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Title: An exploration of familial associations in spinal posture defined using a clinical grouping method

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1. INTRODUCTION

The aetiology of most health conditions is multi-factorial, with familial links (i.e. genetic and shared environment factors) identified in cardiovascular and metabolic diseases (Ordovas, 2009), malignancies (Hemminki & Czene, 2002), psychopatholgies (Nomura et al., 2002), impaired balance (Pajala et al., 2004; Wagner et al., 2009) and low back pain (LBP) (Matsui et al., 1997; Battie et al., 2007; O'Sullivan et al., 2008). Therefore, interventions targeted at a familial level may be a useful strategy for optimising health and preventing the onset or persistence of some conditions, including LBP.

The social and economic significance of spinal health, particularly LBP, is well recognized (Walker et al., 2003; Strunin & Boden, 2004). Consistent with the biopsychosocial aetiologic model for spinal pain (O'Sullivan, 2005), many factors including spinal posture, influence spinal health. In particular, non-neutral spinal postures have been associated with LBP (Smith et al., 2008; Dankaerts et al., 2009; Astfalck et al., 2010), and the persistence of LBP (O'Sullivan, 2004). Non-neutral spinal postures refer to postures which clinically deviate from normal spinal alignment. It is acknowledged, however, that identification of neutral posture can be difficult (Kuntz et al., 2007).

Spinal posture refers to the position of spinal regions with respect to each other and gravity (Claus et al., 2009). While many studies have quantified specific parameters of spinal alignment, such as increased regional or overall lordosis (Korovessis et al., 1999; Dankaerts et al. , 2006) or reduced sacral inclination (Dankaerts et al., 2006), as being associated with LBP, the evidence remains controversial. Inconsistencies in findings may be partly explained by single measures of spinal posture failing to adequately characterise overall spinal posture. It has been hypothesised that the relationship between different spinal regions and body alignment, which is taken into consideration during postural classification, is more important than discrete angles (Kendall et al., 1993; Smith et al., 2008). Furthermore, it also better reflects posture assessment as performed in clinical practice. However, the inter-rater reliability of clinical postural classification remains uncertain.

Numerous descriptions of different sagittal standing posture classifications have been reported, including sway, flat back, hyperlordotic and neutral (McKenzie, 1981; Kendall et al., 1993; O'Sullivan, 2004; Roussouly et al., 2005; Smith et al., 2008). There is some evidence that participants classified as having non-neutral posture types have a greater likelihood of reporting LBP (Smith et al., 2008).

Although several plausible mechanisms exist for a familial association in spinal posture, this issue has not been investigated previously in the normal healthy population. Family studies have established idiopathic scoliosis, the most common postural deformity, as a polygenic disorder (deGauzy et al., 2010; Ward et al., 2010). Genetic links have also been identified in vertebral bone (Makovey et al., 2007; Zhai et al., 2009) and intervertebral disc (Sambrook et al., 1999; Battié et al., 2009) morphology, which influence thoracic kyphosis (Goh et al., 1999) and lumbar lordosis (Been et al., 2010). In addition, familial links in psychosocial traits and emotional experiences within the shared-familial environment may influence a child’s spinal posture. While parental depression and family environment have been identified as strong risk factors for offspring negative affectivity (Nomura et al., 2002), embodiment theories point to a strong relation between emotional experiences and posture (Barsalou, 1999; Oosterwijk et al., 2009). Lastly, a child may also adopt similar postures and movement patterns to his/her parents' through years of observation, learning and modelling (Cech & Martin, 2002).

The abovementioned studies provide preliminary evidence of a likely familial link in spinal posture through biopsychosocial factors and motor pattern learning theories. However, no known studies have examined the relationship between a parent and child's spinal posture. Therefore, the primary aim of this study was to examine the familial associations in spinal posture. A secondary aim was to examine the reliability of clinical classifications of spinal posture.

2. MATERIALS AND METHODS

2.1. Study Design

A cross-sectional study design used data collected in the Joondalup Spinal Health Study (JSHS) (Briggs et al., 2010). The JSHS was a community-based cohort study, carried out between August 2008 and May 2009, to examine familial associations in spinal health. The current study focuses on the familial association in spinal posture.

2.2. Study Population

231 participants (70 families consisting of 109 biological parents, 1 non-biological parent and 121 children) took part in the JSHS. The participants were recruited through random

dialling of residential phone numbers in the Perth electronic telephone directory, from all suburbs within an approximate 10km radius from the centre of Joondalup, a middle-class suburb in the northern corridor of metropolitan Perth, Western Australia. In the JSHS, two groups of families were recruited. The first group consisted of families where at least one parent and at least one child self-reported chronic and disabling LBP. The second group consisted of families where all family members at the residence reported no history of LBP in the previous 12 months. "Parents" were defined as biological or non-biological parents or guardians up to 65 years old, while "children" were defined as individuals who lived with their parents or guardians and were aged between 10-30 years old. In the current study, data from both groups of families were pooled as the intention was to explore a familial association in spinal posture only, and not to explore LBP as a mediating factor. Data from the one non-biological parent were excluded due to an absence of genetic links with her child. Therefore, the final sample size in this study was N=230. Written informed consent was received from all individuals prior to participation in the JSHS. Approval to conduct this study was granted by institutional human research ethics committees.

2.3. Procedure

2.3.1. anthropometrics

Height and mass were measured using a stadiometer and an electronic scale respectively, and body mass index (BMI) was subsequently calculated.

2.3.2 measurement of spinal posture

Participants were dressed in a short singlet and bike shorts to enable accurate placement of markers over anatomic landmarks. Retro-reflective markers were placed on participants' C7, T12 and S2 spinous processes and right canthus, tragus, acromion tip, anterior superior iliac spine, greater trochanter, lateral femoral epicondyle and lateral malleolus, by one of six trained examiners. Lateral full-body photographs (2048 x 1536 pixels) were taken of the right side of participants while they were asked to assume the following positions:

1. Standing in their self-defined normal posture, with the standardised instruction: "Feet shoulder width apart, stand normally and relax, look straight ahead."
2. Sitting on a stool, height adjusted to ensure the thighs were horizontal to the floor, knees flexed to 90^{o} and feet flat on the floor shoulder width apart, with the standardised instruction: "Hands half way up your thighs with the palms up, sit normally and look straight ahead."
3. A maximally slumped sitting posture, with the standardised instruction: "Look down at your hands, tuck in your chin into your chest and roll your back to slump as much as you can into your spine."

A digital camera (Olympus fe-210 Digital Compact Camera, Olympus Corporation, Japan), placed on a tripod 80cm high and 250cm lateral to each participant was used to take the photographs. A 10-cm plumb line, used to provide reference of the vertical, was included in the view. The reliability of analysing standing posture using this method has previously been reported, with standard errors of measurement ranging from 2.6 to 8.7^{o} (Perry et al., 2008). As part of the larger JSHS, all participants also had their back muscle endurance, pain pressure threshold, and bone density assessed in a randomised order, and completed an extensive questionnaire.

2.3.3. postural angle processing

Digital photographs of each participant were stored on a PC and later processed using customised LabVIEW 8.6.1 software (National Instruments, Austin TX, USA) to calculate pre-defined postural angles. Each marker, including the two markers on the plumb line, was identified and their coordinates were used to determine the following postural angles in usual standing and sitting: craniocervical, cervicothoracic, trunk, lumbar, sway and pelvic tilt angle (Figure 1, Table 1). The difference between trunk and lumbar angles in usual and slump sitting were also calculated, to provide an indication of the proximity to end-of-range spinal flexion adopted by participants during usual sitting. Excellent intra-rater digitization reliability using this method has been reported (Perry et al., 2008).

2.3.4. clinical postural grouping

Standing photographs of all participants were independently viewed by two experienced physiotherapists (ABr, POS) and classified into one of four postural groups: sway, flat, hyperlordotic and neutral (Figure 2). Decisions about group allocation were based on the clinician's independent judgement of spinal posture profiles relative to the broad definitions of posture types used in this study and earlier work (Kendall et al., 1993; Roussouly et al., 2005; Smith et al., 2008), agreed photographic examples of each posture type (Figure 2), and clinical experience. 'Sway' was defined as a posterior displacement of the thorax relative to the pelvis, with a long thoraco-lumbar kyphosis and low lumbar lordosis, posterior pelvic tilt, and extended hip joints. ‘Flat back’ was defined as a flattened thoracic and lumbar spine, and neutral or posterior pelvic tilt, while ‘hyperlordotic’ was defined as an increased thoracic kyphosis and lumbar lordosis with anterior pelvic tilt. ‘Neutral’ posture was considered as a neutral body alignment, a “normal” thoracic kyphosis and lumbar lordosis, and a neutral pelvic position (Kendall et al., 1993; Smith et al., 2008). In circumstances where the clinicians felt that a particular participant’s postural group was ambiguous, they gave a secondary classification opinion independently. After all participants were independently classified, discordance was resolved by discussion.

2.4. Data Analysis

Data were analysed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA) and Stata/IC 10.1 for Windows (Statacorp LP, College Station TX) with $\alpha = 0.05$. Independent t-tests were used to examine differences in anthropometric characteristics within parents and children. Pearson’s correlation was estimated using linear regression models with standard errors adjusted for inter-sibling correlation, to assess the strength of association between parent and child’s postural angles. As gender is known to influence posture (Poussa et al., 2005; Straker et al., 2008), analyses were conducted for six different parent-child relationships (i.e. father-child, father-son, father-daughter, mother-child, mother-son, mother-daughter). Chi-Square or Fisher’s exact test was used to identify the presence and strength of the relationship between a parent and child’s postural group. Odds ratios (ORs) and 95% confidence intervals (95% CIs) were calculated for each parent-child relationship of a given postural group compared to the other groups pooled together. Inter-observer reliability of clinical postural classification was quantified with percentage agreement, Kappa coefficient (*K*), and maximum Kappa coefficient (*K*max) based on the examiners' first opinion only (primary classification) and first or second (secondary classification) opinions (i.e. blinded agreement without discussion). *K*, which ranges from -1 to 1, indicates the proportion of agreement beyond that expected by chance, while *K*max acts as a reference value for *K* by reflecting the greatest possible agreement between examiners for a given data set (Sim & Wright, 2005).

3. RESULTS

3.1. Anthropometrics

Table 2 outlines the anthropometric characteristics of the study sample. Fathers were taller (mean difference [95% CI]) (13.7 cm [11.1-16.4]) and heavier (15.5 kg [9.8-21.2]) than mothers, while sons were taller (4.6 cm [0.1-9.2]) than daughters. Fathers and mothers were of similar age and BMI, with parents' mean BMI exceeding the accepted threshold for the classification of 'overweight' ($\geq$25 kg/m^2) (WHO, 1997). Sons and daughters were of similar age and BMI.

3.2. Postural spinal angles

Table 3 summarises participants' postural data for each spinal angle in standing and sitting, and the difference between sitting and slump-sitting for the trunk and lumbar angles. Significant differences between family members are noted in the table.

3.3. Associations between parents and children in postural angles

Although some statistically significant associations between parent and child's postural angles were observed, no consistent pattern was identified, except that there were more associations between father and child than mother and child (Table 4).

3.4. Postural groups

Based on clinical postural classification, the largest groups were neutral for fathers (41.3%), hyperlordotic for mothers (55.6%) and neutral for children (41.8% of sons and 48.5% of daughters) (Table 5). Significant differences in anthropometric characteristics of participants within and between each group were observed (Table 5). The BMI of fathers (mean difference [95% CI]) (3.1 kg/m^2 [0.7-5.5]), mothers (6.5 kg/m^2 [4.4-8.6]) and daughters (2.7 kg/m^2 [0.1-5.3]) in the hyperlordotic group was larger than those same family members in the other postural groups combined.

3.5. Associations between parents and children in postural groups

Of the 24 analyses carried out for the six parent-child relationships for each postural group, only two (8.3%) significant parent-daughter relationships were identified (Table 6), suggesting that familial association was poor across the four posture groups overall. However, daughters of fathers with a hyperlordotic posture were 4.0 times more likely to have a hyperlordotic posture themselves than daughters of fathers with a non-hyperlordotic posture. Similarly, daughters of mothers with a hyperlordotic posture were 3.5 times more likely to have a hyperlordotic posture themselves, compared to daughters of mothers with a non-hyperlordotic posture.

3.6. Inter-observer reliability of clinical postural grouping

Percentage agreement between clinicians' first choice of postural group (primary classification) was 63.5%, *K*=0.48 (95% CI: 0.38-0.56, p< 0.001) and *K*max=0.77. Agreement improved when their 2nd opinion (secondary classification) was taken into consideration with percentage agreement 77.0%, *K*=0.67 (95% CI: 0.59-0.74, p< 0.001) and *K*max=0.86.

4. DISCUSSION

To our knowledge, this is the first study to examine the familial association in spinal posture using a combination of both quantitative (i.e. postural angles) and qualitative (i.e. postural grouping) methods. While no consistent associations between parent and child's discrete postural angle measures were observed, postural classification data suggest a familial association between parents and daughters in the hyperlordotic group. These findings may provide some insight into the factors that underlie development of spinal posture. At the same time, they raise questions about the extent of genetic and environmental influences on posture. Moderate to good inter-rater reliability was observed in postural classification, which provides some support for its use in clinical practice and research.

Postural angle measures of children in sitting were consistent with that of adolescents in another study which used a similar method (Straker et al., 2008). Other studies in adults and children either used different methods (Roussouly et al., 2005; Astfalck et al., 2010) or different definitions of postural angles (Grimmer et al., 2002; McEvoy & Grimmer, 2005), making comparisons difficult. The small standard deviations around mean postural angle measures suggest some consistency within each group. Although 12% of parent-child postural angle associations were statistically significant, with fair to moderate strength (r=0.3-0.5) (Cohen, 1988), there appears to be no clear pattern of association between a parent and child's postural angle measures. The greater number of associations between fathers and their children might support an accumulating body of evidence relating to the role of fathers in a child's physical and psychosocial development (Wake et al., 2007; Hakvoort et al., 2010). However, more evidence is required with regards to the way in which fathers may influence their child's posture before definitive conclusions can be reached. More importantly, a lack of consistency in the data suggests that discrete spinal angles do not adequately characterise one's overall spinal posture, and supports the use of postural classification, which takes into consideration the interaction between different spinal regions and body alignment.

We propose that the strong familial association observed between parents and daughters in the hyperlodotic group could be due to certain biological factors which do not feature as prominently in the other groups. Firstly, there appears to be an association between hyperlordotic posture and increased body mass (Smith et al., 2010). Often people with a hyperlordotic posture are observed clinically to have increased abdominal adiposity, and studies have demonstrated that people who are overweight tend to adopt a posture with increased lumbar lordosis and anterior pelvic tilt (Guo et al. , 2008; Smith et al., 2010; Vismara et al., 2010); characteristics of the hyperlordotic group. Consistent with these findings, our data show that parents and daughters in the hyperlordotic group had a significantly larger BMI than those in the other postural groups combined. It is likely that, similar to findings observed in pregnant women (Franklin & Conner-Kerr, 1998; Sihvonen et al., 1998; Oliveira et al., 2009), the extra fat mass particularly around the abdominal region, alters trunk and abdominal muscle activation and influences body segment inertial parameters, resulting in one adopting a hyperlordotic posture due to the need to keep the centre of mass within the base of support. Although prospective studies are required to demonstrate causation in people who are overweight, familial links such as genetics, level of physical activity and parenting styles have already been established as familial correlates for obesity (Fogelholm et al., 1999; Wake et al., 2007; Ordovas, 2009). These factors which predispose some families to be overweight might therefore result in family members sharing a similar hyperlordotic posture.

Secondly, it has been observed clinically that people with a hyperlordotic posture tend to present with a more rigid posture which is more resistant to change (Danakerts et al., 2006; Danakerts et al., 2009). It is possible that structural characteristics such as spinal flexibility (Battié et al., 2007) and sacral angle structure (Whitesides et al., 2005; Choufani et al., 2009), with known genetic links, may manifest in the hyperlordotic posture.

In contrast, no familial associations were identified in the other postural groups, perhaps because the characteristics of these groups may be less influenced by familial factors and/or are more adapted as a result of non-family environmental influences, such as lifestyle, work, school environment and peer influences. However, we did not collect information about participants' spinal structure or daily activities, and have no direct evidence to support this. Yet it remains plausible that unlike the other postural groups, the hyperlordotic posture is more influenced by biological factors with known familial links, resulting in a familial association in the hyperlordotic posture. Another possible reason for the lack of an association in the other postural groups and between parents and sons in the hyperlordotic group could be the small participant numbers in these groups. Despite the relatively large initial sample size, participants were distributed unevenly among the groups after postural classification. This was comparable to previous posture classification studies (Roussouly et al., 2005; Smith et al., 2008), but the small numbers in some groups may have resulted in low power. It is also plausible that the absence of a familial association between parents and sons in the hyperlordotic group was attributable to sons being relatively less exposed to shared environmental influences (Maccoby, 1998).

4.1. Clinical Implications

Postural classification appears to be clinically more relevant than discrete angles for analysing overall spinal posture. We have shown clinical postural classification to have moderately reliability, with a Kappa coefficient of 0.48 indicating moderate agreement between clinicians beyond that expected by chance (Landis & Koch, 1977) and approximating the maximum attainable *K* (*K*max=0.77).It is important that clinicians are able to agree on posture types, because static postures have been linked to dynamic postures (Mitchell et al., 2008) and non-neutral posture types have been linked to LBP (Smith et al., 2008). A better understanding of posture and its related factors may enable clinicians to better appreciate their influence on spinal health. Previous studies have found posture to be modifiable to some extent (Scannell & McGill, 2003; Perich et al., 2010) with associated reductions in LBP (Perich et al., 2010). However, familial factors may also be a limiting factor to modifying a child's posture. While postural characteristics such as body sway may be more easily modifiable, postures with known familial links may be more difficult to modify due to genetic or structural constraints. Further evidence is required regarding the potential to change habitual posture and to identify the modifiable and non-modifiable factors that influence non-neutral postures.

4.2. Strengths, limitations and recommendations

The main strength of our study is that the participants are representative of the normal population, thus allowing generalisability of the findings. It is acknowledged that due to the study design, we were unable to accurately determine the presence of a parent-child association in some postural groups. Further, due to the small numbers of children in some age-groups, we were unable to account for variability in children's age which influences a child's skeletal maturity and posture (Cil et al., 2005; Poussa et al., 2005), and affect the extent of familial influence on a child (Hestbaek et al., 2004). Future work should be sufficiently powered to examine the familial association in each postural group, and other factors such as a child's age and skeletal maturity should be taken into account. The postural group of some participants was derived through consensus between clinicians if they were not in agreement based on their primary classification. While this could have influenced postural grouping of participants, both clinicians made use of the established clinical postural definitions to arrive at a consensus. The concurrent validity of posture classification by clinicians could be explored using other methods such as statistical clustering models (Smith et al., 2008), to define posture groups.. We recognise that definitive allocation of a posture type is difficult, since posture characteristics are a continuous rather than nominal construct – that is, in some circumstances it is difficult to determine where one posture ends and another begins. This issue creates some ambiguity in allocation of posture groups where people may not display ‘classical’ posture characteristics and represents a limitation of the group allocation method adopted in this study. Clinicians make decisions about posture groups depending whether the posture is pain-provocative, or not, of their disorder. A reliance on images without feedback on pain provocation represents another limitation of this method. Nonetheless, postural classification is undertaken routinely in clinical practice, and this study has established moderate to good inter-reliability for this practice, even in the absence of pain response feedback.

5. CONCLUSION

A familial association exists in hyperlordotic spinal posture between parents and their daughters. Further studies are required to replicate these findings and examine the familial factors that influence spinal posture. Moderate to good inter-rater reliability exists in clinical postural classification, supporting its use in clinical practice and research studies.

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Captions to illustrations

Figure 1 Definitions of postural angles: (A) craniocervical angle, (B) cervicothoracic angle, (C) trunk angle, (D) lumbar angle, (E) pelvic tilt, (F) sway angle.

Figure 2 Sagittal standing postural alignment of a typical member of each postural type: (A) sway, (B) flat, (C) hyperlordotic, and (D) neutral.

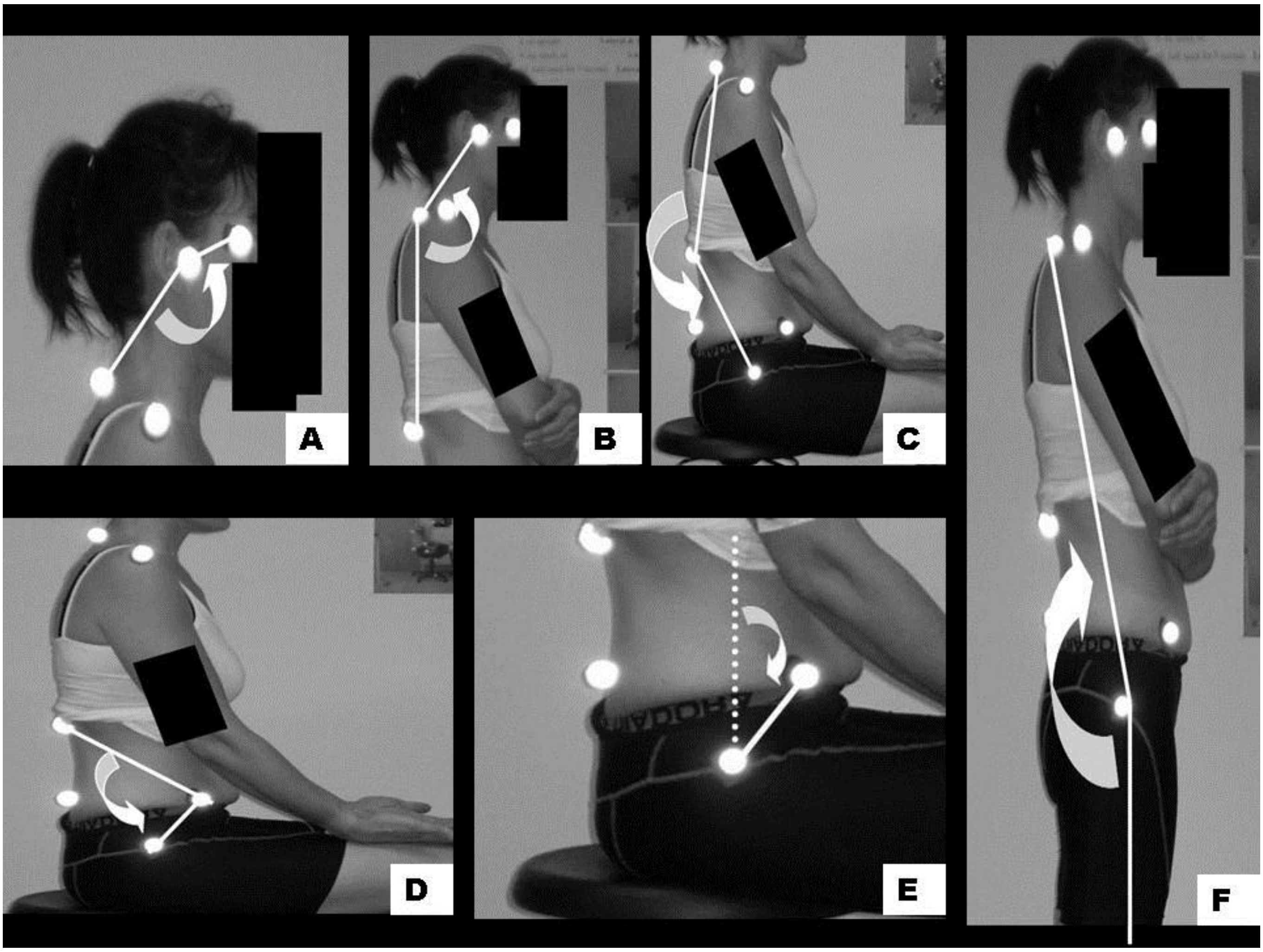

Figure 1 Definitions of postural angles: (A) craniocervical angle, (B) cervicothoracic angle, (C) trunk angle, (D) lumbar angle, (E) pelvic tilt, (F) sway angle.

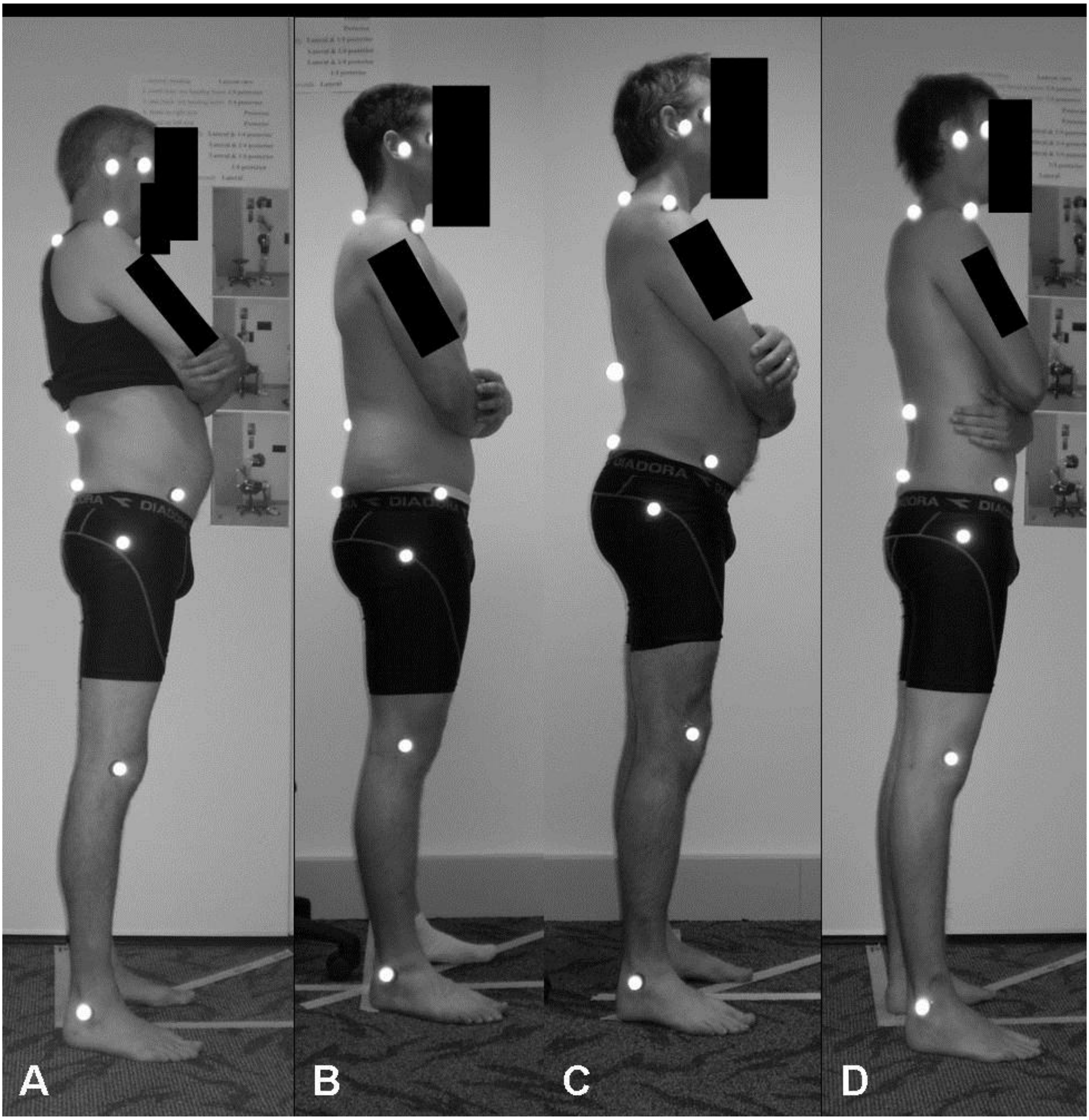

Figure 2 Sagittal standing postural alignment of a typical member of each postural type: (A) sway, (B) flat, (C) hyperlordotic, and (D) neutral.

Tables

Table 1. Postural angle definitions

Angle	Angle Definition
Craniocervical angle	Angle between line of canthus to tragus and line of tragus to C7 spinous process (measured anterior to intersect)
Cervicothoracic angle	Angle between line of tragus to C7 spinous process and line of C7 spinous process to T12 spinous process (measured anterior to intersect)
Trunk angle	Angle between line of C7 to T12 spinous process es and line of T12 spinous process to greater trochanter (measured posterior to intersect)
Lumbar angle	Angle between line of T12 spinous process to ASIS* and line of ASIS to femoral greater trochanter (posterior angle)
Sway angle	Angle between line of C7 spinous process to femoral greater trochanter and line of femoral greater trochanter to lateral malleolus
Pelvic tilt	Line of femoral greater trochanter to ASIS with respect to vertical (measured from vertical above intersect)

*ASIS: anterior superior iliac spine

Table 2. Anthropometric characteristics of cohort expressed as mean ± SD (min, max).

	Father (n= 46)	Mother (n= 63)	Son (n= 55)	Daughter (n= 66)
Age (years)	48.0 ± 5.7 (36.0, 67.0)	46.0 ± 5.7 (33.0, 62.0)	15.7 ± 4.5 (9.0, 30.0)	16.0 ± 3.7 (10.0, 24.0)
Height (cm)	177.1 ± 6.1[a] (162.2, 195.5)	163.3 ± 7.5 (146.2, 178.5)	167.1 ± 15.1[b] (137.5, 196.0)	162.5 ± 8.5 (137.5, 179.0)
Mass (kg)	88.3 ± 13.8[a] (60.4, 120.2)	72.8 ± 16.1 (45.9, 118.1)	60.7 ± 18.3 (30.1, 108.3)	58.1 ± 12.8 (33.4, 95.0)
BMI (kg/m^2)	27.7 ± 4.1 (21.0, 38.0)	26.8 ± 5.5 (19.0, 49.0)	20.7 ± 3.8 (14.0, 34.0)	21.4 ± 3.9 (14.0, 34.0)

a Significant difference between fathers and mothers ($p<0.05$)
b Significant difference between sons and daughters ($p<0.05$)

Table 3. Postural angle measures of the cohort expressed as mean ± SD (min, max) degrees (°).

	Father (n= 46)	Mother (n= 63)	Son (n= 55)	Daughter (n= 66)
In standing				
Craniocervical	146.7 ± 8.3 [a c] (128.0, 168.7)	153.8 ± 8.6 [e f] (134.2, 173.2)	143.0 ± 6.8 [b] (128.1, 161.9)	146.1 ± 8.7 (129.5, 169.3)
Cervicothoracic	141.9 ± 5.0 [a] (127.1, 153.1)	139.7 ± 4.9 [e] (127.3, 149.9)	142.5 ± 5.6 [b] (132.1, 156.4)	140.0 ± 5.0 (123.7, 150.8)
Trunk	209.3 ± 5.2 [c d] (196.7, 220.1)	209.4 ± 7.4 [e f] (191.0, 226.9)	205.0 ± 6.7 (190.3, 227.3)	206.3 ± 7.4 (182.8, 224.2)
Lumbar	87.2 ± 9.6 (67.2, 105.1)	86.4 ± 9.4 (65.2, 112.5)	88.5 ± 10.1 (63.4, 108.8)	88.4 ± 10.1 (67.7, 111.0)
Sway	165.4 ± 3.5 (159.2, 172.8)	164.1 ± 3.8 (153.8, 173.0)	165.3 ± 3.7 (151.5, 172.2)	165.0 ± 3.1 (157.5, 173.4)
Pelvic tilt	39.4 ± 9.5 (19.9, 63.1)	38.3 ± 8.1 (18.6, 52.8)	38.9 ± 8.4 (24.0, 63.0)	39.6 ± 8.6 (18.8, 59.9)
In Sitting				
Craniocervical	157.3 ± 8.0 [a c] (142.3, 181.6)	162.1 ± 9.4 [e f] (132.7, 183.1)	153.4 ± 7.3 (139.8, 167.8)	154.2 ± 9.5 (138.2, 187.0)
Cervicothoracic	145.0 ± 6.5 [c] (128.2, 157.5)	144.1 ± 5.5 [e f] (132.0, 155.4)	151.1 ± 6.1 [b] (134.7, 163.4)	146.5 ± 7.0 (132.7, 165.8)
Trunk	228.1 ± 8.3 [a] (210.2, 246.3)	223.8 ± 7.2 [e] (208.5, 245.4)	230.8 ± 9.3 [b] (212.0, 250.5)	225.5 ± 9.0 (204.2, 245.9)
Lumbar	106.3 ± 11.3 [c d] (82.2, 128.1)	104.2 ± 12.4 [e f] (80.6, 141.3)	113.2 ± 12.3 (84.4, 138.2)	112.1 ± 11.5 (87.1, 138.8)
Pelvic Tilt	20.4 ± 11.8 [c d] (-1.1, 45.5)	22.1 ± 10.4 [e f] (-6.1, 45.6)	12.0 ± 11.9 (-10.5, 44.4)	15.4 ± 10.7 (-9.0, 43.0)
Difference between usual and slump sitting				
Trunk	18.5 ± 7.4 [d] (4.7, 43.0)	20.5 ± 7.8 (5.4, 36.9)	19.1 ± 8.0 (-0.6, 42.9)	22.0 ± 9.0 (4.3, 52.9)
Lumbar	7.0 ± 6.5 [c] (-1.5, 31.7)	6.7 ± 7.3 [e] (-6.5, 30.6)	4.0 ± 7.0 (-17.8, 22.7)	6.1 ± 7.5 (-11.3, 28.8)

a Significant difference between fathers and mothers ($p<0.05$)
b Significant difference between sons and daughters ($p<0.05$)
c Significant difference between fathers and sons ($p<0.05$)
d Significant difference between fathers and daughters ($p<0.05$)
e Significant difference between mothers and sons ($p<0.05$)
f Significant difference between mothers and daughters ($p<0.05$)

Table 4. Correlation coefficients (r) of the different parent-child relationships (father-child, father-son, father-daughter, mother-child, mother-son, mother-daughter) for the different postural angle measures.

Postural Spinal Angles	Father-Child (n=86)	Father-Son (n=40)	Father-Daughter (n=46)	Mother-Child (n=113)	Mother-Son (n=50)	Mother-Daughter (n=63)
In Standing						
Craniocervical	0.054	0.243	-0.124	0.087	0.240	0.019
Cervicothoracic	0.054	0.129	-0.001	0.254**	0.218	0.283*
Trunk	-0.089	0.009	-0.151	0.030	-0.020	0.070
Lumbar	0.328**	0.469**	0.262	0.064	-0.019	0.136
Sway	0.006	-0.024	0.066	0.145	0.112	0.181
Pelvic Tilt	0.239*	0.445**	0.097	-0.011	-0.168	0.117
In Sitting						
Craniocervical	0.114	0.071	0.147	0.168	0.290*	0.100
Cervicothoracic	0.179	0.173	0.310*	0.086	0.172	0.030
Trunk	0.117	0.071	0.141	0.170	0.163	0.154
Lumbar	0.173	0.255	0.118	0.127	0.139	0.128
Pelvic Tilt	0.176	0.225	0.149	0.138	0.206	0.082
Difference between usual and slump sitting						
Trunk	0.069	-0.173	0.227	0.157	0.253	0.065
Lumbar	-0.101	0.115	-0.314*	-0.017	-0.124	0.078

*0.01≤ p< 0.05 (two-tailed)
**p< 0.01 (two-tailed)

Table 5. Frequency distribution of postural group data of cohort (father, mother, son, daughter) and anthropometric characteristics of the participants in each postural group, expressed as mean ± SD (min, max).

Postural group	Father	Mother	Son	Daughter
Sway N (%)	8 (17.4)	10 (15.9)	18 (32.7)	12 (18.2)
Height (cm)	178.7 ± 9.3[a] (165.4, 195.5)	164.4 ± 5.5 (156.0, 172.5)	166.1 ± 13.2 (137.5, 185.0)	166.9 ± 7.0[c] (155.0, 176.0)
Mass (kg)	82.3 ± 16.3[a] (60.4, 105.6)	63.2 ± 4.4[c] (56.5, 71.2)	56.1 ± 13.0 (30.1, 73.2)	53.9 ± 7.0 (39.7, 61.9)
BMI (kg/m^2)	25.3 ± 3.5 (21.0, 32.0)	22.9 ± 1.6[c] (21.0, 26.0)	19.5 ± 3.1 (14.0, 26.0)	18.8 ± 1.6[c] (16.0, 22.0)
Flat N (%)	3 (6.5)	2 (3.2)	4 (7.3)	2 (3.0)
Height (cm)	175.1 ± 4.8 (170.9, 180.3)	168.5 ± 4.2 (165.5, 171.5)	172.1 ± 16.6 (147.3, 182.0)	165.1 ± 0.9 (164.5, 165.7)
Mass (kg)	88.7 ± 1.5[a] (87.0, 89.7)	66.5 ± 4.9 (63.0, 70.0)	74.9 ± 22.8 (40.7, 88.5)	64.4 ± 1.6[d] (63.2, 65.5)
BMI (kg/m^2)	28.3 ± 2.1[a] (26.0, 30.0)	22.5 ± 0.7[d] (22.0, 23.0)	24.0 ± 4.0 (18.0, 26.0)	23.0 ± 0.0[d] (23.0, 23.0)
Hyperlordotic N (%)	16 (34.8)	35 (55.6)	10 (18.2)	20 (30.3)
Height (cm)	176.7 ± 4.1[a] (169.5, 183.0)	163.0 ± 7.4 (149.7, 178.5)	148.0 ± 11.0[b e] (138.6, 176.5)	158.6 ± 9.7[e] (137.5, 171.0)
Mass (kg)	94.5 ± 16.0[a e] (68.8, 120.2)	80.3 ± 16.6[e] (52.8, 118.1)	47.0 ± 22.4[e] (31.5, 108.3)	60.5 ± 17.7 (33.4, 95.0)
BMI (kg/m^2)	29.7 ± 4.4[e] (22.0, 38.0)	29.7 ± 5.7[e] (23.0, 49.0)	20.1 ± 5.3 (16.0, 34.0)	23.3 ± 5.3[e] (17.0, 34.0)
Neutral N (%)	19 (41.3)	16 (25.4)	23 (41.8)	32 (48.5)
Height (cm)	177.0 ± 6.4[a] (162.2, 186.0)	162.7 ± 9.1 (146.2, 176.0)	175.3 ± 9.6[b f] (159.5, 196.0)	163.1 ± 7.8 (143.5, 179.0)
Mass (kg)	85.5 ± 9.9[a] (67.3, 107.0)	63.3 ± 11.6[f] (45.9, 85.9)	67.9 ± 14.8[b f] (46.6, 99.5)	57.9 ± 11.0 (36.4, 81.8)
BMI (kg/m^2)	26.9 ± 3.7[a] (22.0, 33.0)	23.4 ± 2.7[f] (19.0, 28.0)	21.4 ± 3.3 (16.0, 29.0)	21.1 ± 2.9 (14.0, 26.0)
Total N (%)	46 (100.0)	63 (100.0)	55 (100.0)	66 (100.0)

a Significant difference between fathers and mothers within each group ($p<0.05$)
b Significant difference between sons and daughters within each group ($p<0.05$)
c Significant difference in sway group as compared to the other participants pooled, for a given family member ($p<0.05$)
d Significant difference in flat group as compared to the other participants pooled, for a given family member ($p<0.05$)
e Significant difference in hyperlordotic group as compared to the other participants pooled, for a given family member ($p<0.05$)
f Significant difference in neutral group as compared to rest of the other participants pooled, for a given family member ($p<0.05$)

Table 6. Odds ratio of a child being classified into a particular postural group when his/her father or mother is classified into that particular postural group compared to other groups combined.

	Father			**Mother**		
	Odds ratio	**95% CI**	**P (Fisher's Exact test)**	**Odds ratio**	**95% CI**	**P (Fisher's Exact test)**
Sway						
Child	0.72	0.18-2.83	0.753	1.59	0.57-4.44	0.372
Son	0.27	0.03-2.51	0.396	2.14	0.38-11.98	0.396
Daughter	1.78	0.29-11.00	0.613	1.82	0.46-7.18	0.457
Flat						
Child	6.50	0.55-77.32	0.217	b		
Son	5.67	0.39-82.24	0.277	b		
Daughter	a			b		
Hyperlordotic						
Child	2.67	0.95- 7.47	0.057	1.90	0.79-4.57	0.148
Son	1.20	0.19- 7.64	1.000	1.04	0.23-4.78	1.000
Daughter	**4.00**	**1.06- 15.08**	**0.048**	**3.47**	**1.14-10.55**	**0.025**
Neutral						
Child	1.75	0.74-4.14	0.202	1.18	0.50-2.78	0.706
Son	1.80	0.50-6.46	0.366	0.365	0.07-1.98	0.285
Daughter	1.70	0.53-5.47	0.375	1.99	0.67-5.91	0.214

Significant associations are highlighted in bold

a Unable to calculate as there was no father-daughter pair in the flat postural group

b Unable to calculate as there was no mother-child pair in the flat postural group