Defining Patterns of Sagittal Standing Posture in Girls and Boys of School Age

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Background. Sagittal postural patterns are associated with back pain in adolescents and adults. However, whether postural patterns are already observable during childhood is unknown. Such a finding would confirm childhood as a key period for posture differentiation and thus for chronic pain etiology.

Objective. The aims of this study were to identify and describe postural patterns in girls and boys of school age.

Design. This was a cross-sectional study.

Methods. Eligible children were evaluated at age 7 in the population-based birth cohort Generation XXI in Portugal. Posture was assessed through right-side photographs during habitual standing with retroreflective markers placed on body landmarks. Postural patterns were defined from trunk, lumbar, and sway angles with model-based clusters, and associations with anthropometric measures were assessed by multinomial logistic regression.

Results. Posture was evaluated in 1,147 girls and 1,266 boys. Three postural patterns were identified: sway (26.9%), flat (20.9%), and neutral to hyperlordotic (52.1%) in girls and sway to neutral (58.8%), flat (36.3%), and hyperlordotic (4.9%) in boys. In girls, a higher body mass index was associated with a sway pattern (versus a flat pattern: odds ratio=1.21; 95% CI=1.12, 1.29), whereas in boys, a higher body mass index was associated with a hyperlordotic pattern (versus a flat pattern: odds ratio=1.30; 95% CI=1.17, 1.44).

Limitations. Photogrammetry as a noninvasive method for posture assessment may have introduced some postural misclassifications.

Conclusions. Postural patterns in 7-year-old children were consistent with those previously found in adults, suggesting that childhood is a sensitive period for posture differentiation. Sagittal morphology differed between girls and boys, emphasizing sex-specific biomechanical loads during a habitual upright position even in prepubertal ages.

Established abnormal sagittal spinopelvic alignment is associated with back pain and physical disability,[1–3] with overall sagittal imbalance showing a high predictive ability for functional loss and dependency in older ages.[4] Sagittal spinopelvic alignment in adulthood is the end result of the complex process of gaining, during childhood and adolescence, the upright position, which stabilizes after skeletal maturity.[5–7] An initial vertical orientation of the pelvis occurs after birth, with the lordotic curve arising at the lower back as the child begins to assume a sustained upright position. Then, pelvis shape and physiologic curves of the spine gradually develop with growth to ensure adequate balance and an appropriate configuration in terms of responses to skeletal loads and energy expenditure.[5–7] For instance, a progressive increase in the lumbar angle complemented with a backward tilt of the spine over the hips is observed.[8]

Different classifications of sagittal phenotypes have been proposed[9–13]; these generally take, as a reference, a neutral postural pattern characterized by intermediate values of alignment and representing a well-balanced spine. Nonneutral sagittal postures are then characterized by deviations from the neutral pattern and feature different combinations of regional alignment and global balance. Because postural patterns account for the potential synergistic effects of different spinopelvic characteristics aggregated into a unique phenotype, they are expected to offer an advantage for the understanding of standing posture. In terms of clinical meaning, nonneutral sagittal standing postural patterns have been associated with back pain in adulthood[3,14] and in late[10] and early[11] adolescence. However, to our knowledge, classification of postural patterns in children has not been attempted, and whether the division of people into neutral and nonneutral variants occurs in the early stages of life, when extensive growth and development of the musculoskeletal system take place, is unknown.[15] Therefore, our hypothesis is that empirically obtained patterns in children of school age are consistent with those observed in midadolescence and adulthood in terms of sagittal morphology, although less differentiated patterns can be expected because of the continuing development of the musculoskeletal system in children.

To study early childhood as a sensitive period for the development of sagittal postural patterns, it important to focus on children who are prepubertal because both sexes at that age are still largely homogeneous with regard to sexual and skeletal development—that is, before pubertal timing begins to modulate individual posture development.[16] Therefore, we aimed to identify and describe postural patterns in 7-year-old girls and boys and to explore their associations with anthropometric characteristics.

Method

Participants

This study was conducted within Generation XXI, a population-based birth cohort of 8,647 live-born infants and their mothers initially assembled from all 5 public maternity units covering the 6 municipalities of the metropolitan area of Porto, Portugal, in 2005 and 2006.[17,18] At the birth of the infants, 91.4% of the invited mothers agreed to participate. Written informed consent was obtained from the participants. Invitation to the follow-up of the 7-year-old children was carried out on the basis of the children's birth dates, and 79.7% of the children initially recruited participated in this wave of assessment. A subsample of 3,005 children consecutively attending the evaluation of 7-year-old between December 2012 and August 2013 were eligible for posture assessment (Fig. 1). Potential bias was assessed by comparing Generation XXI children who were included and those who were not included.

Data Collection

As part of the evaluation of the 7-year-old children, data were collected by trained interviewers in face-to-face assessments. Weight was measured to the nearest tenth of a kilogram with a digital scale (Tanita, Tokyo, Japan), and height was measured to the nearest tenth of a centimeter with a wall stadiometer (Seca, Chino, California). Body mass index (BMI) was computed as weight (in kilograms) over squared height (in meters).

Sagittal Standing Posture

The sagittal standing posture evaluation was performed by quantitative assessment of photographs of the sagittal right view of children, a method previously validated in adolescents[19–21] and adults[22,23] and characterized by acceptable reproducibility.[24–26] By extrapolation, photogrammetry is recommended as the safest method for postural evaluation in large-scale studies of children.[13,24,25] This assessment occurred between March 2013 and February 2014 (medians of 62 [interquartile range=211] and 63 [interquartile range=212] days after the evaluation of 7-year-old girls and boys, respectively). For both sexes, the median age was 7.3 years (25th percentile–75th percentile=7.1–7.7 years).

With double-faced adhesive tape, spherical retroreflective markers (12 and 30 mm) were placed over anatomical landmarks on the right side of the child's body: lateral canthus of the eye, tragus, anterior border of the acromium (30 mm), spinous processes of C7 and T12 (30 mm), anterior superior iliac spine, greater trochanter, lateral epicondyle of the femur, and lateral malleolus. Additionally, a plumb line with two 20-mm polystyrene circumferences (50-cm distance from each other) was placed behind children and 50 cm from the wall (the same distance as the right side of the child's body) to allow vertical-angle offset and distance calibration during the digitization of photographs. The evaluation was performed by 1 of 2 health professionals in a dedicated room. Both examiners received several theoretical and practical sessions of anatomy tuition before data collection.

Children were barefoot, were wearing underwear or swimwear, and were instructed to rest comfortably in a habitual standing position with the feet slightly apart, looking straight ahead, and moving elbows forward, as previously described by Perry et al,[24] to standardize their positions. Floor markers

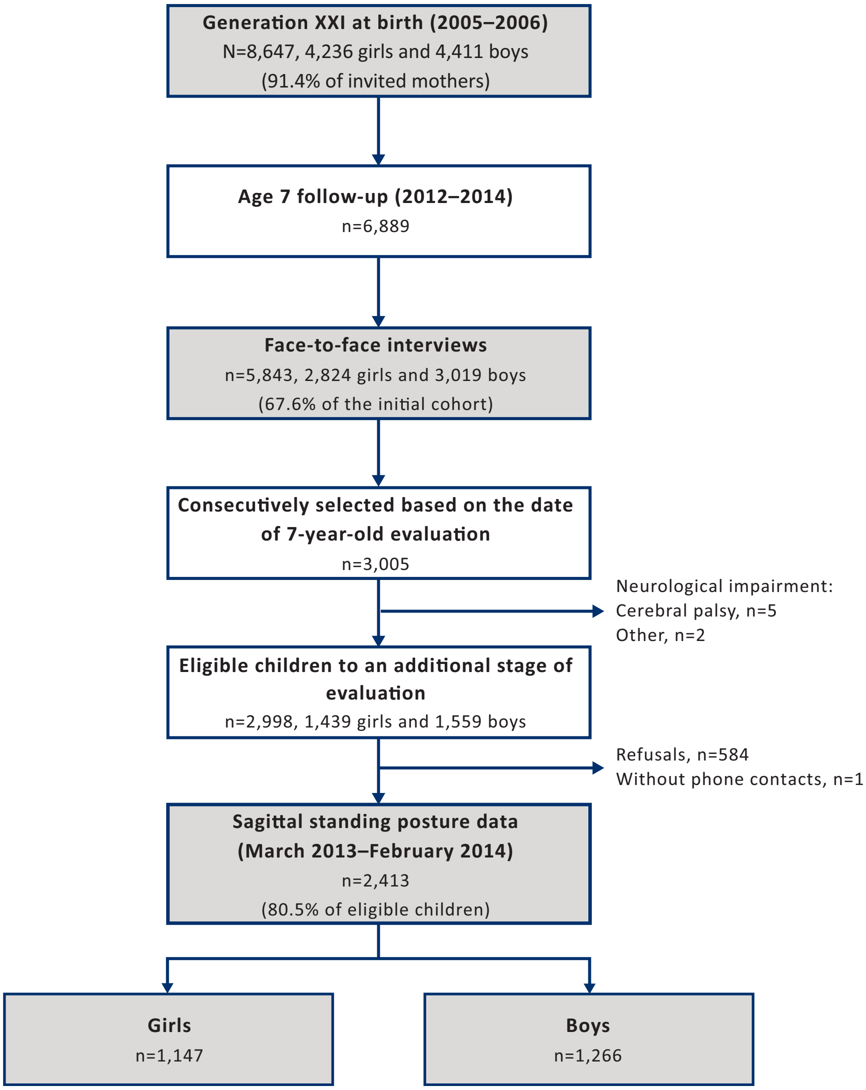

Figure 1.

Flow diagram for inclusion of Generation XXI children. The 584 refusals included 252 children who refused to participate in the posture evaluation and 332 participants who scheduled 3 appointments for evaluation but did not keep the appointments or did not respond to our invitation after at least 5 attempts.

also were used to regulate the relative position of a child with respect to the camera. After the examiner judged that the usual upright position had been attained, full-body flash photographs were obtained with a Canon PowerShot A2300 (4,608 × 3,456 pixels; Canon USA Inc, Arlington, Virginia) attached to a 60-cm-high tripod placed 200 cm from the wall and perpendicular to the child. The tripod was fixed on the floor, and the zoom feature of the camera was not used.

Anatomical landmarks were digitized with the valid and reliable postural assessment software PAS/SAPO,[27] which allowed computation of 9 angles and 3 distances describing the sagittal standing position, in accordance with the protocol suggested by Perry et al.[24] This protocol prioritizes biologically relevant measurements (ie, quantifies the relative positions of body segments), avoiding the use of the vertical line reference and, therefore, optimizing photographic reliability.[24–26] Angles were formed by the lines traced from the labeled anatomical landmarks, and the 2-dimensional coordinates of each marker were used to determine distances, as exemplified in Figure 2. All of the photographs were digitized by one of the researchers who carried out the physical examinations (F.A.A., a physical therapist) in accordance with specific training to measure angles in a systematic manner in terms of order and quality. The zoom feature of the software was used freely.

Data Analysis

Interobserver calibration. Each child was evaluated only by one examiner. Because participants were randomly allocated to each examiner, differences in the distributions of measurements were attributed to observer effects.[28] Therefore, calibration was performed by considering the measurements of the physical therapist examiner as the reference, that is, adding the difference between means obtained by each examiner to the individual values for each child evaluated by the second observer—for this purpose, called calibrated measures.[29]

Sagittal postural patterns. Trunk, lumbar, and sway angles (Figs. 2F–2H) completely characterize thoraco-lumbo-pelvic sagittal alignment in the standing position,[10] corresponding to the most relevant sagittal characteristics evaluated in clinical settings[30] and, therefore, were used to identify postural patterns.

The calibrated measures explained earlier were used to define postural patterns. Because spinal postures differed between girls and boys and seem to contribute to the unequal prevalence of postural deformities in the sexes,[31,32] we chose to identify patterns separately for girls and boys. Model-based clustering[33] was used to identify groups of children who shared similar postures. This clustering procedure was chosen instead of conventional heuristic methods because it has the key advantage of allowing the testing of different variances of angle measures within and across clusters. In this procedure, postural angles

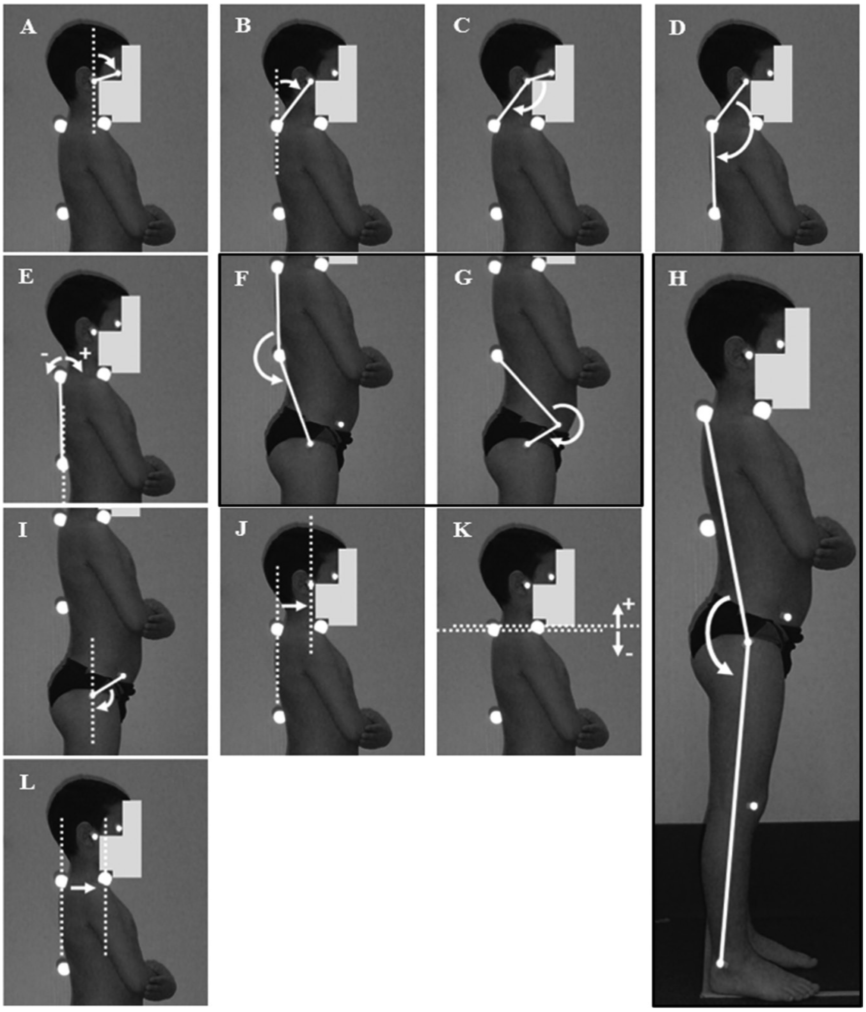

Figure 2.
Definition of angles (A–I) and distances (J–L) describing sagittal standing posture. (A) Head flexion. (B) Neck flexion. (C) Craniocervical angle. (D) Cervicothoracic angle. (E) Thoracic flexion. (F) Trunk angle. (G) Lumbar angle. (H) Sway angle. (I) Pelvic tilt. (J) Head displacement. (K) Scapular elevation. (L) Scapular displacement. Dashed lines indicate vertical or horizontal. Delimited angles (F–H) were used in model-based patterns of sagittal standing posture.

are assumed to have a multivariate normal distribution, parameterized by their means and covariances. The geometric features (orientation, volume, and shape) of the distributions are estimated from the data, and their differences across clusters are tested.[34] Initially, the model assessed as being optimal in terms of geometric features and number of clusters was determined to be that with the smallest Bayesian Information Criterion.[35] Additionally, the choice was also informed by previously identified patterns at older ages[9,10]: increased kyphosis with spinal backward tilt (sway), straight spine with forward trunk lean (flat), neutral alignment and balance (neutral), and increased thoracic and lumbar spinal curves (hyperlordotic). Data analysis was conducted with R software version 2.14.1 (R Foundation; https://www.r-project.org/foundation/).

Associations with covariates. Associations between postural clusters and weight, height, and BMI were assessed through analysis of variance or Kruskal-Wallis tests. Age-adjusted odds ratios (ORs) and respective 95% confidence intervals (CIs) for postural patterns were estimated by multinomial logistic regression models as a function of weight, height, and BMI. For assessment of the effect of weight, estimates were additionally adjusted for height.

Role of the Funding Source

The funding for EPIUnit was obtained from the Fundação para a Ciência e a Tecnologia (FCT) (UID/DTP/04750/2013/002). Generation XXI was funded by the Health Operational Programme–Saúde XXI, Community Support Framework III, and the Regional Department of Ministry of Health. It has been further supported by FEDER funds through the Programa Operacional Factores de Competitividade, by national funds through the FCT (projects PIC/IC/83038/2007, SFRH/BD/72723/2010, and EXPL/DTP-EPI/0280/2012), and by the Calouste Gulbenkian Foundation. The work of Mr Araújo and Professor Lucas was supported by the FCT (grants SFRH/BD/85398/2012 and SFRH/BPD/88729/2012). The funding sources had no role in the design or conduct of the study; collection, management, analysis, or interpretation of the data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

Results

Posture was evaluated in 1,147 girls and 1,266 boys after exclusions and refusals. Included children were slightly older than those not included (P<.001 for both sexes), and the mother's level of formal education was higher for included children (median years for both sexes: 12.0 versus 9.0; P<.001). Despite these differences, the anthropometric characteristics at birth of included children and those not included were similar (eTab. 1, available at academic.oup.com/ptj).

Statistical Criterion for Postural Patterns

Crude analysis revealed very weak linear pair-wise associations between individual postural angles ($|r|$<.20; data not shown); therefore, we chose to not consider covariance parametrizations

Table 1.
Selected Postural Measures and Anthropometrics Used in Model-Based Sagittal Postural Patterns[a]

Measure	Girls					Boys					*P* for Girls vs Boys
	All	1: Sway Pattern (n=309, 26.9%)	2: Flat Pattern (n=240, 20.9%)	3: Neutral to Hyperlordotic Pattern (n=598, 52.1%)	*P*	All	1: Sway to Neutral Pattern (n=745, 58.8%)	2: Flat Pattern (n=459, 36.3%)	3: Hyperlordotic Pattern (n=62, 4.9%)	*P*	
Trunk angle, °	203.7 (6.8)	211.1 (4.4)	205.9 (3.4)	199.0 (4.7)	<.001	204.8 (6.4)	207.7 (5.4)	201.4 (4.9)	194.6 (5.6)	<.001	<.001
Lumbar angle, °	281.7 (7.4)	281.9 (7.2)	275.4 (6.0)	284.2 (6.5)	<.001	276.8 (7.2)	276.4 (6.8)	275.8 (6.5)	288.9 (5.2)	<.001	<.001
Sway angle, °	164.9 (4.6)	161.2 (3.7)	167.5 (3.4)	165.8 (4.2)	<.001	164.8 (4.9)	162.3 (3.4)	169.3 (3.5)	162.7 (4.3)	<.001	.683
Weight, kg	24.8 (22.2–28.9)	25.6 (22.6–30.4)	23.9 (21.5–27.0)	24.8 (22.3–28.7)	<.001	25.0 (22.6–28.2)	25.3 (22.9–28.6)	24.3 (22.1–27.2)	26.2 (23.7–30.3)	<.001	.563
Height, cm	122.8 (5.1)	123.2 (5.0)	122.6 (5.4)	122.7 (5.1)	.237	123.9 (5.3)	124.1 (5.3)	123.6 (5.2)	124.4 (4.7)	.243	<.001
Body mass index, kg/m²	16.49 (15.18–18.60)	16.89 (15.35–19.52)	16.03 (14.87–17.45)	16.55 (15.28–18.62)	<.001	16.30 (15.25–17.77)	16.41 (15.35–17.99)	15.90 (14.94–17.01)	17.36 (15.75–19.35)	<.001	.018

[a] Information for anthropometric measures was missing for 2 girls and 1 boy. Angles and height are reported as mean (standard deviation); weight and body mass index are reported as median (25th percentile–75th percentile).

that allowed correlations between individual measures within patterns. However, after comparison of different types of parametrizations in our postural models, the smallest Bayesian Information Criterion was found for a one-group solution for all of these parametrizations. Therefore, on the basis of the statistical criterion alone, the cluster solution suggested postural homogeneity. The single-cluster solution seemed inappropriate for identifying a theoretically plausible cluster structure featuring expected postural variability at the population level.

Statistical and Theoretical Criteria for Postural Patterns

We chose the next-best-fitting models: 2- and 3-pattern solutions (with similar Bayesian Information Criterion values) in girls and 3-pattern solutions in boys (eFigs. 1 and 2, available at academic.oup.com/ptj). We opted for the 3-pattern model of equal volume, equal shape, and coordinate axis orientation (which assumed different variances between variables within patterns and equal variances between patterns) for both sexes because this model had a better Bayesian Information Criterion than models that assumed different variances between patterns. The selected models were characterized by average probabilities of pattern assignment of 60% in girls and 73% in boys (detailed information regarding quality assignment is provided in eFig. 3, available at academic.oup.com/ptj). Table 1 and Figure 3 show the features of the final 3-pattern solution, separately for girls and boys. Additional postural characterization is provided in eTable 2 (available at academic.oup.com/ptj).

Girls

In girls, patterns were labeled as sway (26.9%), flat (20.9%), and neutral to hyperlordotic (52.1%). Type 1 was labeled as sway because it showed the largest trunk angle and the smallest sway angle, with means of 211.1 degrees (SD=4.4°) and 161.2 degrees (SD=3.7°), respectively. Type 2 was labeled as flat because it showed the smallest lumbar angle (275.4° [SD=6.0°]) and the largest sway angle (167.5° [SD=3.4°]). Type 3 was the most frequent (present

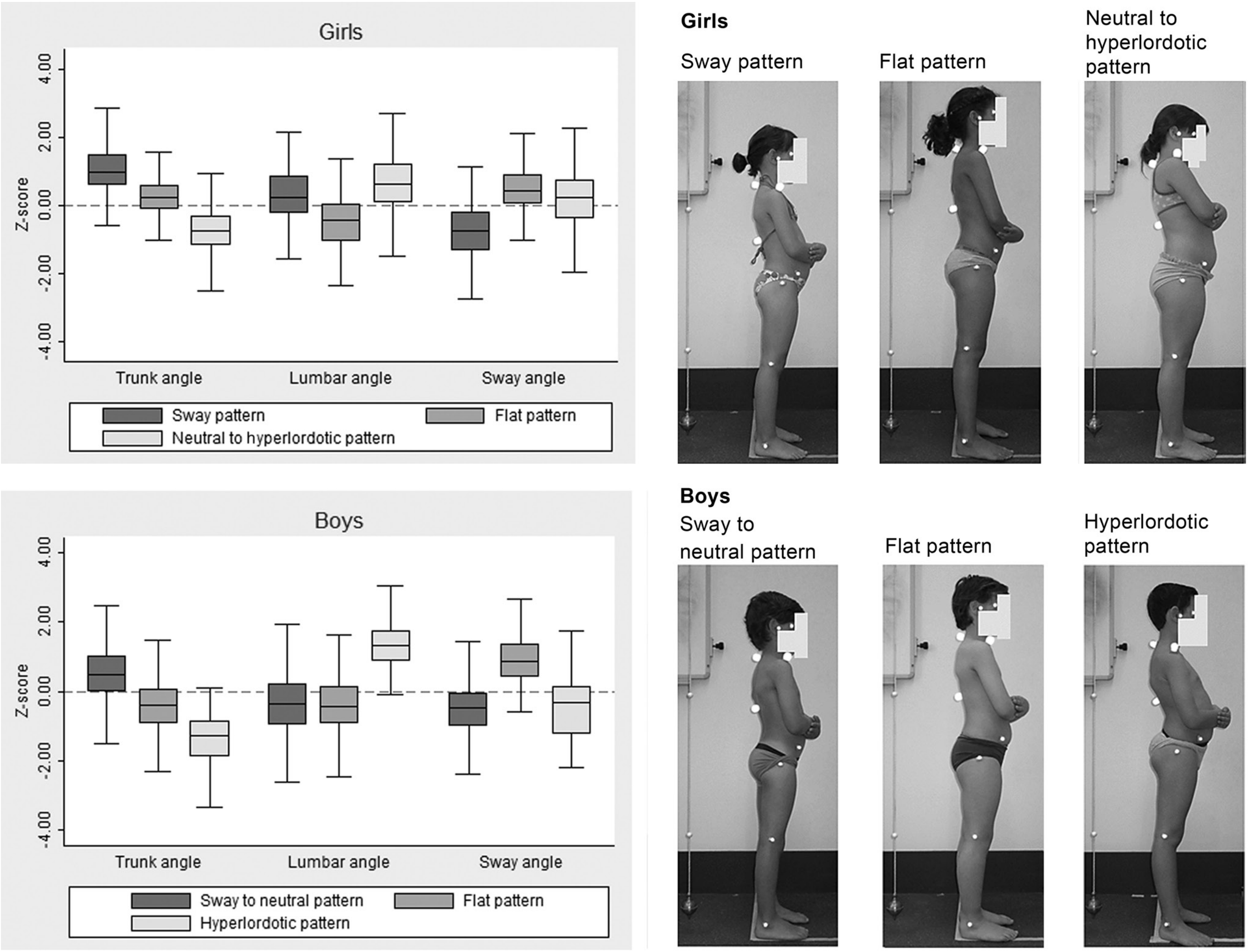

Figure 3.
Box plots showing the distribution (median, interquartile range, and range) for each postural measure, standardized to a mean of 0 and a standard deviation of 1, across model-based sagittal standing postural patterns (left) and examples of patterns (right). Data are shown separately for girls and boys.

in more than half of the sample) and showed the smallest trunk angle (199.0° [SD=4.7°]) and the largest lumbar angle (284.2° [SD=6.5°]); therefore, it was labeled as neutral to hyperlordotic.

Boys

In boys, patterns were labeled as sway to neutral (58.8%), flat (36.3%), and hyperlordotic (4.9%). Type 1 in boys showed the same postural organization as that in girls (trunk angle: 207.7° [SD=5.4°]; sway angle: 162.3° [SD=3.4°]). However, unlike in girls, this was the most prevalent pattern in boys (58.8%) and, therefore, was labeled as sway to neutral. Type 2 was labeled as flat because it showed the smallest lumbar angle (275.8° [SD=6.5°]) and the largest sway angle (169.3° [SD=3.5°]). Type 3 was much less frequent in boys (4.9%) than in girls but had more extreme features—a smaller trunk angle (194.6° [SD=5.6°]) and a larger lumbar angle (288.9° [5.2°])—and, therefore, was labeled as hyperlordotic.

Associations With Covariates

In both sexes, children with the flat pattern were lighter and shorter, with a median weight of 23.9 kg (25th percentile–75th percentile range=21.5–27.0) and a mean height of 122.6 cm (SD=5.4) for girls and corresponding values of 24.3 kg (25th percentile–75th percentile range=22.1–27.2) and 123.6 cm (5.2) for boys. Girls with the sway pattern and boys with the hyperlordotic pattern were the heaviest (25.6 kg [25th percentile–75th percentile range=22.6–30.4] and 26.2 kg [25th percentile–75th percentile range=23.7–30.3], respectively) (Tab. 1).

Tables 2 and 3 show the adjusted associations of anthropometrics (independent variables) with postural patterns (dependent variables), with the flat pattern as a reference for both sexes to improve comparability. For girls, after adjustment for age and height, the proportional increases in ORs per

Table 2.
Adjusted Associations Between Model-Based Postural Patterns (Dependent Variables) and Anthropometrics (Independent Variables) for Girls[a]

Measure	Sway Pattern			Flat Pattern Odds Ratio	Neutral to Hyperlordotic Pattern			P^c
	Odds Ratio[b]	95% CI	*P*		Odds Ratio[b]	95% CI	*P*	
Weight, kg	1.13	1.08–1.19	<.001	1	1.08	1.03–1.12	.001	<.001
Height, cm	1.03	1.00–1.07	.067	1	1.01	0.98–1.04	.489	.011
Body mass index, kg/m²	1.21	1.12–1.29	<.001	1	1.11	1.04–1.19	.001	<.001

[a]Information for anthropometric measures was missing for 2 girls.
[b]All variables were adjusted for age; weight also was adjusted for height.
[c]For the overall test of differences in odds ratios across the 3 groups. Comparisons of the sway pattern and the neutral to hyperlordotic pattern reached statistical significance ($P < .05$) for weight and body mass index.

Table 3.
Adjusted Associations Between Model-Based Postural Patterns (Dependent Variables) and Anthropometrics (Independent Variables) for Boys[a]

Measure	Sway to Neutral Pattern			Flat Pattern Odds Ratios	Hyperlordotic Pattern			P^c
	Odds Ratios[b]	95% CI	*P*		Odds Ratios[b]	95% CI	*P*	
Weight, kg	1.08	1.04–1.12	<.001	1	1.17	1.09–1.26	<.001	<.001
Height, cm	1.02	1.0009–1.05	.042	1	1.04	0.98–1.09	.179	<.001
Body mass index, kg/m²	1.14	1.08–1.21	<.001	1	1.30	1.17–1.44	<.001	<.001

[a]Information for anthropometric measures was missing for one boy.
[b]All variables were adjusted for age; weight also was adjusted for height.
[c]For the overall test of differences in odds ratios across the 3 groups. Comparisons of the sway to neutral pattern and the hyperlordotic pattern reached statistical significance ($P < .05$) for weight and body mass index.

1-kg increase in weight were 1.13 (95% CI=1.08, 1.19) for having the sway pattern and 1.08 (95% CI=1.03, 1.12) for having the neutral to hyperlordotic pattern. After adjustment for age, for a BMI of 1 kg/m², the ORs were 1.21 (95% CI=1.12, 1.29) for having the sway pattern and 1.11 (95% CI=1.04, 1.19) for having the neutral to hyperlordotic pattern. For boys, after adjustment for age and height, the proportional increases in ORs per 1-kg increase in weight were 1.08 (95% CI=1.04, 1.12) for having the sway to neutral pattern and 1.17 (95% CI=1.09, 1.26) for having the hyperlordotic pattern. After adjustment for age, for a BMI of 1 kg/m², the ORs were 1.14 (95% CI=1.08, 1.21) for having the sway to neutral pattern and 1.30 (95% CI=1.17, 1.44) for having the hyperlordotic pattern.

Discussion

In the present study, we identified 3 patterns of sagittal standing posture in girls and boys of school age that are consistent with those previously described in adults. The flat pattern was observable in both sexes, but the relative prevalence in boys was higher. In addition, the sway and neutral to hyperlordotic patterns were identified in girls, whereas the sway to neutral and hyperlordotic patterns were found in boys. In both sexes, the patterns differed according to anthropometric measures—a finding supporting them as biologically plausible types of sagittal posture in 7-year-old children.

Our types 1 and 2 in both sexes resembled, in their relative features, those previously described in adults as sway (increased kyphosis with backward tilt of the spine over the hips) and flat (straight spine with forward trunk lean), respectively. Our type 3 corresponded to the neutral pattern (relatively increased lumbar lordosis and intermediate body sway) in girls and to the hyperlordotic pattern (extremely increased lumbar lordosis) in boys. However, 4 postural patterns were previously described in adults (age range=18–48 years)[9] and then were suggested to be present in adolescents (between 13 and 15 years old) as well[10]: sway, flat, neutral, and hyperlordotic patterns. Therefore, our type 3 in girls was labeled as neutral to hyperlordotic. The aggregation of these 2 patterns seemed to result from a larger lumbar angle in girls than in boys (4.9°; $P \leq .001$). In one other type, nearly 60% of boys and 2 different patterns were aggregated; this type (type 1) was labeled as sway to neutral.

These findings support the hypothesis that, when statistical and theoretical criteria are both used, sagittal patterns are observable even in early childhood. It seems likely that, to some extent, they will track over time, leading to the patterns described in adolescence[10] and adulthood.[9] Our finding of a single-pattern solution when only statistical criteria were applied is in accordance with an initial hypothesis of less differentiated patterns in children, in which a progressive maturational process of the constitutional sagittal typology is expected because of a stronger control of sagittal balance as children get older.[7,26]

Longitudinal studies are required to confirm that both covariance structure and number of patterns will change over time, but our hypothesis is further supported by the direction of the relationships between the observed patterns and anthropometrics. In particular, an increasing gradient of BMI from the flat pattern to the hyperlordotic pattern was observed, in agreement with the increasing gradient reported across the flat, neutral, sway, and hyperlordotic types.[10,13,36] Furthermore, differences in BMI across patterns in the present study still hold after comparison of patterns weighted by the probability of pattern membership (data not shown). Body mass index is indeed the most consistent determinant of sagittal posture development[13] because adiposity is thought to cause plastic deformation of spinopelvic structures in the early stages of life, thus allowing tracking of specific sagittal patterns throughout life. Additionally, when we used the same statistical procedures as those used for research with adolescents (ie, hierarchical analysis by the Ward method followed by the K-means algorithm)[10] separately for each sex, the best solution was congruent with the results of the present study (data not shown). The same postural patterns were observed, despite the homogeneous prevalence of patterns (varying from 30% to 37%).

In the present study, the neutral to hyperlordotic pattern was by far the most prevalent in girls (52.1%), and 58.8% of the boys showed a sway to neutral pattern. The most plausible reason for the clear differences in patterns between girls and boys seems to be a true sex-related heterogeneity of postural types in children of school age. Although in girls the hyperlordotic posture was merged with the broad neutral type and this merging seemed to have been driven by the similar high lumbar angles,[9,10] in boys the sway and neutral types were the most similar—probably because of the predominant backward tilt of the spine in children,[7] which was observed only in boys in the present study. Differences in lumbar lordosis between the sexes have been reported incongruently,[13] but the female spine features structural phylogenetic adaptations that may justify an increased lumbar angle in girls.[13,31,32,37,38]

Concordantly, only a small group of boys with hyperlordosis (4.9%) was identified, and model-based procedures were able to differentiate this pattern, with a large lumbar angle, from those for all of the other boys, with a smaller angle in the lumbar region. Therefore, we still chose to retain this solution despite the small group of boys with the hyperlordotic pattern.

The flat pattern was the only one commonly observed in both sexes, but it seems to have been more prevalent in boys than in girls (36.3% versus 20.9%), as reported in adolescents[10,36] and adults[13,39] and in agreement with the general knowledge that the male spine is less curved in the lumbar region.[13,31,32,37,38]

Evidence of the clinical relevance of postural patterns is compelling.[3,9–11,14,40,41] In adults, both flat and lordotic postural types have been associated with back pain.[3,14] Additionally, the sway and flat types are expected to contribute to the mechanical etiology of discopathy, and the hyperlordotic type is expected to contribute to vertebral listhesis.[9,40,41] In midadolescence, all nonneutral types were associated with different measures of back pain,[10] and in boys who were 12.6 years old, sway-backed balance was associated with a higher prevalence of pain in the low back and neck.[11] Follow-up of the children in our sample to assess the onset of back pain will be of great value for improving knowledge regarding the clinical role of posture throughout life. However, one of the main findings of this work—the lack of a neutral variant of sagittal standing posture in both sexes—emphasizes the need for caution regarding the interpretation of neutral alignment or balance as the ideal variant in children of school age—a notion frequently implied in clinical settings.[9,13,42]

To our knowledge, the present study is the largest population-based investigation of sagittal postural patterns so far and the first to focus on children younger than 10 years. According to cluster analysis, the recommended sample size would be 5×2^k (where k is the number of input variables)[43]—in this case, a minimum sample size of 40—meaning that our sample size clearly provided enough power to carry out the present analysis. Model-based clustering allowed us to assess the most appropriate configuration among 10 different solutions of covariance structures, whereas previously used[10–12] heuristic clustering methods (Ward method and K-means algorithm) considered only 1 restricted covariance structure.[33]

Conceptually, sagittal patterns are an attempt to categorize a continuum of the postural spectrum. Classifying children into mutually exclusive classes may lead to some misclassification, especially if children show a combined distribution of individual postural angles that is compatible with more than one pattern. For example, children classified as having the flat pattern still had a 31% average probability of being classified as having the neutral to hyperlordotic pattern (girls) and a 25% average probability of being classified as having the sway to neutral type (boys) (eFig. 3). Nevertheless, our statistical approach allowed us to quantify uncertainty for each pattern assignment; this approach is particularly useful for modeling sagittal posture within a probabilistic framework.[44]

Finally, the use of photogrammetry to assess our major outcome may have introduced some misclassification because of systematic or random differences in the placement of markers between and within examiners, which can depend on children's anthropometric characteristics; for example, lower accuracy in pelvic anatomical identification can occur in children with higher subcutaneous adiposity.[24] However, these issues were not expected to compromise our findings for several reasons: systematic differences were accounted for by quantifying the distance between the children's values and the average values within each examiner's distribution; consistent statistically significant associations between weight or BMI and postural types were still observable in both sexes; and we confirmed the validity of proposed patterns against postural measures not used in the cluster solution and expected to vary across clusters (as shown in eTab. 2). Prominent landmarks were used to obtain these postural measures; therefore, they were not expected to be associated with the accuracy of landmark identification. Additionally, we identified 3 main patterns that were clearly distinct from each other (differences varying from 6.3° to 13.1°); the random error of the measurement method was estimated to vary between 3.5 and 6.7 degrees.[24] Furthermore, sagittal posture assessment by photogrammetry is well recognized as the safest available method for the postural evaluation of children.[13,24,25]

We identified a meaningful summary model for the distribution of sagittal standing posture in girls and boys of school age. The patterns were consistent with childhood as a sensitive period for posture differentiation. However, postural dichotomy (neutral versus nonneutral) clearly did not apply to children, and substantial sex-related heterogeneity in the features and frequencies of different patterns existed among children of school age. These findings highlight the potential for sex-specific biomechanical frameworks of spinopelvic structures during a habitual upright position even in prepubertal ages, implying different biomechanical loads and perhaps contributing to the well-known sex differences in pediatric spinal deformities, such as higher frequencies of scoliosis in girls and Scheuermann disease in boys.

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Ethics Approval

The Generation XXI cohort study was approved by the Ethics Committee of Centro Hospitalar São João/University of Porto Medical School and complies with the Helsinki Declaration and current national legislation and was also approved by the National Committee of Data Protection.

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