Balance and Skeletal Alignment in a Group of Elderly Female Fallers and Nonfallers

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The purpose of this study was to determine whether sagittal plane posture differed between fallers and nonfallers and to explore the relationship between skeletal alignment and balance in elderly females. Forty-eight women > 65 years of age were recruited from various medical and senior citizen centers. Thirteen of these women were classified as fallers. Postural alignment was measured in standing using an inclinometer, and lower extremity joint angles were assessed in standing using a universal goniometer. The Berg Balance Scale, the Functional Reach Test, and a modified Timed Get Up and Go Test were used to measure balance. Spinal alignment did not differ significantly between fallers and nonfallers; however, knee joint angle was significantly greater in fallers compared to nonfallers. Significant, but low, correlations were found between the inclination of the upper thoracic spine and all three balance measures. Lower thoracic slope and knee joint angle in standing were also weakly related to two of the three balance measures. This study supports the hypothesis that a significant but weak relationship exists between balance and skeletal alignment in elderly females.

It is estimated that every year one in three community-dwelling elderly persons will experience a fall (Tinetti et al., 1988; Campbell et al., 1989). A fall event occurs when the postural control system fails to maintain equilibrium (Holliday et al., 1992; Richardson, 1993). To achieve and maintain equilibrium, an individual must control and regulate specific postural outputs during voluntary, involuntary, or externally imposed movements of the center of gravity (Horak et al., 1989; Chandler and Duncan, 1993). Several subsystems are believed to be involved in postural control, including sensory systems, motor response synergies, higher nervous system components, and the musculoskeletal system (Woollacott, 1990).

Postural responses are executed through the musculoskeletal system, and changes to any part of the musculoskeletal system may lead to increased difficulty in maintaining equilibrium. Reduced isometric knee extensor and ankle dorsiflexor strength is associated with an increase in postural sway under reduced visual and support surface conditions (Lord et al., 1991). Isometric hip flexor, extensor, and abductor strengths are associated with scores on the One Limb Stance Test (Iverson et al., 1990). Lower extremity muscle strength is lower in fallers compared to nonfallers (Studenski et al., 1991; MacRae et al., 1992).

Loss of spinal and peripheral joint range of motion is also associated with decreased postural control. Findings of a preliminary study have indicated that the amount of cervical and lumbar range of motion affect stability during head motion in healthy older adults (Studenski et al., 1992). A weak and inconsistent relationship exists between passive hip and knee ranges of motion and postural sway in older adults (Duncan, G. et al., 1992).

Theoretically, postural changes that occur with aging may also contribute to balance impairment and falls. The relationship between skeletal alignment and balance has been less extensively investigated and findings are inconclusive. Brocklehurst et al. (1987) noted that a loss of height, associated with spinal deformity, and knee joint angle in standing were significantly related to postural sway. The researchers measured loss of height by determining the difference between height and armspan. Knee joint angles were measured from a lateral photograph, and an ataximeter was used to record postural sway. Cunha et al. (1987), however, found no association between sway path and measures of “stoop” in older adults. Sway path was recorded during relaxed standing using a Kistler force plate. Stoop referred to three measures: eye-to-ear angle, chin-sternum distance, and the shank angle. Eye-to-ear angle and chin-sternum distance were measured on lateral photographs of subjects. The shank angle was recorded in standing, using a goniometer.

These previous studies examined balance only as an ability to maintain a position/posture, rather than the ability to respond to external displacement, and/or the ability to change positions/postures. The objectives of the present study were to (a) determine whether skeletal postural measures differed between fallers and nonfallers, and (b) to examine the relationship between skeletal alignment and balance in community-dwelling elderly subjects using a more activity-based assessment instrument that examined more than one component of balance.

METHODS

Subjects

Forty-eight elderly female volunteers were recruited from local family medicine clinics, geriatric and home care programs, and local senior citizen centers. All were 65 years of age or older, were able to ambulate without supervision with or without the use of a cane, and were living in-

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dependently (alone in a house or apartment, or living in a boarding-type residence or with family). None of the subjects exhibited cognitive impairment, defined by a score of 24 or less on the Folstein Mini-Mental State Examination (Folstein et al., 1975) or postural hypotension defined as a drop in systolic blood pressure of > 20 mmHg or a drop in diastolic pressure of > 10 mmHg upon rising from sitting to standing or after 2 minutes of standing (Caird et al., 1973). All subjects denied a medical history of active vestibular disorders, severe musculoskeletal disorders such as polymyalgia rheumatica, active lower extremity arthritis (defined by acutely inflamed joints), neurological disorders such as Parkinson’s disease, or major depressive/affective disorder. None required constant usage of a walker or a more sophisticated aid to assist in ambulation.

Thirteen of the 48 tested subjects were classified as fallers, and 35 were classified as nonfallers. A fall was defined as an event during which a subject comes to rest on the ground or at some lower level, not as the result of a major intrinsic event or overwhelming hazard (Tinetti et al., 1988). Major intrinsic events included syncope, stroke, seizure, or the presence of an acute infection. Overwhelming hazards included slipping on ice or water on the floor, falling off a ladder, or any other situation that would likely precipitate a fall in a normal individual. A subject who reported one or more falls during the one-year period immediately prior to the date of recruitment into the study was classified as a faller. Subjects who denied any fall episodes during this same period were classified as nonfallers. Self-reporting of falls is limited by underreporting; however, recall of falls by subjects over one year has been noted to be superior to recall over 3 to 6 months (Cummings et al., 1988).

Equipment and Protocol

Balance and skeletal alignment measures were obtained using standardized procedures in a randomized order. An assistant was present during all testing to ensure safety.

Balance. — Balance was measured using the Berg Balance Scale (BBS), the Functional Reach Test (FR), and a modified version of the Timed Get Up and Go Test (TGUGT). The BBS provides a numerical measure of balance by grading an individual’s ability to perform 14 common everyday movements each on a scale of 0–4 (Berg et al., 1989). The maximum score possible is 56 points. These items assess an individual’s ability to maintain positions of decreasing stability, to change positions with ease, to perform movements of increasing speed, and to perform tasks in unstable positions (Berg et al., 1989). This scale has been shown to be a valid and reliable measure of balance in older adults (Berg et al., 1989, 1992).

For the purpose of this study, one subscale of the BBS was expanded to provide interval data in addition to ordinal data. Subscale 8 of the BBS provides an ordinal measurement of functional reach. Functional reach (FR), a balance measurement developed by Duncan et al. (1990), is defined as the maximal distance a subject can reach forward while maintaining a stable base. The instructions provided to subjects are as follows: lift your arm 90°, stretch out your fingers, and reach as far forward as you can. For subscale 8, an ordinal score was recorded, as per instructions on the Berg Balance scale, and the actual distance in centimeters that subjects achieved was measured. The distance measured provided an indication of the area within the base of support in which subjects can confidently move their center of mass (Duncan et al., 1990). FR is a reliable (Duncan et al., 1990, 1992) and valid (Duncan et al., 1990; Weiner et al., 1992) measure of balance in the elderly.

A modified version of the TGUGT was the third measure of balance (Podsiadlo and Richardson, 1991). This modification allowed for ease of administration within the lab environment of the current study. The time in seconds required for subjects to rise from a chair without arm rests, ambulate three meters, turn and sit in a second chair with arm rests, rise from the second chair, ambulate back to first chair, turn, and sit down in chair was recorded. The original TGUGT is reliable for use in an elderly sample (Podsiadlo and Richardson, 1991). The modifications made to the test were not considered major, and reliability of the measure was not reexamined in this study.

Skeletal alignment. — The degree of thoracic and lumbar curvature was measured in standing using an inclinometer, fabricated by the engineering department of Queen’s University (Figure 1). The inclinometer, specially designed to measure spinal angles, consisted of two plastic buttons approximately 9 centimeters apart attached to a dial which measures degrees (Loebl, 1967). Inclinometer readings reflect the angle formed by tangents to the spinous processes (Loebl, 1967; O’Gorman & Jull, 1987). Intra-rassessors, intrarater reliability testing of the inclinometer for use in the present study, reached highly acceptable levels for all spinal slopes measured, with intraclass correlation coefficient values ranging from .896–.965.

Figure 1. Schematic diagram of the inclinometer used to measure spinal inclines. The distance between the feet of the inclinometer was 9 centimeters. The number of vertebrae spanned was dependent on the curve measured and subject stature.
Anatomical locations of spinous processes of T1, T12, and S1 were palpated (Magee, 1987) and marked with a grease pencil with subjects in a sitting position. These markings were rechecked through palpation once subjects assumed a standing posture. Subjects were asked to stand up as straight as possible. The inclinometer was then positioned to measure the inclination in degrees from T1 downward and T12 upward for measurements of upper and lower thoracic slope, respectively. The inclinometer was next positioned to measure the inclination from T12 downward and S1 downward for measurements of upper lumbar and sacral slopes. Measures of thoracic kyphosis and lumbar lordosis were obtained by calculating the angle formed by the tangents to the spinal processes of end vertebrae of thoracic and lumbar curves (O’Gorman and Jull, 1987; see Figure 2).

Bilateral knee and ankle joint angle positions were measured in standing using a universal goniometer. Subjects were asked to stand as straight as possible while the following bilateral anatomical landmarks were palpated and marked with a grease pencil: center of the greater trochanter, center of the lateral epicondyle of the femur, head of the fibula, lateral malleolus, and the base of the fifth metatarsal. To measure knee joint angle position, a large-sized goniometer was positioned with the center of the fulcrum placed over the center of the lateral femoral epicondyle, the proximal arm aligned along the lateral mid-line of the femur, using the greater trochanter as a reference, and the distal arm aligned along the mid-line of the fibula using the lateral malleolus as a reference point (Norkin, 1985). To measure ankle joint angle position, a small-sized universal goniometer was positioned with the center of the fulcrum placed below the lateral aspect of the lateral malleolus, the proximal arm of the goniometer aligned along the lateral mid-line of the fibula, using the head of the fibula for reference, and the distal arm aligned along the lateral aspect of the fifth metatarsal (Norkin, 1985). Knee and ankle joint angle positions were measured bilaterally, and the average of the two limbs was used for data analysis.

The reliability of goniometry for measuring lower extremity joint range of motion has been well documented (Boone et al., 1978; Smith and Walker, 1983; Walker et al., 1984). Goniometry has also been used to measure lower extremity joint position and shank angle in two previously cited studies (Brocklehurst et al., 1982; Cunha et al., 1987); however, reliability was not assessed. Intrarater reliability was examined in the current study by measuring knee angle bilaterally in standing in five subjects on two occasions within the same test session. The intraclass correlation coefficient for this measure was .987.

**Data Analysis**

A SYSTAT (Chicago, IL) software program was used to manage and analyze the data. Histograms and box plots of the raw data were constructed to visually display the distribution of values on each variable for all subjects and for subjects separated according to fall status. As the assumptions of normal distribution and homogeneity of variance \( t \)-test were not met for all interval variables, Spearman’s rho nonparametric test was performed to analyze relationships between balance and skeletal alignment measures.

The Mann Whitney U Test statistic was performed to compare fallers and nonfallers on all variables except lower extremity joint angles and age, which were compared using an independent \( t \)-test.

**RESULTS**

**Comparison of Fallers and Nonfallers**

A preliminary analysis of results indicated a significant difference \((p = .01)\) between the mean age of fallers and nonfallers. In order to achieve equivalence of the two groups on the basis of age, the data of all nonfallers aged 69 years and younger \((n = 12)\) were not included for the comparison studies. This resulted in 23 nonfallers with...
mean age of 73.8 ± 4.1 years. There was no significant difference (p = .23) between the mean age of these two groups when compared using an independent t-test. Comparative analyses are presented for nonfallers aged 70 years and older and fallers aged 66 years and older. Analyses of the interactive effects between balance and skeletal alignment are presented for all tested subjects meeting inclusion and exclusion criteria (n = 48).

There was a significant difference between fallers and nonfallers in all three balance measures (Table 1). Fallers scored significantly lower than nonfallers on 12 of the 14 subscales of the BBS. The two subscales where the groups did not differ were (a) independent sitting and (b) turning to look over one’s shoulder in standing. Fallers had a lower average score on the functional reach test and required significantly longer to complete the modified TGUGT.

Fallers exhibited significantly more knee flexion in stance than nonfallers (p = .01; see Table 2). No significant differences existed between the two groups in the ankle angle in stance. Although fallers on average had a greater upper thoracic slope and greater kyphosis angle than nonfallers, no significant difference was found between fallers and nonfallers on these or any of the spinal measures. Subsequent analysis determined that the power of the comparison of UTS between groups was 50% (GraphPad Software, San Diego, CA). Thirty-five subjects would be needed per group to detect a difference in UTS (α = .05; β = 0.8; see Table 3).

Interactive Effects

There were weak, but significant negative correlations between scores on the BBS and the FR test and upper thoracic slope, indicating deteriorating performance on these balance measures as the slope of the upper thoracic spine increased (Table 4). The association between the modified TGUGT and upper thoracic slope was significant and positive, also indicating deterioration in this balance performance measure as the upper thoracic slope increased. The correlation between FR and the modified TGUGT with lower thoracic slope also was significant, indicating a decreased ability to perform these tasks as the lower thoracic slope increased (approached the vertical). The scores on the BBS and the modified TGUGT were also significantly associated with knee angle in stance. None of the remaining skeletal alignment measures was significantly correlated with balance (Table 4).

**DISCUSSION**

Changes in posture with aging are common and include an increase in thoracic kyphotic curvature (O’Gorman and Jull, 1987), a decrease in lumbar lordosis (Milne and Lauder, 1974), an increase in knee flexion angle (Brocklehurst et al., 1982), a more posterior hip position, and a greater anterior lean of the trunk (Woodhull-McNeal, 1992). Little is known about the effect of these changes on balance and fall incidence in the elderly. Osteoporosis and degenerative joint disease may lead to skeletal deformities, accompanied by muscle and connective tissue changes, which may result in postural control deficits (Cunha et al., 1987). Kauffmann (1987, 1990) suggested a possible relationship between skeletal alignment and balance by noting that postural changes may result in stretch weakness of muscle, particularly the scapular retractors and trunk extensors. Stretch weakness is an untested theory, described by Kendall and McCreary (1983) as the effect of muscle remaining in lengthened position, however slightly, beyond neutral. This weakness may influence the speed of muscle contractions such that the ability to recover from a loss of balance or a postural disturbance is impaired.

Of the postural parameters measured in this study, only knee angle differed significantly between fallers and nonfallers; the average knee flexion angle in standing was greater in the group classified as fallers. Knee flexion angle was also significantly correlated with both the total score on the BBS and with the modified TGUGT. As knee flexion angle increased, performance on the BBS and the modified TGUGT deteriorated. These findings are in agreement with Brocklehurst et al. (1982), who reported a significant relationship between knee angle in standing and postural sway in subjects aged 65–84 years. Cunha et al. (1987), however, found that although shank angle relative to the vertical increased with age, this measure was not associated with postural sway in subjects over 65 years of age, and suggested that older individuals may assume a flexed or stooped posture in an effort to lower the center of mass in order to increase stability.

Itoi (1991) reported that the increased knee flexion angle was associated with two postural subtypes found in older women with osteoporosis; a total kyphotic curvature of the spine and lower acute kyphosis, where the apex of the kyphotic curvature was at or below the thoracic-lumbar junction. In both of these postural subtypes, the lumbar lordosis is decreased and the pelvis and sacrum tilted posteriorly, potentially leading to greater inclination of the femoral shaft and flexion of the knee. Forward trunk lean and a more anterior position of the center of gravity of the trunk may occur in individuals with these postural subtypes; these could lead to further impairment in balance performance (Woodhull-McNeal, 1992).

**Table 1. Comparison of Balance Measures in Fallers and Nonfallers**

<table>
<thead>
<tr>
<th>Balance Measurement</th>
<th>Fallers (n = 13)</th>
<th>Nonfallers (n = 23)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berg Balance Scale (max. score = 56)</td>
<td>Median = 45.0</td>
<td>Median = 55.0</td>
<td>&lt; .01</td>
</tr>
<tr>
<td></td>
<td>(21.0–54.0)</td>
<td>(46.0–56.0)</td>
<td></td>
</tr>
<tr>
<td>Functional Reach (cm)</td>
<td>M = 22.2, SD = 5.9</td>
<td>M = 27.7, SD = 4.9</td>
<td>&lt; .05</td>
</tr>
<tr>
<td></td>
<td>Median = 21.0</td>
<td>Median = 29.0</td>
<td></td>
</tr>
<tr>
<td>Modified Timed Get Up and Go Test (sec)</td>
<td>M = 21.5, SD = 11.3</td>
<td>M = 11.3, SD = 2.4</td>
<td>&lt; .01</td>
</tr>
<tr>
<td></td>
<td>Median = 17.9</td>
<td>Median = 11.4</td>
<td></td>
</tr>
</tbody>
</table>
Skeletal alignment among the elderly is highly variable (Woodhull-McNeal, 1992), which may partially explain why the current and past studies have failed to illustrate differences in spinal curves between fallers and nonfallers. The variability is greatest in the lumbar spine, where changes in curvature are dependent on postural subtype and may be compensatory to changes occurring more proximally. Lumbar lordosis increases in subjects with a thoracic kyphotic curvature and decreases in individuals with a lower acute kyphosis or a total thoracic kyphosis. This may explain why lumbar spine measures in the current study did not correlate with measures of balance. Conversely, the upper thoracic slope is increased in subjects with a thoracic kyphosis, a lower acute kyphosis, or a total kyphotic curvature. This measure is therefore more likely to correlate with measures of balance.

The present study shows that although specific measures of skeletal alignment are weakly related to performance on specific performance-orientated balance tests in elderly females, it is not possible to conclude whether skeletal alignment deformities occur in response to balance impairments or that balance impairments occur in response to skeletal deformities. However, there is some indication from this and previous studies that posture should be considered, along with other musculoskeletal parameters, in the assessment of risk factors for falling in the elderly.

The instrumentation employed in the present study is suitable for use in the clinical setting for both research and monitoring clients’ outcomes. Professionals working with older adults should examine balance, posture, and the musculoskeletal system to determine necessary treatment plans (Kauffman, 1987).

Future research is required to explore the relationship between proximal muscle strength and skeletal alignment, and determine what influence these two variables have upon the speed and strength of balance reactions. The effect of lateral spinal curvatures upon balance also deserves further research attention.

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Table 2. Comparison of Lower Extremity Joint Angles in Fallers and Nonfallers

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fallers (n = 13)</th>
<th>Nonfallers (n = 23)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee angle (degrees)</td>
<td>M = 4.5, SD = 5.2</td>
<td>M = 1.3, SD = 2.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Median = 4.0</td>
<td>Median = 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle angle (degrees)</td>
<td>M = 1.5, SD = 2.2</td>
<td>M = 1.1, SD = 2.6</td>
<td>0.60</td>
</tr>
<tr>
<td>Median = 0.0</td>
<td>Median = 0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Comparison of Spinal Curves of Fallers and Nonfallers

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fallers (n = 13)</th>
<th>Nonfallers (n = 23)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTS (degrees)</td>
<td>M = 31.1, SD = 18.2</td>
<td>M = 22.4, SD = 7.2</td>
<td>0.08</td>
</tr>
<tr>
<td>Median = 27.0</td>
<td>Median = 23.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTS (degrees)</td>
<td>M = -12.7, SD = 5.4</td>
<td>M = -15.0, SD = 6.7</td>
<td>0.19</td>
</tr>
<tr>
<td>Median = 13</td>
<td>Median = 16.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kyphosis (degrees)</td>
<td>M = 43.8, SD = 19.9</td>
<td>M = 37.3, SD = 10.5</td>
<td>0.38</td>
</tr>
<tr>
<td>Median = 37.0</td>
<td>Median = 38.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULS (degrees)</td>
<td>M = -6.9, SD = 11.8</td>
<td>M = -4.2, SD = 9.8</td>
<td>0.87</td>
</tr>
<tr>
<td>Median = -5.0</td>
<td>Median = -5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS (degrees)</td>
<td>M = 9.5, SD = 7.3</td>
<td>M = 7.0, SD = 8.1</td>
<td>0.58</td>
</tr>
<tr>
<td>Median = 9.0</td>
<td>Median = 9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lordosis (degrees)</td>
<td>M = 16.3, SD = 10.7</td>
<td>M = 11.3, SD = 10.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Median = 15.0</td>
<td>Median = 11.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Relationship Between Overall Scores of the BBS, the Two Modified Subscales of the BBS, and Skeletal Alignment Measurements

<table>
<thead>
<tr>
<th>Skeletal Alignment Measure (n = 48)</th>
<th>BBS (n=56)</th>
<th>FR (cm)</th>
<th>TGUGT (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper thoracic slope (degrees)</td>
<td>r = -.439**</td>
<td>r = -.311*</td>
<td>r = .347*</td>
</tr>
<tr>
<td>Lower thoracic slope (degrees)</td>
<td>r = -.187</td>
<td>r = -.305*</td>
<td>r = .303*</td>
</tr>
<tr>
<td>Kyphosis (degrees)</td>
<td>r = -.212</td>
<td>r = -.048</td>
<td>r = .067</td>
</tr>
<tr>
<td>Upper lumbar slope (degrees)</td>
<td>r = -.132</td>
<td>r = -.018</td>
<td>r = .124</td>
</tr>
<tr>
<td>Sacral slope (degrees)</td>
<td>r = .142</td>
<td>r = .180</td>
<td>r = .077</td>
</tr>
<tr>
<td>Lordosis (degrees)</td>
<td>r = .117</td>
<td>r = .053</td>
<td>r = -.067</td>
</tr>
<tr>
<td>Knee joint angle (degrees)</td>
<td>r = -.382**</td>
<td>r = -.262</td>
<td>r = .380**</td>
</tr>
<tr>
<td>Ankle joint angle (degrees)</td>
<td>r = -.166</td>
<td>r = -.245</td>
<td>r = .017</td>
</tr>
</tbody>
</table>

Note: UTS = upper thoracic slope, LTS = lower thoracic slope, ULS = upper lumbar slope, SS = sacral slope.

Our findings indicated that the spinal inclines of fallers and nonfallers did not differ significantly. However, there was a weak but significant correlation between upper thoracic slope and all three balance measures, indicating that as the inclination of the upper thoracic spine increased, performance on all three measures deteriorated. Lower thoracic slope correlated significantly with FR and the TGUGT but not with the total score on the BBS. Performance on both balance measures decreased as the slope of the lower thoracic spine increased or approached a more vertical orientation.

Previous studies comparing spinal curve measurements of elderly fallers and nonfallers also failed to demonstrate significant differences. Woodhull-McNeal (1992) reported no significant association between a history of falling and measures of kyphosis and forward lean. Similarly, Cunha et al. (1987) found no differences between 16 elderly fallers and 11 nonfallers in three measures of a flexed or stooped posture. Brocklehurst et al. (1982) reported no association between a measure of thoracic kyphosis and postural sway in elderly subjects.

Skeletal alignment among the elderly is highly variable (Woodhull-McNeal, 1992), which may partially explain why the current and past studies have failed to illustrate differences in spinal curves between fallers and nonfallers. The variability is greatest in the lumbar spine, where changes in curvature are dependent on postural subtype and may be compensatory to changes occurring more proximally. Lumbar lordosis increases in subjects with a thoracic kyphotic curvature and decreases in individuals with a lower acute kyphosis or a total thoracic kyphosis. This may explain why lumbar spine measures in the current study did not correlate with measures of balance. Conversely, the upper thoracic slope is increased in subjects with a thoracic kyphosis, a lower acute kyphosis, or a total kyphotic curvature. This measure is therefore more likely to correlate with measures of balance.

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