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Acute systematic and variable postural adaptations induced by an orthopaedic shoe lift in control subjects

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Abstract A small leg length inequality, either true or functional, can be implicated in the pathogenesis of numerous spinal disorders. The correction of a leg length inequality with the goal of treating a spinal pathology is often achieved with the use of a shoe lift. Little research has focused on the impact of this correction on the three-dimensional (3D) postural organisation. The goal of this study is to quantify in control subjects the 3D postural changes to the pelvis, trunk, scapular belt and head, induced by a shoe lift. The postural geometry of 20 female subjects ($\bar{x} = 22$, $\sigma = 1.2$) was evaluated using a motion analysis system for three randomised conditions: control, and right and left shoe lift. Acute postural adaptations were noted for all subjects, principally manifested through the tilt of the pelvis, asymmetric version of the left and right iliac bones, and a lateral shift of the

pelvis and scapular belt. The difference in the version of the right and left iliac bones was positively associated with the pelvic tilt. Postural adaptations were noted to vary between subjects for rotation and postero-anterior shift of the pelvis and scapular belt. No notable differences between conditions were noted in the estimation of kyphosis and lordosis. The observed systematic and variable postural adaptations noted in the presence of a shoe lift reflects the unique constraints of the musculoskeletal system. This suggests that the global impact of a shoe lift on a patient's posture should also be considered during treatment. This study provides a basis for comparison of future research involving pathological populations.

Key words Leg length inequality · Orthopaedics · Posture · Scoliosis

Introduction

A tilt of the pelvis in the frontal plane is often associated with articular degenerations, injuries to the back or hip and thoraco-lumbar scoliosis [3–5, 7–9, 11, 12]. This pelvic tilt may be the result of postural abnormalities, inherent bone asymmetries or a combination of both [18, 20]. Diagnosed radiologically [7] or clinically [1], the tilt of the pelvis is often corrected to limit the progression of associated pathologies, to improve function, and for aesthetic purposes [11]. Specific examples include the cor-

rection of a frontal plane inclination of the pelvis with a shoe lift to diminish the Cobb angle of scoliosis patients [4, 7, 12] and, when in association with chronic back and hip pain, to alleviate the magnitude of the symptoms [3].

Postural changes that may accompany the correction of a leg length inequality have been noted to include a tilt of the superior part of the spine towards the leg elevated by a lift [12], a displacement and rotation of the pelvis and scapular belt in the same direction [13] and asymmetric version of the innominate bones of the pelvis [2]. The effect of a shoe lift on the global three-dimensional (3D) posture – position and orientation of the pelvis, trunk,

scapular belt and head as well as the relative position of the shoulders in reference to the pelvis – has rarely been investigated. It is important to consider these possible postural changes, as their persistence alters the mechanics of movement and may lead to the development of musculoskeletal disorders [6, 14, 15]. When a shoe lift is implemented within reasonable limits of the musculoskeletal system, the researcher has the opportunity to assess the pertinence of the observed postural reactions. This knowledge could then guide further research that more specifically investigates a pathological population and possible postural adaptive processes which may occur over time. The goal of this study is to quantify among control subjects the acute 3D postural changes induced by a shoe lift.

Materials and methods

Twenty adult women, between 19 and 24 years of age ($\bar{x} = 22$, $\sigma = 1.2$), reporting no orthopaedic or neurological disorders, participated in this project. A scoliometer was used to verify that the gibbosity was less than 5° .

The postural geometry evaluation was performed using a motion analysis system. Eight video cameras were used to calculate the 3D co-ordinates of reflective markers placed on 36 anatomical landmarks. The accuracy (1 mm) and precision (0.5 mm) on the reconstruction of these marker co-ordinates were estimated using a reference object. The anatomical landmarks that defined the postural geometry of the subject were palpated bilaterally and included

1. The base of support: heel and tip of second toe
2. The lower extremities: lateral malleolus, external tibial plateau and greater trochanter
3. The pelvis: anterior and posterior superior iliac spines, and the most lateral border of the iliac crest
4. The scapular belt: inferior lateral tip of the scapula, acromion, superior and inferior sternum
5. The spine: every second spinous process between T1 and L5 including S1, and
6. The head: glabella, opisthocranium, right and left tragi.

With the subject in an upright standing position, the elevation of the right or left foot was obtained using a shoe lift that covered the full length of the foot, with a vertical height of 15 mm. This height was chosen to maintain a balance between the subject's musculoskeletal limits and to maximise the probability of observing postural changes. A foot template was used to standardize the foot position of each subject and to enhance upright standing postural stability and reproducibility. This foot template imposed a distance of 30 cm on the external border of each heel and had an open angle of 20° between the external border of the foot and the postero-anterior axes. The subject was asked to stand comfortably within the foot template, to slightly abduct her arms and to look straight ahead at a line fixed on the wall. The absence of knee flexion was verified by the evaluator. Three conditions were evaluated in a random order: control condition, shoe lift right (SLR) and shoe lift left (SLL). Two trials (1 s, 60 Hz) were acquired for each condition. Between each trial the subjects were asked to move in a leisurely way outside of the foot template. The between-trial interval was around 60 s.

The 3D co-ordinates of the anatomical landmarks were used to calculate the postural parameters of position and orientation of the pelvis, shoulders and head with reference to the base of support. Rotation and tilt were calculated as the angle between a line joining the anterior superior iliac spines for the pelvis, both acromions for the scapular belt, and both tragi for the head with reference to

the frontal (rotation) or horizontal (tilt) planes. Right and left iliac bone versions (RIB, LIB) were defined as the angle between a line joining posterior superior iliac spines to ipsilateral anterior superior iliac spines and the horizontal plane. Rotations, version and tilts are positive in the counter-clockwise direction in transversal (apical), right lateral and posterior-anterior views respectively. Medio-lateral (ML), postero-anterior (PA) shift and vertical height were represented by the position of S1 (pelvis), T1 (scapular belt) and the opisthocranium (head) relative to the centre of the posterior edge of the base of support. ML and PA shifts were defined as positive anteriorly and laterally towards the left side of the subject. Geometry of the spine was analysed using an estimation of kyphosis and lordosis. These parameters were defined, using surface markers, similar to the method described by Voutsinas and MacEwen [19]. Kyphosis and lordosis were quantified in the sagittal plane, using the distance between the spinous process marker at the posterior and anterior apex respectively and the straight line between T1 and S1. These parameters are normalised over the linear distance between T1 and S1 and are expressed as a percentage.

Results

The initial pelvic tilt for the control condition and the induced tilt with reference to the control condition by the shoe lift (right and left) is presented in Fig. 1. In the control condition, the pelvic tilt ranged between -4.5° (clockwise) and 1.5° (counter-clockwise) across all subjects (Fig. 1). With the adjustment of the shoe lifts the induced pelvic tilt was observed to range from -9° to 5.8° . Due to the presence of these initial postural asymmetries, the results are normalised by calculating the difference between the shoe lift conditions to the control condition. The postural parameters for the control condition, and difference with respect to the shoe lift conditions are presented in Table 1.

The measures of orientation and position of the head were variable within and between subjects. This variability makes the results difficult to interpret and no data will be presented here. The large number of degrees of freedom at numerous articulations between the shoe lift and the head could be the origin of this excessive variability.

Orientation of the body segments

The tilt of the pelvis and scapular belt, and the relative difference between the pelvis and the scapular belt for the control condition were $-1^\circ \pm 1.7^\circ$, $-1^\circ \pm 1.2^\circ$, and $-1^\circ \pm 1.6^\circ$ respectively. A repeated measures ANOVA revealed a significant difference in pelvic tilt between the control and shoe lift conditions ($P < 0.05$). The elevations on the right side induced a counter-clockwise tilt and the elevations on the left produced a clockwise tilt. For the scapular belt, the difference in tilt between the shoe lift conditions and the control condition ranged between -1° (clockwise) and 2° (counter-clockwise), with a mean difference close to 0° ; thus no significant differences were found between conditions. As a result, a significant difference was noted to exist between the relative difference in tilt between the pelvis and the scapular belt for both shoe

Fig. 1 Tilt induced by the right and left shoe lifts with reference to the control condition (SLR shoe lift right, SLL shoe lift left)

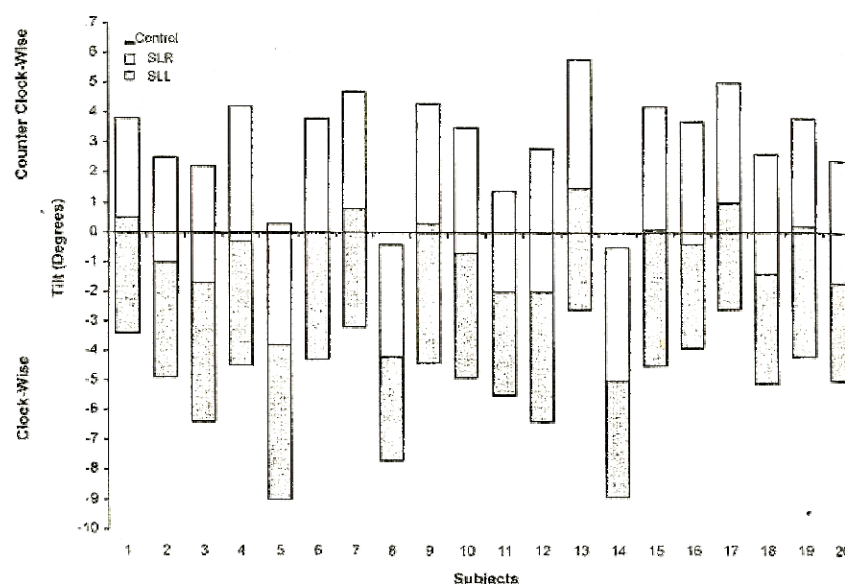


Table 1 Postural parameters: values for the control condition and the difference calculated for each experimental condition (SLR shoe lift right, SLL shoe lift left, RIB right iliac bone, LIB left iliac bone, PA postero-anterior, ML medio-lateral)

	Control	Δ SLR	Δ SLL
Pelvis			
Tilt ($^{\circ}$)	-1 (1.7)	4 (0.4)*	-4 (0.5)*
Rotation ($^{\circ}$)	1 (2.5)	1 (2.4)	0 (1.7)
RIB version ($^{\circ}$)	-11 (4.7)	1 (1.5)*	-2 (1.4)*
LIB version ($^{\circ}$)	-10 (4.6)	-2 (1.4)*	1 (1.3)*
PA shift (mm)	3 (15)	0 (8)	-2 (10)
ML shift (mm)	-1 (8)	12 (14)*	-12 (8)*
Height (mm)	951 (43)	9 (3)*	9 (3)*
Shoulders			
Tilt ($^{\circ}$)	-1 (1.2)	0 (0.8)	0 (0.7)
Rotation ($^{\circ}$)	1 (1.9)	0 (1.4)	0 (1.5)
PA shift (mm)	29 (16)	2 (11)	-1 (9)
ML shift (mm)	0 (10)	10 (15)*	-12 (10)*
Height (mm)	1388 (55)	8 (2)*	8 (2)*
Shoulders/pelvis			
Tilt ($^{\circ}$)	-1 (1.6)	-4 (1.0)*	4 (0.9)*
Rotation ($^{\circ}$)	1 (3.1)	0 (1.3)	0 (1.1)
PA shift (mm)	27 (15)	1 (8)	1 (6)
ML shift (mm)	0 (8)	-2 (4)	0 (4)
Height (mm)	437 (24)	-1 (3)	-2 (2)*

* $P < 0.05$ (shoe lift with reference to control condition)

lift conditions ($P < 0.05$). With the elevations placed under the right foot there was a relative clockwise tilt between the pelvis and scapular belt and with the elevations placed under the left foot there was a relative counter-clockwise tilt.

Regarding the version of each iliac bone, there was a significant difference between the control condition and

the shoe lift conditions ($P < 0.05$). The right elevations induced a retroversion of the right iliac bone and an anteversion of the left iliac bone, while a left elevation induced a retroversion of the left iliac bone and an anteversion of the right iliac bone. The difference between the version of the right and left iliac bones (RIB-LIB) varied significantly between all conditions ($P < 0.05$): control ($-1^{\circ} \pm 1.8^{\circ}$) right elevation ($2^{\circ} \pm 1.7^{\circ}$) and left elevation ($-4^{\circ} \pm 1.7^{\circ}$). There was a positive correlation between the RIB-LIB difference in version and pelvic tilt for each condition: control (0.88), shoe lift right (0.87), shoe lift left (0.85) (Fig. 2).

The induced rotation of the pelvis and shoulder by the shoe lift with reference to the control condition was found to be specific to each subject in both direction and amplitude (see Fig. 3), and no statistical difference was noted for the three parameters. This rotation had a range of -6° to 4° for the pelvis and -3° to 3° for the scapular belt.

Position of the body segments

The vertical position of the pelvis (S1) and the scapular belt (T1) for the shoe lift conditions were noted to be significantly different from the control condition ($P < 0.05$). Across conditions, there was an increase in height of 9 mm and 8 mm for the pelvis and the scapular belt respectively. There was also a lateral displacement of S1 with reference to the control condition towards the side opposite to the shoe lift ($P < 0.05$). Similar results were noted for the scapular belt ($P < 0.05$), resulting in no relative ML displacement between T1 and S1 (-2 mm and 0 mm for SLR and SLL respectively).

An examination of the induced postero-anterior shift of the pelvis, scapular belt, and scapular belt with reference to the pelvis revealed no significant difference between

Fig. 2 Correlation between the difference in version between the right and left iliac bones and the tilt of the pelvis

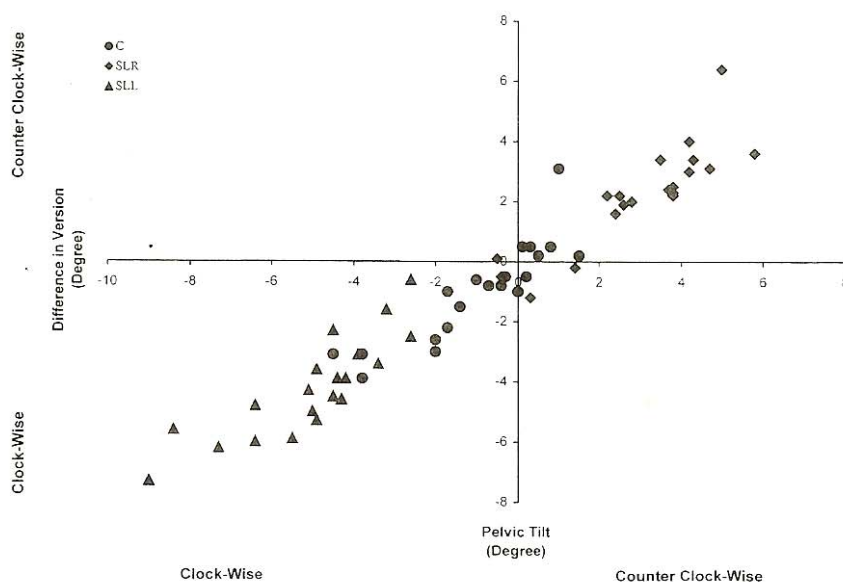
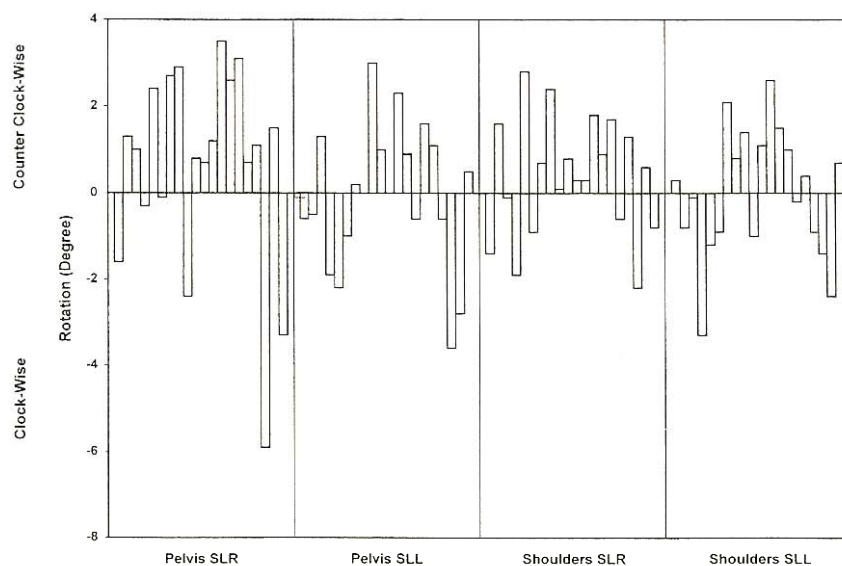


Fig. 3 Difference for each subject between shoe lift conditions in relation to the control condition for the rotation of the pelvis and scapular belt



conditions. However, the direction and amplitude of these changes, which varied between subjects, were of sufficient amplitude to be noted. The pelvis had a maximum shift of 13 mm in the anterior direction and 28 mm in the posterior direction. The shift in the scapular belt ranged from 28 mm anteriorly to 24 mm posteriorly. The shift of the scapular belt with reference to the pelvis ranged between a maximum of 25 mm anteriorly to 7 mm posteriorly.

No notable modifications were noted in kyphosis and lordosis with the application of a shoe lift. The average difference between the left and right shoe lift conditions and the control condition was -0.2% and 0.1% for kyphosis, with a maximum difference of 1.2% and minimum of -1.3% . The average difference for lordosis was 0.0% and

0.2% , with a maximum of 1.0% and minimum of -1.2% for the right and left shoe lift conditions respectively.

Discussion

The questions pursued in this study were:

1. Does a shoe lift create a tilt of the pelvis?
2. Are there simultaneous changes to the orientation and position of the pelvis?
3. Are the other body segments affected (scapular belt, trunk and head)?

As hypothesised, a shoe lift of 15 mm induced a tilt of the pelvis. However, this postural adjustment was accompa-

nied by modifications to the position and orientation of all the body segments studied. Certain modifications were present in a systematic manner across all subjects, whereas others were found to be specific to individuals.

The elevation of a single lower limb created a systematic tilt of the pelvis in the frontal plane for all of the subjects of 4° for both left and right shoe lifts. Part of the between-subject variability (0.4° and 0.5°) for the right and left shoe lifts respectively could be attributed to the difference in the width of the pelvis of different subjects. The effectiveness of a shoe lift to elevate the pelvis in relation to the horizontal (transverse) plane is in agreement with the results reported by previous authors [4, 7, 10, 12]. These authors investigated the impact of a shoe lift on the Cobb angle for scoliosis patients [4, 7, 12], and on intrapelvic asymmetry and decompensated scoliosis [10]. Irvin [7] noted in a group of 42 adults that a significant reduction of a lower leg length discrepancy coincided with a significant reduction in the angle of lumbar lateral bend. Gibson et al. [4] observed that a leg length correction in 15 patients with a leg length discrepancy of 1.5 cm or more, resulting from femoral shaft fractures, produced a reduction of compensatory lumbar scoliosis as well as poor vertebral alignment in some patients.

The effect on the orientation and alignment of the pelvis due to the use of a shoe lift to correct lower leg length inequalities has for the most part focused on two-dimensional analysis techniques [4, 12]. However, 3D changes to the position and orientation of the pelvis should not be overlooked. Pitken and Pheasant [13] noted a rotation of the pelvis specific to the side of elevation in control subjects. In the present study, 37% of the subjects showed a minimum rotation of 2° across all conditions. This rotation was found to be variable between subjects in both direction (counter-clockwise 53%, clockwise 46%) and amplitude (ranging from 6° clockwise to 4° counter-clockwise).

A difference between the version of the left and right iliac bones was observed with the shoe lift. There was a retroversion of the iliac bone of the elevated side and an anteversion of the iliac bone of the contralateral side. This version was found to correlate positively with the amplitude and direction of pelvic tilt. The observed relative version of the iliac bones represents an important percentage of the relative movement of the sacro-iliac joint, noted by Smidt et al. [17] to be 5° and 4° for right and left straddle positions respectively. Pitkin and Pheasant [13] and Cummings et al. [2] reported antagonistic version movements of the iliac bones ranging from 2° to 11° with an increase in elevation from 0.63 cm to 3.3 cm. Maganiello and Scapin [9] reported a strong correlation between lumbar and thoracolumbar scoliosis curves and lower leg length inequalities. The use of a lift to try to correct these scoliotic curves should be approached with caution when the pelvic tilt is accompanied by a relative version of the iliac bones. It therefore seems pertinent to verify in a popula-

tion of scoliosis patients with a leg length inequality whether or not the antagonistic version is reduced or increased by a correction of the leg length inequality.

The shoe lifts induced a tilt of the pelvis, a relative tilt between the scapular belt and pelvis, a difference in version between the left and right iliac bones and a lateral shift of the pelvis and the scapular belt. The observed tilt between the scapular belt and the pelvis may be an adaptation by the body to preserve a stable visual platform and vestibular system. The rotation of the scapular belt complimented the pelvis, and the posterior anterior and lateral shift of T1 complimented the shift of S1. This suggests that certain postural adjustments in the presence of a shoe lift involved a displacement of the trunk as a whole unit. The parameters of lordosis and kyphosis did not reflect any adaptive mechanisms of the spine. This lack of difference may be attributed to two causes. The first suggests that with an acute adjustment of a shoe lift the impact on the spine is minimal; however, over an extended period of time there is the possibility that chronic adaptations may occur. The second may be associated with a lack of sensitivity of these two variables in detecting a change in the spine. These variables are limited to measurements in the sagittal plane, while an adaptive mechanism specific to the transverse or frontal planes may be overlooked. New parameters should be developed to account for a global shift of the trunk as well as a relative movement between the scapular belt and pelvis, which reflects possible adaptations of the spine.

With an unequilibrated posture, depicted by a lateral shift and rotation of the pelvis and scapular belt, it is possible that an unbalanced stress is applied to the musculoskeletal system during quiet standing and complex integrated movements such as walking. With a change in the position and orientation of the scapular belt, pelvis and spinal vertebrae, postural and movement-associated pathologies may develop. If the position of the centre of mass of individual body segments changes, the amplitude and the position of the forces exerted on individual joints may also change, affecting the contact stress within a joint and the load exerted on the supporting ligaments and musculature. The implication of an abnormal posture, reflected through the alignment or shape of the spine and poor alignment of the scapular belt and pelvis, has not been thoroughly evaluated [14]. The implications can be diverse and noted principally through the degeneration of articular surfaces and the possible chronic development of muscular disorders [14]. Greigel-Morris et al. [6] examined the frequency of postural abnormalities and pain among adult subjects. The subjects, who had a greater forward head shift, increased kyphosis and right and/or left rounded shoulders, had an increased incidence of pain. At a neuromuscular level, neuromuscular disorders may develop based on the constant loading of specific muscle fibres, ultimately leading to pain and dysfunction. With a change in the position of the contact force distribution of

a joint, the development of articular cartilage may also be inhibited [15]. The impact of this change may be magnified during dynamic activity such as walking, where asymmetrical movements may lead to increased internal joint forces. Schuit et al. [16] investigated the effect of a lift on the ground reaction forces of adults. Increased ground reaction force was noted when the subjects were fitted with a lift and was associated with possible increased joint stress on the lower extremity. Although cadence was a controlled variable, stride length was not. Increased stride length is known to be associated with increased walking speed, which in return will increase the amplitude of ground reaction forces. In contrast, Bandy and Sinning [1] noted no changes in the amplitude or velocity of angular movements about the ankle, knee and hip in adult subjects fitted with a heel lift, only a tendency was noted toward a more symmetrical movement between the range of hip motion.

Conclusion

The addition of a shoe lift induced global postural reactions which could have an impact on the spinal geometry and associated forces exerted on this structure. If these postural reactions persist or an adaptation process occurs in which the subject would favour an optimal posture, possible secondary effects may develop whose potential impact on the health of the subject need to be considered. Some of the modifications noted in this study are systematic, where specific postural adaptations such as an induced pelvic tilt were noted in all of the subjects, while other postural adaptations are more variable between individuals and have unique amplitude and directional characteristics. The evaluation of the postural geometry of a patient before and after the application of a shoe lift is recommended so that the induced postural changes are recognised and their potential impact evaluated.

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