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Diagnosis

An investigation into the relationship between spinal curvature and postural sway in asymptomatic healthy young adults

C Johnson[1,2], JA Bettany-Saltikov[2*], J Ling[3]

Abstract

Introduction

There is a lack of published research investigating the relationship between thoracic hyperkyphosis and postural balance, both of which are independent contributory factors to falls in older people. The aim of this investigation was to evaluate the relationship between spinal curvature and postural sway in the frontal and sagittal planes. A secondary aim was to examine the difference in each of the variables over a period of 15 minutes.

Materials and Methods

A Microscribe 3DX Digitiser was used to measure back shape and a Kistler Force Plate calculated postural sway values. A convenience sample of 25 healthy young adults, aged 20-32 years was recruited. Each participant stood on the force plate for 15 minutes. Back shape measurements and a 30 second force plate reading were taken at the start and again at 15 minutes.

Results

A significant positive correlation was found between lumbar lordosis and antero-posterior sway measured at the start ($r[24]=0.398$, $p<0.05$). The change in medio-lateral sway over 15 minutes was also significantly different ($Z=-2.435$, $p<0.05$). No other statistically significant correlations were found but a number of general trends were seen between spinal angles and postural sway in both planes.

Discussion

Whilst a larger sample is required to investigate the aims further, this research has demonstrated that back shape and postural sway values have the potential to be used to identify those at risk of falling. Those identified could be referred to necessary balance and falls rehabilitation classes.

Conclusion

If relationships between back shape and postural sway are already present in asymptomatic young adults it is reasonable to hypothesize that in older and very old adults these relationships will be even more marked. Further larger scale studies on asymptomatic older adults are needed to further evaluate this hypothesis.

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Introduction

Over a third of people aged 65 years or older have a fall each year and in around half of these cases the falls are recurrent[1,2]. The increased fall injury risk in the elderly population has been linked to impaired postural control[3]. It has also been hypothesised that a forward curvature of the spine displaces the Centre of Pressure (CoP) towards the limits of stability and therefore affects balance[4]. Identifying different types of back shape and postures that may increase postural sway could therefore provide insight into those at risk of injury or falls. Knowledge of the relationships in the elderly population is slowly expanding but it may also be possible to identify these in younger age groups. Those individuals could then be referred to the appropriate health professional and educated with the relevant strengthening/ balance exercises to correct their posture and improve balance to reduce the risk of falling. This preliminary study focused on examining whether there were any relationships between spinal curvature and postural sway in young adults.

According to Tsai et al.[3] static postural control, or steadiness, is the ability to hold the body as motionless as possible for a given time and position as in the control needed to maintain posture during upright standing[5]. CoP typically reflects the overall stability and organisation of an individual's automatic postural responses[6]. CoP coordinates are derived from ground reaction forces registered with the aid of a force platform[7]. If both feet are in contact with the ground then the CoP will lie somewhere in between the two feet depending on the weight distribution[8]. The net CoP or Postural Sway is often reported in the literature referring to excursions of the CoP in both antero-posterior (AP) and medio-lateral (ML) directions[8]. The maximal range of the CoP's excursion and standard deviation are typically reported in research using force plates[7]. Postural Sway is a term that is commonly used to signify variations in the CoP[9].

Current evidence on the relationship between back shape and postural sway remains limited, with researchers concentrating on the separate areas of postural sway and balance or back shape assessment rather than establishing whether certain back shapes are linked to an increased postural sway[6]. Traditionally, physiotherapists have relied on observations and a subjective history to complete their assessments of patients[10] and palpatory skills and analysis used to treat problems and progress rehabilitation[11]. However, such methods are subject to error and provide no reproducible objective measurements[12]. To improve evidence-based practice, more objective measures should

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be utilised to improve diagnostic accuracy and determine treatment progression[13]. Back shape measurement is an area were objective measurements will be beneficial to both patient and physiotherapist and improve evidence based practice.

The measurement of back shape has developed from general observations to simple surface measuring tools to equipment which can produce 3-D coordinates of each spinal level. Curvatures of the spine are 3-dimensional therefore any changes will occur in the frontal, horizontal and sagittal planes[14]. In any back shape assessment a 3-D measurement will give more information than any other method[15]. The measurement of spinal angles through a range of different devices is well documented in the literature[10,15,16].

As stated previously, research has typically focused on back shape or postural sway but there is little research into their relationship. Greig et al.[4] found balance deficits had a strong relationship with vertebral fractures but not with the angle of thoracic kyphosis. However, with low subject numbers the authors did accept the possibility of a Type II error. External factors including pain may also have also contributed to the increase in sway for those with a fracture. Similarly, examining subjects with osteoporosis, Lynn et al.[17] found individuals with a thoracic kyphosis had greater postural sway than those in a `normal` posture group.

Individuals with an increased kyphosis have also been reported to have an increased medio-lateral sway and a decreased antero-posterior sway compared to a control group[18]. This further supports the findings of Lynn et al.[17] who suggested that balance rehabilitation may be useful to decrease the amount of falls in this specific population.

Of the few studies investigating the effects of increased thoracic kyphosis on postural sway none have provided sound evidence from a large sample. An increase in thoracic kyphosis may increase postural sway but whether this is due to fracture or increased angle alone remains unknown. Earlier work did not use 3-D scanning or force plates to collect data nor did it examine the effects of standing lumbar curvature on postural sway. Findings from work investigating increased thoracic kyphosis and the subsequent increase in postural sway suggest that those at risk of falling may be identified early if the appropriate equipment is available. It may be possible to

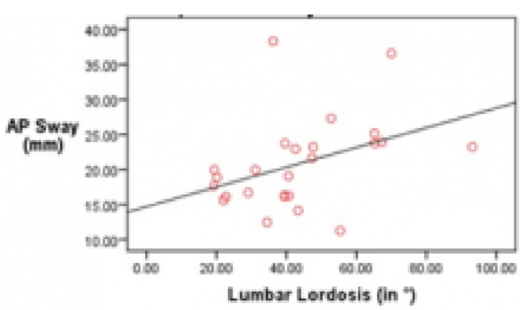

Figure 3: Relationship between lumbar lordosis and anteroposterior sway at the start.

Figure 1: Participant with spinal markers and digitiser.

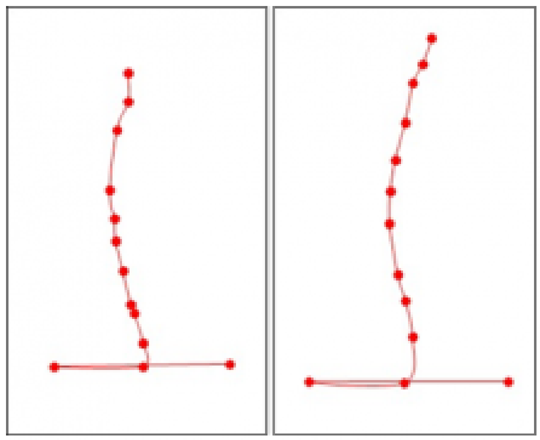

Figure 2: Frontal Plane Curves captured at start and after 15 min.

use healthy individuals to try and identify from an early stage any changes in spinal angles in the frontal or sagittal planes which are prone to an increase in postural sway and therefore more at risk of falling in older age.

Little is known about both angles in the thoracic and lumbar spine and their relationships with postural sway. It is also unclear whether these relationships change over time. This study investigates the relationship between spinal curvatures in the frontal and sagittal planes and postural sway, and whether any changes occur in these over time.

Materials and methods

This work conforms to the values laid down in the Declaration of Helsinki (1964). The protocol of this study has been approved by the relevant ethical committee related to our institution in which it was performed. All subjects gave full informed consent to participate in this study.

Design

A correlational design with repeated measures was used to evaluate the relationship between spinal curvature and postural sway over time.

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Participants

A non-probability convenience sample of 25 student participants (16 females) with a mean age of 24 years (SD: 2.29) was recruited. Male participants had a mean weight of 81.89kg (SD: 14.92; BMI: 25.14, SD: 4.69), female participants had a mean weight of 62.34kg (SD: 9.16; BMI: 22.62, SD: 3.49).

Instrumentation

Height and Weight Measurement

Each participant's height was taken prior to testing using a Leicester Height Measure (SECA, UK). Weight was measured using floor scales (SECA, UK, model number: 7617019009). All participants were measured without their shoes on. Height and weight information also allowed calculation of Body Mass Index (BMI).

Kistler Force Plate

A Kistler Force Plate (Kistler, UK) was used to assess balance by determining the Centre of Pressure for each participant and calculating the difference in range over time. The forces are measured in 3 axes, x, y and z. The measuring rate was set at 60s with frequency at 50 Hz. Software (Bioware Version 3.2.5) calculated the position of the centre of pressure on the plate's surface as a result of the forces applied over each 60s period. As this study was only interested in investigating the postural sway of a subject and not their ability to repeatedly stand on an exact location, mean scores were not of interest. The standard deviation and range based on the subjects CoP co-ordinates were calculated and reported, measures which are commonly used in studies looking at CoP on a force plate[2,7].

Microscribe Digitiser

Spinal Curvature was measured using a Microscribe 3DX Digitiser (Immersion Corp. Ltd., California). The digitiser produces coordinates in the x, y and z axis for the stylus tip relative to the initial starting position. The digitiser was mounted on a tripod for ease of testing and height adjusted where necessary. The digitiser was connected to a laptop for data storage. Software calculated an angle for thoracic kyphosis and lumbar lordosis in the sagittal plane and thoracic lateral asymmetry and lumbar lateral asymmetry in the frontal plane.

Procedure

Testing was carried out on an individual basis in a university physiotherapy laboratory. An information sheet detailing the aims and procedures of the research was provided and informed consent gained prior to testing. Confidentiality was maintained throughout; all participants were given a unique number which could identify their data if they wished to withdraw. Participants were informed that they could withdraw from the investigation at any time up to the data analysis stage. Potential participants with a history of back pain and/or surgeries or lower limb problems preventing them from standing for the duration of the investigation were excluded from the study. Any participants with a known allergy to sticky tape were also excluded.

Participants were provided with a T-shirt which had a panel cut out of the back so the spinous processes could be seen, Every other spinous process was palpated and marked with an 8mm circular sticker: C2, C4,C6, C7, T3, T5, T7, T9, T12, L1, L3, L5 and posterior superior Iliac spines on the left and right sides. These points were rechecked once each participant was standing to ensure that none had moved. The points used were adapted from similar studies on spinal shape[14].

After spinal processes were palpated and marked (Figure 1), participants were asked to stand barefoot on the force plate. The only instruction regarding stance was that participants should stand as comfortably as possible with feet approximately shoulder width apart and arms by their sides. A television and headphones were provided at eye level in front of the force plate; for standardisation purposes the same 15 minutes of a DVD was played to each individual.

The stylus tip of the digitiser was placed at each of the marked spinal levels and the points recorded by the software. In conjunction with this, a 60s reading was taken from the force plate. The participant then remained standing for 15 minutes on the force plate. At 15 minutes the procedures for measuring back shape and a force plate reading were repeated.

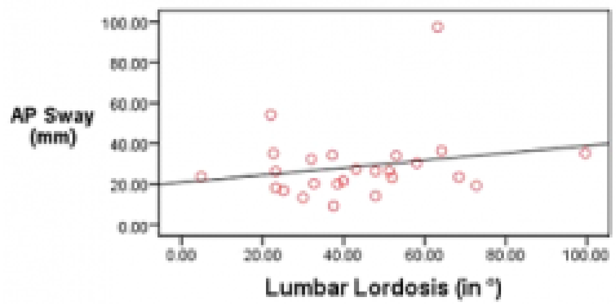

Figure 4: Relationship between lumbar lordosis and anteroposterior sway after 15 min.

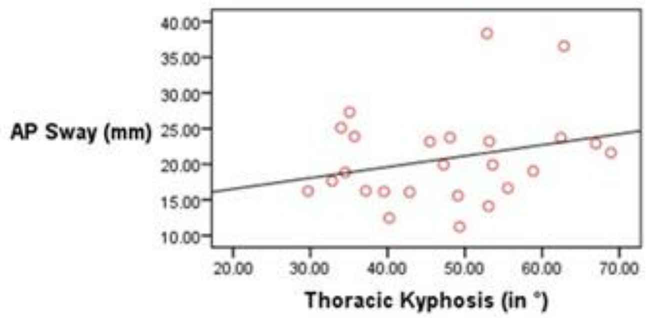

Figure 5: Relationship between thoracic kyphosis and anteroposterior sway at start.

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Data Analyses

The Statistical Package for Social Sciences (SPSS) version 16 was used for data analysis. A series of Kolmogorov-Smirnov tests revealed that the data for thoracic kyphosis, lumbar lordosis, thoracic lateral asymmetry, lumbar lateral asymmetry and antero-posterior sway were all normally distributed. Pearson Correlations were used to evaluate relationships and repeated measures t-tests were used to explore any differences. Relationships between both anterior-posterior as well as medio-lateral sway and other variables were examined with Spearman's Rho and a Wilcoxon Signed Ranks test used to investigate differences.

Results

Back Shape and Postural Sway values

Thoracic Lateral Asymmetry (TLA) and Lumbar Lateral Asymmetry (LLA) angles were calculated in the frontal plane. Table 1 shows the means, standard deviations and ranges for all angles in the frontal plane measured at the start and after 15 minutes. Table 1 shows the means, standard deviations and ranges for postural sway values measured in the medio-lateral and antero-posterior directions. Measurements taken at the start and after 15 minutes are shown. Figure 2 shows a typical start and 15 minute representation of all points measured in the frontal plane only for a single participant.

Relationships between Spinal Curvatures and Sway

Pearson's Correlation was used to investigate the following relationships: thoracic kyphosis and antero-posterior sway, lumbar lordosis and antero-posterior sway, lumbar lateral asymmetry and antero-posterior sway and thoracic lateral asymmetry and antero-posterior sway for values at the start and after 15 minutes. Lumbar lordosis was significantly correlated with antero-posterior sway for values taken at the start ($r[24] = 0.398$, $p<0.05$). None of the other correlations were significant. Spearman's rho was used to investigate each of the above spinal curvatures with medio-lateral sway at the start and after 15 minutes. No significant differences were found. Figure 3 shows the significant correlation found between lumbar lordosis and antero-posterior sway measured at the start as well as the best line of fit. There are two outliers which did not fit the general trend which may have affected the overall correlation outcome.

Figure 4 shows the same relationship as Figure 3 but taken after 15 minutes. Excluding one extreme value, Figure 4 shows a positive relationship between the two variables, with increased lumbar lordosis associated with increased antero-posterior sway.

Some relationships were closer to being significant than others. Figure 5 shows the relationship between thoracic kyphosis and antero-posterior sway at the start ($r[24] = 0.267$, $p>0.05$) and figure 6 shows the relationship between thoracic lumbar asymmetry and medio-lateral sway at 15 minutes ($\rho[24] = 0.219$, $p>0.05$). Both

Table 1: Means, standard deviations and ranges for postural sway values measured in the medio-lateral and antero-posterior directions.

Angle	Mean ± S.D (in °)	Range (in °)
Thoracic Lateral Asymmetry – Start	1.15° ± 0.48°	0 – 1.9°
Thoracic Lateral Asymmetry – 15 min	1.09° ± 0.48°	-0.03 – 2.2°
Lumbar Lateral Asymmetry – Start	2.48° ± 1.16°	0.45 – 5.47°
Lumbar Lateral Asymmetry– 15 min	2.46° ± 1.21°	0.47 – 5.75°
Thoracic Kyphosis – Start	47.56° ± 11.27°	29.69 - 68.92°
Thoracic Kyphosis – 15 min	50.16° ± 11.79°	32.05 – 74.27°
Lumbar Lordosis – Start	43.35° ± 18.38°	19.25 – 93.18°
Lumbar Lordosis – 15 min	43.61° ± 20.4°	4.87 – 99.61°
Medio-lateral sway – Start	14.47mm ± 16.85mm	5.48 - 91.06mm
Medio-lateral sway – 15 min	23.75mm ± 20.35mm	5.19 – 83.2mm
Antero-posterior sway – Start	20.79mm ± 6.5mm	11.23 – 38.34mm
Antero-posterior sway– 15 min	28.71mm ± 17.15mm	9.14 – 97.4mm

relationships were better correlated than the majority of results although neither was significant.

Generally, an increase in spinal curvature is related to an increase in sway (Figures 6). An unexpected relationship was located between lumbar lordosis and medio-lateral sway taken at the start. Figure 7 shows this relationship. In general as lumbar lordosis increased, medio-lateral sway also increased. Although unexpected, it does show that spinal curvature can affect sway.

Changes over time (15 minutes)

Along with investigating the relationships between back shape and postural sway, this research also looked at the differences in the individual variables over duration of 15 minutes. For the parametric data, repeated measures t-tests were used. For non-parametric data the Wilcoxon Signed Ranks test was used. A repeated measures - test showed that the difference in means for thoracic lateral asymmetry over time were not significant ($t[24] = 0.472$, $p>0.05$). The difference in means for thoracic kyphosis over time ($t[24] = -1.158$, $p>0.05$), lumbar lateral asymmetry over time ($t[24] = 0.050$, $p>0.05$), lumbar lordosis over time ($t[24] = -0.101$, $p>0.05$) and antero-posterior sway over time ($t[24] = -2.048$, $p>0.05$) were also not significant. A Wilcoxon test revealed that the difference in means for medio-lateral sway over time was however significant ($Z = -2.435$, $p<0.05$). Table 1 shows the means and standard deviations for all variables at the start and after 15 minutes.

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The mean differences in medio-lateral range at start and after 15 minutes were significant (Wilcoxon Signed Ranks test, Z = -2.435, $p<0.05$). The differences in antero-posterior sway over the 15 minute period were just over the $p<0.05$ significance threshold. The difference in antero-posterior sway over time was from 20.79° at the start and 28.17° at 15 minutes, a mean change of 7.38°.

The values represent a mean range which is reported in mm relative to the central point on the force plate. Sway did increase over the 15 minutes of standing but only medio-lateral sway showed a significant increase. None of the mean values for back shape measurement were significantly different over the 15 minute period. Thoracic kyphosis in the sagittal plane was the nearest value to significance.

The mean angle of thoracic kyphosis was measured as 47.56° at the start and 50.16° at 15 minutes, therefore a mean change of only 2.6° over the 15 minute period. However, individual angles of thoracic kyphosis ranged from 29.7°-68.9° at the start to 32.1°-74.3° at 15 minutes. Therefore on an individual basis it did show that the angles increased over the 15 minutes. There is a possibility of a Type II error as relationships and differences have been found but not necessarily significant ones. The experimental hypothesis would therefore be rejected in this case in favour of the null when in fact it may be that with an increased sample size the experimental hypothesis could be accepted. An initial target population size of 25 students was calculated based on a prospective power analysis of Pearson's Correlation. This revealed that to detect a large effect size ($r=0.5$) within conventional limits of power (0.8) and level of alpha (0.05), a total of 26 participants were needed.

Discussion

The aim of this investigation was to evaluate the relationship between spinal curvature and postural sway in the frontal and sagittal planes. A secondary aim was to compare the difference in each of the variables after a period of 15 minutes. Overall, results showed one significant correlation between spinal curvature and postural sway and one significant difference after 15 minutes. Lumbar lordosis was significantly correlated with antero-posterior sway when measured at the start. Medio-lateral sway changed significantly over a 15 minute period. No other significant results were found. Despite only two significant results, several trends were however observed.

Sagittal plane values - Thoracic kyphosis and antero-posterior sway

The relationship between thoracic kyphosis and antero-posterior sway measured at the start showed that an increase in thoracic Kyphosis angle was related to an increase in antero-posterior sway. The maximum thoracic angle for one of the individuals at the start was 68.9° which was a very high value. Normal kyphosis angles in a young population range from 20° to 40°[19] and some researchers

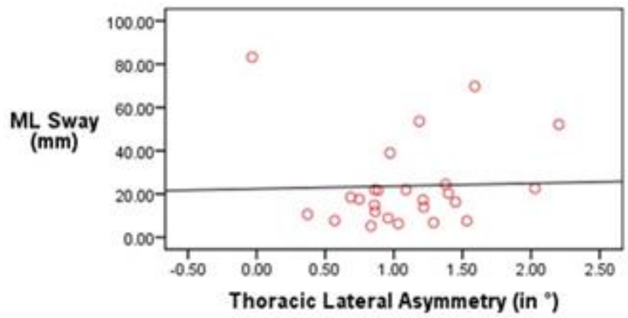

Figure 6: Relationship between thoracic lateral asymmetry and mediolateral sway taken at 15 min.

have defined hyperkyphosis as more than 54° in the sagittal plane[17]. There is a possibility therefore that this individual had a hyperkyphosis or may have been bending forwards slightly at the time of measurement. For the same relationship measured at 15 minutes, similar results were found. As thoracic angle increased so did antero-posterior sway. However, sway increased less than the thoracic angle. O'Brien et al.[20] found similar results to those found in the current study with female participants who were all aged 65 or above. They found a weak correlation between upper thoracic angle (measured from T1 downwards) and a series of balance tests. Lynn et al.[17] also found a relationship between an increased thoracic kyphosis and postural sway using elderly subjects all with osteoporosis.

Sagittal plane - Lumbar lordosis and Antero-posterior sway

The relationship between lumbar lordosis and antero-posterior sway measured at the start was significant. The same relationship measured at 15 minutes also showed that as lumbar angle increased so did antero-posterior sway. This relationship was not significant. There is very little published work which has looked into the relationship of lumbar spine angles and postural sway. Most work concentrates on the angle of kyphosis and its related risk to falls. O'Brien et al.[20] suggested that lumbar lordosis is the most variable angle between subjects and it may be related to changes occurring more proximally such as muscle lengths, strengths and pelvic inclination. Such variation makes it difficult to correlate with sway and balance parameters. Results from the current study support this, as the biggest range was located in lumbar lordosis angles.

Frontal plane values- Relationship between thoracic lateral asymmetry and medio-lateral sway

When thoracic lateral asymmetry was measured along with medio-lateral sway at the start this showed that in general as one increased so did the other. The mean thoracic lateral curvature was 1.2° ± 0.5°. A maximum individual value of 91.1mm range in the medio-lateral sway direction strongly suggests an outlier or error as this does not fit with the remainder of the results (mean 14.5mm ± 16.8mm). Participants were measured in their

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first minute of standing on the force plate so it may be that some participants were more settled into a stance than others during the initial measurement. The same relationship measured at 15 minutes showed no clear trend. Research[12] found mean thoracic lateral asymmetry in normal young adults was 16.1° ± 6.9° (n=48, aged 18-28 years). It is important to note however that the instrumentation used was the ISIS (Integrated Shape Imaging System) which measures the surface topography of the back. As no studies to our knowledge have so far compared these two different instrumentation systems it is difficult to know which is the more accurate. The values found in the current research are therefore much lower than these values. The lateral thoracic angle in the current study ranged from 0-1.9° at the start and -.03-2.2° at 15 minutes. The results from the current study do suggest that even the smallest degree of thoracic lateral asymmetry angle can affect sway in the medio-lateral direction although no clear relationship was found at 15 minutes.

Frontal plane values- Relationship between lumbar lateral asymmetry and medio-lateral sway

We hypothesised that lateral lumbar asymmetry would have a relationship with medio-lateral sway as they are both measurements in the frontal plane. Measurements taken at the start revealed a slight negative correlation; as lumbar angle in the frontal plane increased medio-lateral sway decreased or remained fairly stable. The same relationship measured at 15 minutes revealed similar results with no clear trend. The mean lateral lumbar curvature at the start was 2.48° ± 1.16° and 2.46° ± 1.21° after 15 minutes. Similarly to the thoracic lateral curvature angles, these values appear low. Bettany-Saltikov et al.[12] using the Isis system reported a mean lateral lumbar curvature of 13.4° ± 6.9° in healthy young adults. As with the previous results no studies (to our knowledge) have compared these two different instrumentation systems it is difficult to know which is the more accurate.

Relationship between lumbar lordosis (sagittal plane) and medio-lateral and antero-posterior sway

An unexpected relationship was found between lumbar lordosis in the sagittal plane and medio-lateral sway in the frontal plane measured at the start. This relationship was not statistically significant but does show an increase in lumbar angle being positively related to an increase in medio-lateral sway. However, a negative relationship was found at 15 minutes and on average an increase in Lumbar angle was related to a decrease in medio-lateral sway. The relationship between lumbar lordosis and antero-posterior sway at 15 minutes was also positive

Changes over time (15 minutes)

Over 15 minutes the means for thoracic kyphosis, lumbar lordosis, medio-lateral sway and antero-posterior sway all increased. The means for both thoracic lateral asymmetry and lumbar lateral asymmetry decreased minimally. It appears that as an individual relaxes into a standing

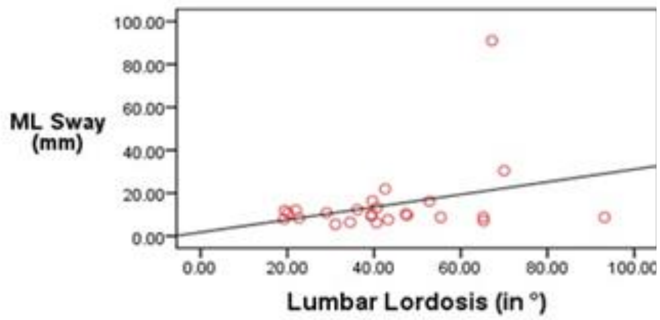

Figure 7: Relationship between lumbar lordosis and mediolateral sway at start.

position, spinal angles in the sagittal plane become more pronounced. Sway in both directions subsequently increased, although angles in the frontal plane may change more in individuals with scoliosis. Further research should investigate the change over time in individuals with scoliosis compared to those without to see if changes in angles are found.

Overall Clinical Implications

The clinical implications of these results suggest that if these relationships are already present in young healthy adults it is reasonable to hypothesize that in older adults and the very old, these relationships will be even more marked. Drzal-Grabec et al.[21] compared the posture of a group of young women (20-25 years of age) with a group of older women aged from 60-90 years old and found that Thoracic kyphosis depth increased gradually with age in groups of women aged 60–70 years, 71–80 years, and 81–90 years. Similar results were obtained by other authors[22,23]. The cause of the deepening of thoracic kyphosis with age is multifactorial; Drzal-Grabec et al.[21] state that as

"the aging process causes changes in the body in an upright position due to changes in passive and active stabilizers of the spine (Mika et al 2005)[24]. This contributes to the development of degenerative-deforming processes, especially at the spine and hip joints, which are particularly vulnerable to weight load. Regressive changes in ligaments and articular cartilage causes deterioration of body mechanics, progressing with age. As a result of diminishing muscle strength, elderly people subconsciously balance their body weight by adjusting the spine, which significantly affects body posture and postural sway. This leads to further impairment of the physiological curvature of the spine, and when in the standing position, compensate by bending (flexing) their hip and knee joints. Tilting of the whole body forward results in the movement of the centre of gravity forward in the same direction (Toledo et al 2010) [25]".

This increased thoracic kyphosis in old age has been shown to result in numerous consequences; the progression of disability[23], increase in falls due to the forward transfer of the centre of gravity, increased postural sway[26], lung disease[27], diminished quality of life[28],

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increased risk of fractures[29], overload of disease and increased mortality[23].
Hammerburg et al.[30] and Gelb et al.31 have also shown a positive correlation between age and decreased lumber lordosis whilst Glassman et al.32 and Djurasovic and Glassman[33] have demonstrated that a loss of lumbar lordosis at a younger age is also a predictor for low back pain in adulthood and old age. These results are clinically important as they concern parameters that could significantly affect the activities of daily living, quality of life and risk of mortality in people when they eventually reach the age of 60 years and over. As Drzal-Grabec et al.21 state, "Exacerbation of these pathologies in the consecutive decades of life requires physiotherapy in geriatric patients to prevent or postpone involuntary changes of the spine. Targeted preventive physiotherapy will significantly improve the fitness and health of the population over 60 years of age".

Limitations

Several limitations were identified. First, several participants stated that the force plate was cold on their feet. This could impact on their ability to stand still but it is difficult to know to what extent from the current data and requires further examination. Second, the (non-adjustable) height of the television meant that taller people may have had to bend forwards slightly and therefore increase thoracic kyphosis. If a television were used for future research then a height adjustable stand would rule prevent unnecessary upper thoracic and neck flexion. Third, each participant was given headphones to wear throughout the study to enable them to concentrate on the television without any distractions. However, it was noted that in some cases this isolated the individual so much that when back measurements were taken they were not expecting it and therefore they moved from a relaxed position to stand almost upright again. Further research would need to identify the best way to deal with this. It may help to have a 2 minute settling in period prior to taking the first measurements. A final issue was the technique used for placing the spinal markers. Each marker was placed with the participants in a prone position. They were then rechecked once that individual was in standing. However, with only one tester there could have been inconsistency in the marker placements and hence the calculated spinal angles. A further consideration is the relatively high technical measurement error in the comparative analysis of the surface changes of the trunk due to positioning and movement of any living subject. Weiss[34]has reported a relatively high measurement error in repeated measurements with the Formetric surface topography optical system. Weiss35 also showed that breathing can also influence the results of surface topography. The maximal and lateral deviations were not statistically significantly different between inspiration and expiration but values in the sagittal plane were significantly affected. Weiss further suggests that these measurements should be done on expiration. A limitation of our study is that we did not include different measurements for inspiratory and expiratory values. However our instrument differs from the Formetric system in that it is not an optical system but rather a mechanical digitizer. A study by Mcalpineetal.[36] demonstrated that both intra-rater and inter-rater reliability values between three different raters were found to be very high between repeated measures and between markers (intra-rater agreements all greater than 0.96). Error values for the z-axis (height) were lowest. We are confident therefore that whilst measurement error exists it was relatively low.

Conclusion

This study found has shown that in normal 'asymptomatic' young adults a change in spinal curvature or posture can result in a change in back sway and that over time both spinal curvature and sway tend to increase. We suggest that if these relationships are already present in young healthy adults it is reasonable to hypothesize that in older and very old adults these relationships will be even more marked. Further larger scale studies on asymptomatic older adults are needed to further evaluate this hypothesis. This research may help in identifying those older people at risk of falls, with balance training one strategy to effectively reduce the risk of falling in those identified as 'at risk' of falls.

Abbreviations list

CoP, Centre of Pressure: point where the pressure of the body over the feet would be if concentrated at one point
LLA, Lumbar Lateral Asymmetry: the lumbar spinal curvature in the frontal plane. TLA, Thoracic Lateral Asymmetry: the thoracic spinal curvature in the frontal plane

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