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ORIGINAL ARTICLE

Loading rate patterns in scoliotic children during gait: the impact of the schoolbag carriage and the importance of its position

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Abstract

Purpose Concerns have been raised regarding the effects of schoolbag carriage on adolescent schoolchildren and particularly those with a pre-existing spinal deformity. The purpose of this study was to determine the effect of school backpack loads in scoliotic and healthy school-age children during walking, in terms of peak vertical ground reaction forces and loading rates. We hypothesized that walking with a loaded backpack would have a greater effect on gait kinetics of scoliotic compared to healthy.

Methods Eight children with idiopathic scoliosis and eight healthy children were assessed. Kinetic data were collected using two AMTI OR6-7 force-plates, while the subjects walked freely along a 6-m walkway under three walking conditions: (1) without a schoolbag, (2) carrying a schoolbag bilaterally (over both shoulders—symmetrical load) and (3) carrying a schoolbag unilaterally (over each shoulder—asymmetrical load). Kinetic data were collected and four parameters were calculated; peak ground reaction force at the first maximum force peak (*F*1), time needed to reach *F*1 (*T*1), loading rate of *F*1 (LRF1) and total contact time (*T*2).

Results We found no significant differences between the scoliotic and healthy children for any of the kinetic variables examined. In addition, the position of the bag did not seem to have any effect on loading rate.

Conclusions The results of this study indicate that in terms of kinetic parameters during normal gait, the schoolbag load (symmetrical or asymmetrical) does not have a different effect on children with mild adolescent idiopathic scoliosis compared to normal controls.

Keywords Idiopathic scoliosis · Loading rate · Kinetics · Backpack · Schoolchildren

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Introduction

Adolescent idiopathic scoliosis (AIS) frequently develops during the period of rapid growth and the resulting spine deformity involves both translational and angular asymmetry of the vertebrae, rib cage and back surface [1]. However, the progression and risk factors for AIS are still not well understood. Most investigations involving movement analysis in scoliotic children, concentrate mainly on kinematic measurements. Nevertheless, as scoliosis is a structural deformity affecting the normally symmetrical vertebral column and resulting in an alteration of the centre of mass position, the examination of kinetic data could lead to a better understanding of scoliosis progression.

Perdriolle et al. [2] suggested that abnormal external loading is an essential factor affecting spine growth and may exacerbate an existing scoliotic deformity. A spine that is straight in the coronal plane is habitually loaded symmetrically, whereas a scoliotic spine is loaded asymmetrically. This asymmetric loading is assumed to cause the observed progressive deformity, especially during the growth period [1, 3]. This mechanical modulation of growth that subsequently produces asymmetrically wedged vertebrae and discs can be deteriorated by external factors, like a heavy schoolbag, which can have adverse effects on balance control in school-age children.

There are very few studies in the literature so far that have actually investigated the effect of external loading (in terms of a heavy schoolbag) in such populations [4]. Studies in healthy children, concerning the impact of backpack use on gait patterns have shown significant gait and posture adaptations depending on weight and position in which the backpack was carried during analysis [5]. The increased weight on the back results in excessive forward trunk lean and rounding of the shoulders, causing the spine to be altered from its neutral position. Grimmer et al. [6] have suggested that the backpack load should be limited to somewhere in the region of 10–15 % of body weight (BW) in adolescents. However, it seems that the loads carried daily in schoolbags are relatively high with respect to the child's body weight, and have generally been found to exceed the recommended BW limits. Carrying an overweight backpack makes a child unable to maintain a proper standing posture [7] and may present loading rate asymmetries, which are the most sensitive indicators of gait dysfunction [8].

During gait, the trunk assists in the maintenance of equilibrium and interacts with the limb movements to achieve efficient locomotion. Scoliosis has been shown to affect spinal mobility and trunk balance [9], therefore altering gait patterns. In the present study, we tried to reproduce in a clinical setting, the 'loading conditions' from the heavy schoolbag, observed in schoolchildren daily, so as to investigate the instantaneous postural adjustments they prompt. The aim of the study was to examine the effect of both symmetrical and asymmetrical school backpack loads in scoliotic and healthy schoolage children during walking, in terms of peak vertical ground reaction forces and loading rates. It was hypothesized that walking with a loaded schoolbag would result in more apparent kinetic changes and increased loading rates in scoliotic children compared to the healthy population.

Methods

Subjects

Eight male children with adolescent idiopathic scoliosis (mean age 12 ± 1 years; mean mass 51 ± 9 kg; mean height 1.59 ± 0.08 m) and eight healthy male children who were randomly selected as a control group (mean age 12 ± 2 years; mean mass 55 ± 7 kg; mean height 1.61 ± 0.1 m) were recruited for our protocol. Inclusion criteria for this study required that children in both groups had no history of orthopaedic trauma, no history of gross motor delay or any other orthopaedic or neurological problem. All subjects were assessed by an experienced spine surgeon (I.D.G.). Children with leg length discrepancies, any locomotor disorders, neurological abnormalities observed on clinical examination or with any previous treatment for their scoliosis were not included in the study. They all participated in usual school sports activities, without reporting any back-pain issue. All children and their parents agreed with the testing protocol and gave their consent to participate in accordance with the Institutional Review Board policies of our Medical School.

Clinical evaluation

The curve pattern in 3 children was a Lenke type 1 (main thoracic) and in 5 children a Lenke type 5 (thoracolumbar/lumbar). The mean ± SD Cobb angle for structural curves (thoracic and lumbar) was 18.3° ± 2.3° and for non-structural (thoracic and lumbar) curves 17.5° ± 2.1°. At the time of data collection, no clinical evidence of back pain was found.

Data acquisition

We equipped for our protocol, the children's own schoolbags with a 7-kg load inside, which was considered as the average daily weight of their school backpacks. This load represented a percentage almost around 15 % of the subjects' mean BW. All children were given time to become familiarised with the lab environment and were allowed a number of walking trials prior to data collection. They were instructed to walk freely with their normal walking speed along the walkway, without targeting the force plate, to simulate their normal gait. The testing trials were performed to ascertain appropriate starting points to allow the desired limb to strike the force plate on at least the fourth step. Accurate calculation of the subject's starting point during testing, allowed free walking mid-gait data to be acquired without a great number of rejected trials.

Our aim was to examine the effect of both symmetric and asymmetric loads in gait kinetics. Therefore, the subjects performed the trial under three walking conditions: (1) without the schoolbag, (2) carrying the schoolbag unilaterally over each shoulder—asymmetrical load and (3) carrying the schoolbag bilaterally over both shoulders—symmetrical load. Vertical ground reaction forces were measured for each limb using an AMTI force plate system (© Advanced Mechanical Technology, Inc.). The system consisted of a walkway (6 × 1 m) with the two embedded force plates type AMTI OR6-7 (464 × 508 × 83 mm) linked via an interface unit to a personal computer installed with the data collection software package APAS for Win98. The operator acquired data at a sampling rate of 200 Hz, activated by manual triggering for a period of 5 s. Criteria for data acceptance were: entire foot contact on the force plate, no apparent targeting of the force plate and sufficient sampling time to capture data for the total foot contact period. The software automatically produced force curve graphs for each data acquisition trial.

Mean readings were taken for four parameters of the force curves: peak ground reaction force at the first maximum force peak ($F1$), time needed to reach $F1$ ($T1$), loading rate of $F1$ (LRF1) and total contact time ($T2$). Loading rate was defined as the unsigned slope of the straight line connecting the zero intercept of the force curve at heel contact with the maximum peak ($F1$) of the same curve. Figure 1 shows a typical force/time curve from a scoliotic child, demonstrating all these variables. Kinetic measurements were normalized to body weight to allow comparison between subjects.

Statistical analysis

Descriptive statistics [mean and standard deviations (SD)] were calculated for all variables. Four independent t tests were used to compare values between healthy and scoliotic children for each dependent variable. In addition, a one-way fully repeated analysis of variance (ANOVA) was used to address the scoliotic group and examine if the position of the schoolbag had an effect in the children's loading rate. The statistical significance for all comparisons was set at 0.05.

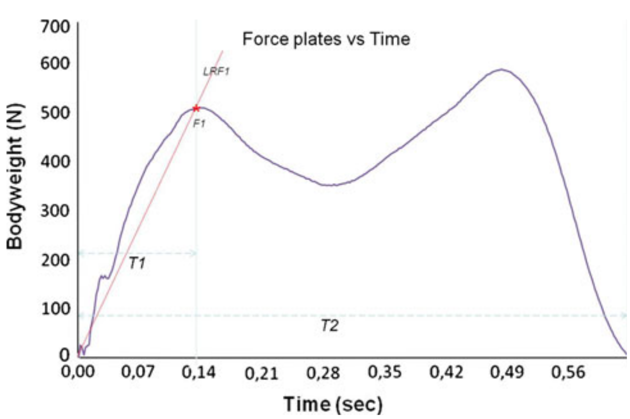

Fig. 1 A typical force/time curve from a scoliotic child, demonstrating the impact force peak ($F1$), his loading rate (LRF1), the time needed to reach the first maximum force peak ($T1$) and the total contact time ($T2$). Loading rate was defined as the unsigned slope of the straight line connecting the zero intercept of the force curve at heel contact with the maximum peak ($F1$) of the same curve

Results

No children reported any low-back pain from carrying their backpacks, either unilaterally or bilaterally. However, both healthy and scoliotic children stated that they usually carry their backpack over both shoulders.

Descriptive statistics and p values for all kinetic parameters examined, of both the scoliotic and healthy children are demonstrated in Table 1. The results indicated no significant difference between the two groups for the peak vertical ground reaction forces ($F1$) for all three walking conditions: (a) walking without carrying a schoolbag ($p = 0.823$), (b) unilateral carrying of schoolbag ($p = 0.917$) and (c) bilateral carrying of schoolbag ($p = 0.915$). Similarly, we found no significant difference between the two groups for all walking conditions for the time needed to reach the first maximum force peak ($T1$) ($p = 0.221$, $p = 0.\ 111$ and $p = 0.753$, respectively) and for the total contact time ($T2$) ($p = 0.897$, $p = 0.106$ and $p = 0.126$, respectively). The t test comparisons within the scoliotic group between the right and left leg also demonstrated no statistical difference for $T1$ ($p = 0.331$, $p = 0.653$ and $p = 0.121$, respectively) and for $T2$ ($p = 0.751$, $p = 0.091$ and $p = 0.413$, respectively).

No significant differences were also observed between the scoliotic and healthy children for loading rate (LRF1) for all three walking conditions ($p = 0.282$, $p = 0.205$ and $p = 0.878$, respectively). In addition, the one-way ANOVA that was performed in the scoliotic group to examine if the position of the schoolbag had an effect on loading rate, also showed no significant differences ($F = 0.214$; $p = 0.80$). Therefore, both symmetrical and asymmetrical schoolbag carrying produced similar loading rates in the scoliotic population.

Discussion

It is already established that mechanical forces influence vertebral growth. However, there is very little quantitative information about how scoliosis affects the loads acting on the spine and on the effect of asymmetric loading on the forces acting on the spine [1]. This is of great interest especially for the time of growth spurt, which is the danger period for idiopathic scoliosis progression. The goal of this study was to detect asymmetries in the gait pattern and loading rates of young children with an idiopathic scoliosis who carry a typical schoolbag symmetrically and asymmetrically, and compare them to healthy populations. We hypothesized that walking with a loaded schoolbag would result in more apparent kinetic changes in the scoliotic children. Our results, however, refuted our hypothesis. Specifically, we did not find any significant differences

Table 1 Means and SDs for the four force curve parameters examined (peak ground reaction force *F*1 at the first maximum force peak, time *T*1 needed to reach this force peak, loading rate LRF1 and total contact time *T*2), for all walking conditions, of both the scoliotic and healthy children

Parameter	Condition	Scoliotic (mean ± SD)	Control (mean ± SD)	*p* values
Impact force peak (*F*1) (body weight)	Without schoolbag	576.390 (±130.390)	587.800 (±116.927)	0.823
	Schoolbag in one shoulder	640.668 (±143.584)	644.789 (±122.640)	0.917
	Schoolbag over both shoulders	649.094 (±127.074)	654.607 (±128.550)	0.915
Loading rate (LRF1) (BW/s)	Without schoolbag	9.116 (±2.554)	8.016 (±1.230)	0.282
	Schoolbag in one shoulder	9.404 (±3.113)	8.253 (±1.923)	0.205
	Schoolbag over both shoulders	8.588 (±2.357)	8.741 (±1.943)	0.878
Time to impact force peak (*T*1) (s)	Without schoolbag	0.134 (±0.032)	0.149 (±0.021)	0.221
	Schoolbag in one shoulder	0.146 (±0.031)	0.160 (±0.024)	0.111
	Schoolbag over both shoulders	0.151 (±0.024)	0.154 (±0.023)	0.753
Total contact time (*T*2) (s)	Without schoolbag	0.645 (±0.046)	0.642 (±0.046)	0.897
	Schoolbag in one shoulder	0.648 (±0.054)	0.681 (±0.047)	0.106
	Schoolbag over both shoulders	0.639 (±0.056)	0.669 (±0.040)	0.126

between the scoliotic and healthy children, concerning the kinetic variables examined. We also observed that the position of the bag within the AIS group did not seem to have any effect on any kinetic variable. Therefore, schoolbag carriage seems to have a similar effect on both normal and AIS subject groups and there is no evidence for any interaction between the effects of scoliosis and the effects of load carriage on the recorded gait parameters.

When carrying the heavy backpack, significant biomechanical compensations occur. In case of symmetrical loading (schoolbag carried bilaterally), the subject's center of gravity is displaced posteriorly. Pelvic tilt or forward lean increases, to keep the subject in an upright, vertical position. This leads to increased lordosis causing compression of the posterior lumbar vertebral bodies and facet joints, therefore increased intradiscal pressure. In case of asymmetrical loading (schoolbag carried over one shoulder), we have an elevation and retropositioning of the ipsilateral shoulder, as well as contralateral trunk lateral flexion in an effort to keep the center of mass within the base of support, therefore also impairing walking symmetry. As scoliosis has been shown to affect spinal mobility and trunk balance [9], scoliotic children were expected to present more prominent gait adaptations and increased loading rates, in their effort to achieve efficient locomotion and retain a balanced posture. However, our results demonstrated that there was no significant difference in peak vertical ground reaction forces or loading rates between scoliotic and healthy children. This suggests that children with idiopathic scoliosis develop effective adaptive mechanisms that counteract the external increasing forces.

The effects of load carriage have become an area of concern in schoolchildren, as the loads carried daily in schoolbags are relatively high with respect to the child's BW, and have generally been found to exceed the recommended BW limits. Hong et al. [10] recommended a backpack weight limit of 10 % on the basis of significant changes in forward trunk lean and blood pressure recovery time of 10-year-old boys walking on a treadmill. Cavallo et al. [11] found that over a quarter of the female students in a fourth grade group carried a backpack of greater than 15 % BW, while Negrini and Carabalona [7] reported a mean backpack load of over 20 % BW. The daily loads applied by schoolbags are of particular concern in patients with AIS as abnormal external loading has been suggested as one of the possible factors that may affect the growth of the spine and exacerbate the scoliotic deformity [2].

It is common knowledge that a scoliotic spine experiences greater loading on the concave side and that this asymmetric loading causes asymmetric growth and progression of deformity. Stokes et al. [1] and other authors [2] have suggested the "vicious cycle" theory of scoliosis progression which proposes that scoliosis causes loading of the spine that is asymmetric in the coronal plane, and that vertebral growth and disc remodeling respond to the chronic presence of these asymmetric forces. External factors, like the schoolbag, act additionally as a burden on the balance mechanism and may have adverse effects on balance control. However, it seems that due to mechanisms that the body of the scoliotic children adapts, there is no obvious deterioration of the existing loading symmetry patterns.

In the literature, there is a limited number of gait studies comparing adolescents with idiopathic scoliosis and healthy controls, and even fewer studies have investigated the effect of load. Chow et al. [12–14] in a series of studies, progressively evaluated backpack loads of 0, 7.5, 10.0, 12.5 and 15.0 % of BW in a healthy and scoliotic population with mild AIS. They demonstrated a reduction of walking speed and cadence, an increased anterior flexion of the trunk on the pelvis and antero-posterior balance difficulty both in healthy and scoliotic patients. The authors identified a possible critical load in approximately 10 % body weight [14], and proposed that presumably should be decreased in scoliosis population [12]. Their results are in agreement with ours, as they reported that carriage of a standard backpack has a similar effect on both normal and AIS subject groups and there was no evidence for any interaction between the effects of scoliosis and the effects of load carriage on their recorded gait parameters.

Several other reports have also demonstrated that some selected measures derived from the vertical ground reaction forces can be used as objective measures in assessing the pathomechanics of gait [15, 16]. Asymmetry of the loading rate has been identified as one of them and as the most sensitive indicator of gait dysfunction [8]. Inability to adequately attenuate forces during gait can lead to an overload in soft tissues; that's why it is widely considered that lower rates of loading are less damaging [17]. Loading rate is the speed at which we apply forces to our body. If the forces are not attenuated to below a critical level, tissue destruction could result, with healing responses leading to further structural change altering mechanical behaviour of the tissues. Schaffler et al. [18] have shown in vitro that repeated loading at higher physiological loading rates, such as those occurring during running, is more damaging than repeated loading at lower loading rates. Milner et al. [19, 20] have suggested that decreasing the loading rate applied to the tissues in runners can minimize the effects of microtrauma from endurance training. Changes in the loading rates in scoliotic children could cause increased forces acting on the vertebrae during gait, leading to a repetitive microtrauma to the sub-chondral tissues during walking. However, we found no differences between the AIS group and the control group for any of the conditions examined. Our study is the first one that investigates the effect of schoolbag carrying on the children loading rate.

A possible explanation for the normal loading rates observed in the scoliotic children may be related to adaptations of the lumbar and pelvis muscles. Mahaudens et al. [21] have demonstrated indeed that patients with mild AIS exert 30 % more physical effort than healthy subjects to ensure habitual locomotion, and this additional effort requires an important increase of oxygen consumption. They suggested that this excessive energy cost may be a consequence of the bilateral timing activation increase of the lumbo-pelvic and pelvi-femoral muscles. It has been proposed that the muscles and the trabecular bone take over most, and articular cartilage only little, of the loads during locomotion [22]. The mechanism that the body probably uses to lower the loading rate and reduce the energy of the ensuing shock wave is through appropriate muscular adaptations and subsequent limb actions. Proper positioning of the knee prior to initial contact with the ground and eccentric contraction of the thigh muscles during that moment can help disperse the load and decrease stress on the joint [23].

Another finding of our study was that the time needed to reach the first maximum force peak ($T1$) and the total contact time ($T2$) in scoliotic subjects did not differ significantly from the healthy subjects. In addition, the comparisons within the scoliotic group between the right and left leg also demonstrated no statistical difference for all three walking conditions. Due to this result, we concluded that gait symmetry was maintained in the subjects studied. Therefore, adaptations of the neuromuscular system may play the most crucial role in maintaining the gait symmetry and normal loading rates in scoliotic children.

Our study was limited due to the fact that only the short-term effects of the heavy schoolbag carriage have been investigated and fatigue of children has been avoided. Longer term load carriage and associated fatigue may result in differing effects on the gait patterns of healthy subjects and subjects with AIS and should be addressed in future studies. Gait speed also affects test–retest reliability of several parameters and must be taken into consideration. Normalization to body mass reduces the test–retest reliability for the kinetic parameters, which suggests that it might be more appropriate to assess the reliability with absolute gait data in a specific group if there are no growth effects [24]. Other limitation of our study includes the limited number of children. As the effect of curve magnitude is unknown, this study has been limited to mild AIS cases only, with a Cobb angle of 20° or less. Differences between the normal and AIS subjects may be more apparent with increasing curve severity and future studies are planned to investigate changes in load-bearing gait for a wider range of AIS curve magnitudes.

Conclusion

This study indicated that in terms of kinetic parameters during normal gait, the schoolbag load presents similar effect on subjects with mild AIS than healthy controls. In addition, the position of the bag does not seem to have any effect in the children's loading rate. Our results serve to highlight the value of using kinetic parameters in developing further understanding of the pathogenesis and aetiology of scoliosis. The backpack load effect on schoolchildren posture should be further evaluated in future studies with the addition of muscle activity measurement. The combination of knowledge on spinal loading asymmetry and on the effect of load on spinal growth, would allow quantification of how mechanical factors determine scoliosis progression during growth.

Conflict of interest None.

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