizado pelo contato sucessivo de dois contatos do calcanhar com o solo. Resultados indicaram diferenças entre as cargas (10 e 20% PC). Um número de mudanças na cinemática da coluna foi encontrada. No plano sagital a amplitude de movimento permaneceu inalterada, todavia, houve um aumento na flexão a qual foi interpretada como uma estratégia compensatória em resposta ao efeito da carga. Os resultados estão em linha com a idéia que o uso de mochilas aumenta a inclinação anterior do tronco, mas em discordância com a noção que pronunciadas mudanças na amplitude de movimento ocorrem. O carregamento de cargas não produz um efeito claro sobre as variáveis selecionadas para identificar as alterações nas regiões lombar e torácica no plano sagital. Conclusão: o carregamento de cargas que correspondem a 20% PC influenciam a cinemática da coluna em todos os planos de movimento. Essas mudanças podem impor importantes mudanças sobre a postura e o estresse aplicado sobre os aspectos anteriores e posteriores da coluna vertebral. A baixa velocidade de deslocamento usada no presente estudo podem não ter induzido grandes mudanças na cinematica da coluna vertebral, como demonstrado em outros estudos que usaram maiores velocidades de deslocamento. Desta forma, sugere-se que o peso da mochila não é o único ator que determina os movimentos da coluna vertebral.

UNITERMOS: Carregamento de cargas; Dor nas costas; Mochilas.

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Recebido para publicação: 05/05/2008
Aceito: 30/07/2008