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Associations of anthropometry since birth with sagittal posture at age seven: a population-based cohort study

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ABSTRACT

Objectives Adult sagittal posture is established during childhood and adolescence. A flattened or hypercurved spine is associated with poorer musculoskeletal health in adulthood. Although anthropometry from birth onwards is expected to be a key influence on sagittal posture design, this has never been assessed during childhood. Our aim was to estimate the association between body size throughout childhood with sagittal postural patterns at 7 years of age.

Design: Population-based cohort study.

Setting and participants: A subsample of 1029 girls and 1101 boys taking part in the 7-year-old follow-up of the birth cohort Generation XXI (Porto, Portugal) was included. We assessed the association between anthropometric measurements at birth, 4 and 7 years of age and postural patterns at age 7, defined using latent profile analysis.

Results: Postural patterns identified were Sway, Flat and "Neutral to Hyperlordotic" in girls, and "Sway to Neutral", Flat and Hyperlordotic in boys; with flat and hyperlordotic postures representing a straightened and a rounded spine, respectively. In both girls and boys, higher weight was associated with lower odds of a Flat pattern compared to a Sway/"Sway to Neutral" pattern, with stronger associations at older ages: e.g. odds ratios (ORs) were 0.68 (95% CI: 0.53-0.88) per standard deviation (SD) increase in birth weight and 0.36 (95% CI: 0.19-0.68) per SD increase in weight at age 7 in girls, with similar findings in boys. Boys with higher ponderal index at birth were more frequently assigned to the Hyperlordotic pattern compared to the "Sway to Neutral" pattern (OR=1.44 per SD; p=0.043).

Conclusions: Our findings support a prospective sculpting role of body size and therefore of load on musculoskeletal spino-pelvic structures, with stronger associations as children get older.

Strengths and limitations of this study

- We studied the associations of anthropometrics at different ages during childhood with sagittal postural patterns at 7 years of age among a large population-based cohort of children.
- Children from the original cohort not included in this study were heavier and taller during the 4- and 7-year follow-up.
- Measurements of anthropometric characteristics were considered at birth, 4 and 7 years of age and additional measurements across childhood would provide more detailed information of the growth-related changes in the associations between anthropometrics and posture.

INTRODUCTION

Sagittal standing posture evolves with growth and it contributes to the development of pediatric spinal deformities.(1-3) Posture is also crucial in the long term,(4-8) since mature sagittal spino-pelvic alignment is involved in a variety of orthopedic disorders,(2) as well as unspecific back pain and loss of function.(2, 9, 10)

In the first months after birth, profound morphological changes to the pelvis and spine take place.(4, 5, 8) There is an initial verticalization of the pelvis, followed by the rising of the lordotic curve in the lower back as the child begins to assume a sustained upright position, leading the sacrum to a more horizontal position. Then, as walking abilities are acquired, constant dynamic adaptation takes place between pelvis shape, sagittal anatomy of the sacrum and physiologic curves of the spine, all of which gradually develop and interact during growth.

Children's anthropometry is expected to contribute to the mechanical framework of posture modulation, i.e. weight and height modulate gravitational actions and regulate the net direction of forces imposed on the immature spino-pelvic structures.(11) Plastic deformation of bones, discs and other spinal structures can occur,(12-14) as a result of reactive forces by muscles to ensure a stable center of mass.(4, 6, 8)

Overall, there is strong biomechanical support for the hypothesis that children's anthropometric trajectories have the potential to shape postural morphotypes. However, this has never been empirically tested in a pediatric population. Longitudinal, population-based evidence is essential to assess the potential effects of body size in promoting a healthy posture, and also, to identify periods in childhood when prevention and management of weight disorders may be more effective for promoting optimal posture.

By using prospective data from the Generation XXI birth cohort, our aim was to estimate the associations of body size from birth onwards with sagittal postural patterns at 7 years of age.

METHODS

This study is based on the population-based birth cohort Generation XXI, which has been previously described at length.(15, 16) Briefly, participants were recruited between 2005 and 2006 at five public maternity units serving the six municipalities of the metropolitan area of Porto, Portugal. At birth, 8647 infants were enrolled in the cohort (91.4% of mothers invited agreed to participate). Four and seven years after birth, 69% and 68%, respectively, of all children recruited at birth were reevaluated by face-to-face interviews and physical examinations. During the 7 year-old follow-up, a subsample of 2998 children consecutively assessed between December 2012 and August 2013, and without a diagnosis of severe neurological impairment, was invited for sagittal standing posture evaluation. Of those, 80% agreed to participate and attended the scheduled assessment. After excluding 118 girls and 165 boys with missing information on anthropometrics, 1029 girls and 1101 boys were included in the present analysis. The Generation XXI cohort study was approved by the Ethics Committee of São João Hospital/University of Porto Medical School and complies with the Helsinki Declaration for medical research and with current national legislation, and was also approved by the National Committee of Data Protection.

Birth weight and recumbent length at birth were retrieved from medical records by trained researchers. Ponderal index was then computed (weight in grams/length in centimetres^3 *100).(17) Additionally, weight and height were assessed at mean ages [standard deviation (SD)] 4.3 (0.3) and 7.1 (0.2) years. Weight was measured in light indoor clothing to the nearest 0.1kg using a digital scale (TANITA®) and height to the nearest 0.1cm using a wall stadiometer (SECA®). Body mass index was defined as weight in kilograms divided by height in squared meters.

Sagittal standing posture evaluation in both genders occurred at 7.4 years of age on average (SD: 0.4). Spherical retro-reflective markers were placed over anatomical landmarks on the right-side of the child's body: spinous processes of C7 and T12, anterior superior iliac spine, greater trochanter and lateral malleolus. Children assumed their habitual standing position with feet slightly apart and looking straight ahead.(18, 19) Full-body flash photographs of the sagittal right view of children were then acquired. Angular measures formed by the lines drawn from the anatomical landmarks were obtained using the postural assessment software PAS/SAPO:(20) trunk, lumbar and sway angles (Figure 1). These individual parameters were used to define postural morphotypes through the clustering algorithm Mclust,(21) and a 3-pattern solution was obtained separately for girls and boys (publication under review). The geometric features (orientation, volume and shape) of the distributions of postural parameters were estimated from the data, and allowed to vary between clusters, or constrained to be the same for all the clusters.(22) We then selected the type of model and number of clusters with the smallest Bayesian Information Criterion (BIC).(23)

In this paper, we replicated the 3-pattern solution using the software Mplus version 6.12 (Muthén & Muthén, Los Angeles, CA), because the previously used clustering algorithm in the R package Mclust does not allow joint estimation of postural clusters and their associations with anthropometrics in the same model. This one-step approach was used to account for uncertainty in the assignment of patterns and consequently to obtain unbiased estimates of the association between anthropometrics and posture.(24) Specifically, five latent profile models (different parametrizations of variance-covariance matrices) were tested in Mplus, with a fixed 3-class solution for each gender. We selected the model with the highest concordance (observed agreement) for pattern assignment compared with the solution previously found in Mclust. Overall concordance was 70% in girls and 78% in boys (detailed information provided in online supplementary table S1).

In order to quantify the associations of weight, height/length and body mass/ponderal index at birth, 4 and 7 years of age with postural patterns, we re-ran the selected models simultaneously using multinomial logistic regression (i.e., including anthropometrics as predictors of postural latent profiles). Anthropometric measures were standardized to enable comparisons across different ages. Estimates at 4 years of age were adjusted for birth measurements and estimates at 7 years were adjusted for measurements at birth and 4 years of age.

RESULTS

There was no association between inclusion in this study and anthropometric characteristics at birth. However, included girls and boys were lighter and shorter at 4- and 7-year-old than those not included{mean differences 95% [confidence intervals (CI)]}: -0.29kg (-0.53;-0.05), -0.40kg (-0.81;0.01), -0.64cm (-1.02;-0.26) and -0.42cm (-0.83;-0.01) in girls, and -0.62kg (-0.83;-0.40), -0.81kg (-1.20;-0.43), -0.84cm (-1.21;-0.46), and -0.53cm (-0.92;-0.13) in boys; respectively.

Identification of postural patterns

Individual angular measures were different between genders (multivariate analysis of variance, $p<0.001$) with the main difference being higher lumbar angle in girls (4.90º, $p<0.001$).

In girls, the selected model was the one restricting variance of angular measures to be the same within patterns (identity covariance matrix) but allowing them to vary across patterns, while homogeneous variance was constrained only across patterns in boys (diagonal matrix). The average latent class probabilities (for the most likely latent class membership) varied between 0.73-0.81 in girls and 0.72-0.86 in boys. Figure 2 displays the features of the three postural patterns (left panel) and a typical member of each pattern (right panel); angular values are provided in online supplementary table S2. The patterns were characterized by: increased trunk angle with backward tilt of the spine over the hips – decreased sway angle (Sway in girls and “Sway to Neutral” in boys given the high gender-specific prevalence of this pattern); straight spine with forward trunk lean – increased sway angle (Flat pattern in both genders); relatively increased lumbar angle and intermediate body sway (“Neutral to Hyperlordotic” pattern in girls); or extremely increased lumbar angle (Hyperlordotic pattern in boys).

Associations between anthropometry and sagittal posture

Table 1 and Figure 3 show descriptive analyses of the average anthropometric characteristics at birth and ages 4 and 7 years according to participants' most likely class assignment. Odds ratios (OR) and respective 95% CI for the associations between anthropometric traits and posture are shown in Table 2, using the Sway and "Sway to Neutral" patterns as reference given their intermediate overall anthropometric profile.

Girls

Girls with the lowest average weight at all ages belonged more frequently to the Flat pattern at age 7. Higher weight at birth was associated with the Sway pattern, while higher weight at ages 4 and 7 was related with a "Neutral to Hyperlordotic" pattern. Per one SD increase in weight at birth, the odds of a Flat pattern compared to Sway changed by 0.68 (95% CI: 0.53-0.88). This association became stronger with age, with an OR of 0.36 (95% CI: 0.19-0.68) at 7 years of age. The same directions of associations were observed for body mass/ponderal index, with an OR of 0.68 (95% CI: 0.51-0.89) for Flat compared to Sway pattern per SD increase in birth weight and 0.39 (95% CI: 0.21-0.70) per SD increase in weight at 7 years. Lower height was observed in children with the Flat pattern, with mean (SD) height at 7 years of age 122.45cm (4.91) for the Flat, 123.00cm (5.25) for the "Neutral to Sway" and 123.06cm (5.08) for the Sway pattern. Taller girls were 22% to 40% less likely to develop a Flat pattern at 7 years of age ($p \leq 0.080$), but these associations were weaker than those for weight/body mass index.

Boys

As in girls, higher birth weight in boys was associated with the "Sway to Neutral" pattern, while the highest weight thereafter was shown for those assigned to the Hyperlordotic pattern. Per SD increase in weight, the OR for a Flat pattern compared with Sway/Neutral

was 0.66 at birth and 0.33 at 7 years of age. The same decreasing trend for the Flat type was observed in body mass/ponderal index with the OR being stronger than for weight. Boys who were born with higher ponderal index were more likely to have the Hyperlordotic pattern (OR=1.44 per 0.27g/cm^3; p=0.043). Regarding length/height, boys showing a "Sway to Neutral" pattern were born 0.97 cm longer, but those assigned to a Hyperlordotic pattern reach a similar stature at 4 years old, and were 1.04 cm taller at 7 years of age, while shorter boys at birth were more likely to show a Flat pattern [OR=0.65 per SD (2.47cm); p=0.001].

Sensitivity analysis

Similar associations between anthropometry and sagittal posture were observed after restricting the sample to children assigned to the same postural pattern in both Mplus and Mclust (online supplementary table S3). Additionally, sensitivity analyses excluding twins (girls: n=46; boys: n=49) and children born small or large for gestational age(25) (small: n=153, large: n=45 in girls; small: n=155, large: n=27 in boys), and also including adjustment for gestational age at birth, did not change the previous overall patterns of associations.

Table 1 Anthropometric characteristics at birth and ages 4 and 7 years according to sagittal standing postural patterns, shown separately for girls and boys

	All	Sway pattern	Flat pattern	Neutral to Hyperlordotic pattern
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Girls, n=1029				
Weight				
Birth, g	3102.1 (521.3)	3155.7 (507.5)	3063.1 (539.3)	3112.5 (511.2)
4 years, kg	17.9 (3.0)	18.0 (3.3)	17.3 (2.7)	18.3 (3.1)
7 years, kg	25.9 (5.4)	26.1 (5.7)	24.6 (4.6)	26.9 (5.6)
Length/Height, cm				
Birth	48.2 (2.3)	48.4 (2.1)	48.2 (2.5)	48.2 (2.3)
4 years	104.3 (4.5)	104.6 (4.5)	104.1 (4.4)	104.4 (4.6)
7 years	122.8 (5.1)	123.1 (5.1)	122.4 (4.9)	123.0 (5.3)
Ponderal index/BMI				
Birth, 100*(g/cm^3)	2.74 (0.26)	2.77 (0.26)	2.71 (0.26)	2.76 (0.27)
4 years, kg/m^2	16.36 (1.99)	16.36 (2.21)	15.92 (1.78)	16.67 (2.00)
7 years, kg/m^2	17.08 (2.67)	17.11 (2.79)	16.31 (2.30)	17.63 (2.75)
	All	**Sway to Neutral pattern**	**Flat pattern**	**Hyperlordotic pattern**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Boys, n=1101				
Weight				
Birth, g	3198.9 (516.1)	3229.3 (491.0)	3064.1 (600.0)	3189.3 (519.0)
4 years, kg	17.8 (2.6)	17.9 (2.6)	17.3 (2.3)	18.4 (1.6)
7 years, kg	25.8 (4.7)	26.0 (4.8)	24.5 (3.9)	26.9 (4.1)
Length/Height, cm				
Birth	48.9 (2.5)	49.1 (2.3)	48.2 (3.1)	48.2 (2.9)
4 years	105.3 (4.5)	105.5 (4.5)	104.8 (4.6)	105.4 (3.3)
7 years	123.9 (5.3)	123.9 (5.4)	123.3 (5.3)	125.0 (5.4)
Ponderal index/BMI				
Birth, 100*(g/cm^3)	2.71 (0.27)	2.71 (0.27)	2.70 (0.28)	2.85 (0.36)
4 years, kg/m^2	16.00 (1.49)	16.06 (1.52)	15.71 (1.32)	16.55 (1.26)
7 years, kg/m^2	16.70 (2.19)	16.85 (2.24)	16.00 (1.79)	17.19 (1.98)

SD, standard deviation; BMI, body mass index.

Table 2 Associations between standardized anthropometric measures at birth, 4 and 7 years of age and sagittal postural patterns, shown separately for girls and boys

	Sway pattern	Flat pattern			Neutral to Hyperlordotic pattern		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Girls, n=1029							
Weight							
Birth	1	0.68	0.53-0.88	0.003	0.83	0.64-1.07	0.154
4 years	1	0.53	0.35-0.79	0.002	1.32	0.84-2.07	0.228
7 years	1	0.36	0.19-0.68	0.002	1.89	0.87-4.10	0.110
Length/Height							
Birth	1	0.78	0.61-1.01	0.056	0.84	0.67-1.05	0.133
4 years	1	0.76	0.57-1.02	0.070	0.93	0.70-1.24	0.618
7 years	1	0.60	0.34-1.06	0.080	1.20	0.38-3.76	0.751
Ponderal index/BMI							
Birth	1	0.68	0.51-0.89	0.005	0.92	0.72-1.18	0.534
4 years	1	0.49	0.30-0.78	0.003	1.34	0.81-2.21	0.249
7 years	1	0.39	0.21-0.70	0.002	1.63	0.89-2.97	0.111

	Sway to Neutral pattern	Flat pattern			Hyperlordotic pattern		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Boys, n=1101							
Weight							
Birth	1	0.66	0.51-0.87	0.003	0.92	0.56-1.51	0.745
4 years	1	0.62	0.35-1.09	0.099	1.93	1.43-2.60	<0.001
7 years	1	0.33	0.11-0.99	0.048	1.88	0.90-3.92	0.092
Length/Height							
Birth	1	0.65	0.50-0.84	0.001	0.70	0.49-0.998	0.049
4 years	1	0.86	0.65-1.14	0.300	1.00	0.59-1.72	0.993
7 years	1	1.39	0.70-2.74	0.349	2.33	1.10-4.98	0.028
Ponderal index/BMI							
Birth	1	0.93	0.73-1.19	0.566	1.44	1.01-2.04	0.043
4 years	1	0.51	0.25-1.03	0.061	2.08	1.34-3.25	0.001
7 years	1	0.23	0.11-0.51	<0.001	1.50	0.88-2.56	0.139

OR, odds ratio; CI, confidence interval; BMI, body mass index.
Odds ratios are per one standard deviation higher anthropometric measure. Estimates at 4 years of age adjusted for birth measurements; estimates at 7 years adjusted for measurements at birth and 4 years.

DISCUSSION

In this population-based birth cohort we analyzed the associations of anthropometrics at different ages during childhood with sagittal posture at 7 years of age. In both genders, children who remained lighter had an increased likelihood of a Flat posture, and this relationship became stronger with increasing age. Concordantly, being heavier at 4 and 7 years old was associated with a posture characterized by increased lumbar angle: “Neutral to Hyperlordotic” in girls and Hyperlordotic in boys. Shorter girls tended to present a Flat posture and taller boys a Hyperlordotic pattern.

This is the first study evaluating the role of anthropometric characteristics from birth and throughout childhood in shaping standing posture organization. Our findings showed that adiposity was inversely related with a flattened spine, and concordantly, directly associated with a rounded posture. Only one other research group evaluated the relation between anthropometrics and patterns of standing posture before skeletal maturity is reached(13, 19) and cross-sectional analyses have shown that 14-year-old adolescents with a Flat pattern had the lowest weight/body mass index, while those in the Hyperlordotic pattern were the fattest.(19) Similarly, children in the Flat pattern less frequently belonged to ascending, high or very high trajectories of body size defined from 3 to 14 years of age, while those in the Hyperlordotic pattern were at higher risk of showing overweight trajectories.(13) Our results during childhood are also consistent with cross-sectional findings in adult populations(12, 14, 26) suggesting that higher adiposity levels during the development of posture is crucial for the shape and orientation of the spino-pelvic unit, and implying a role of anthropometrics at early ages in shaping overall postural patterns during adulthood. In adults, both a flattened or hypercurved posture generally represent a poor postural health status on the basis of their relation with back pain,(27, 28) and also by contributing to the etiology of pattern-specific spine pathologies, such as discopathy and vertebral listhesis, respectively.(11, 29, 30) In contrast with later stages of life,(13, 14, 19, 26, 29) a neutral labelling was not considered appropriate to characterize postural patterns in children, but non-ideal patterns were already differentiated in childhood (Flat and Hyperlordotic) and it seems plausible that they will progressively mature and partially track over the life course.

In both genders, anthropometric characteristics at ages 4 and 7 were more strongly associated with posture at 7 than body size at birth, as reflected by the age-related increase in the magnitude of associations between weight and the Flat pattern, and also the association of weight with increased lumbar curve observed only at ages 4 and 7. Previous studies describing the changes in sagittal posture throughout different stages of growth,(1, 4-8) highlighted the potential effect of morphologic anthropometric-related changes to be stronger during walking ages and potentially having a cumulative mechanical effect over time. Our observations at different ages in childhood support a cumulative result of weight bearing on spino-pelvic structures.

Although height was associated with postural patterns, associations were generally weaker than for weight. Consequently, the latter seems to be the main driver of the direction and magnitude of the associations seen for body mass index; as expected for a mechanical mechanism. However, this was not the case for the Hyperlordotic pattern in boys, where height showed a stronger association with posture than weight. This particular relation between height/length and the Hyperlordotic pattern may be a consequence of an anterior displacement of the center of gravity related to an increased weight of the upper body as the child gets older.(7) In order to reestablish a stable basis of support, the lumbar curve increases by means of higher vertebral growth, reflected in height, and this mechanism seems to be responsible for restoring sagittal balance.(7) In agreement with this hypothesis, the Hyperlordotic pattern was characterized by a substantially increased lumbar angle. However, this study was not designed to investigate this pattern-specific association and the usefulness of length/height to predict the presence of this particular pattern in school-aged boys deserves future specific exploration. Interestingly, the same average ascending trajectory of weight in the Hyperlordotic pattern in boys was observed for the "Neutral to Hyperlordotic" pattern in girls, even though with less extreme values of weight, which supports a functional aggregation of neutral and hyperlordotic postures in school-aged girls.

Some limitations of this work should be highlighted. Children from the original cohort not included in this study were heavier and taller during the 4- and 7-year follow-up. Bias of our analysis is unlikely, as the association between anthropometry and postural patterns is unlikely to differ between included and excluded children. Measurements of anthropometric characteristics were considered at birth, 4 and 7 years of age and additional measurements across childhood would provide more detailed information of the growth-related changes in the associations between anthropometrics and posture. Although photogrammetry is the safest available method for postural evaluation of children,(14, 18, 31) radiographies directly allow us to measure spinal curvatures and are the gold-standard which would have allowed more robust conclusions. Additionally, the present postural patterns have not yet been reproduced in other samples and therefore future research is needed to confirm validation of the postural classifications. Furthermore, latent profile analysis in Mplus was performed in this study, although Mclust(21) has been previously used for postural pattern identification. Since the two clustering methods use different estimation algorithms,(32) classifications were not completely overlapping (online supplementary table S1). However, the solutions between the two clustering algorithms have been initially compared: while the same 3-pattern solution was obtained in boys, for girls, Mplus suggested two and Mclust three patterns (based on the smallest BIC). Based on patterns' interpretability and also because Mplus solution aggregates two of the three groups suggested by Mclust, we opted to use three class models for both genders in order to replicate the solution provided by Mclust. Despite this, our conclusions should not be meaningfully affected since a good concordance between final models was obtained (≥70%), as well as comparable face validity of patterns (i.e., their postural meaning). Our findings were further supported by sensitivity analysis restricted to children assigned to the same postural pattern in both Mplus and Mclust; as shown in online supplementary table S3.

This is the first study evaluating the association of different measures of anthropometry and posture in children, using a large sample of children recruited from a population-based cohort with considerable variability both in exposure and outcome. Additionally, to examine overall postural patterns instead of isolated parameters is a key advantage because patterns allow a better characterization of overall posture, permitting the analysis to account for the relationships between different anatomical regions.(14, 19, 30) Our work used, for the first time, a probability based posture classification (i.e., considering posterior probabilities of pattern membership), in order to avoid bias in the estimates of associations between anthropometry and postural patterns.(24)

We quantified the associations of early anthropometric features with sagittal posture during childhood and we found that children who were lighter from the time of birth were more likely to develop a flattened posture at 7 years of age, while being heavier was associated with a rounded posture in both genders. The mechanical load imposed by body size seems to have a cumulative sculpting role throughout the first decade of life, especially after walking abilities are acquired.

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Contributors:

FAA, RL, NA and HB collaborated in the conceptualization, design and acquisition of data. FAA, RL, AJS, JH, NA, KT, LDH and HB collaborated in the analysis and interpretation of data. FAA drafted the initial manuscript. RL, AJS, JH, NA, KT, LDH and HB critically reviewed the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Conflict of Interest:

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data Sharing

No additional data are available.

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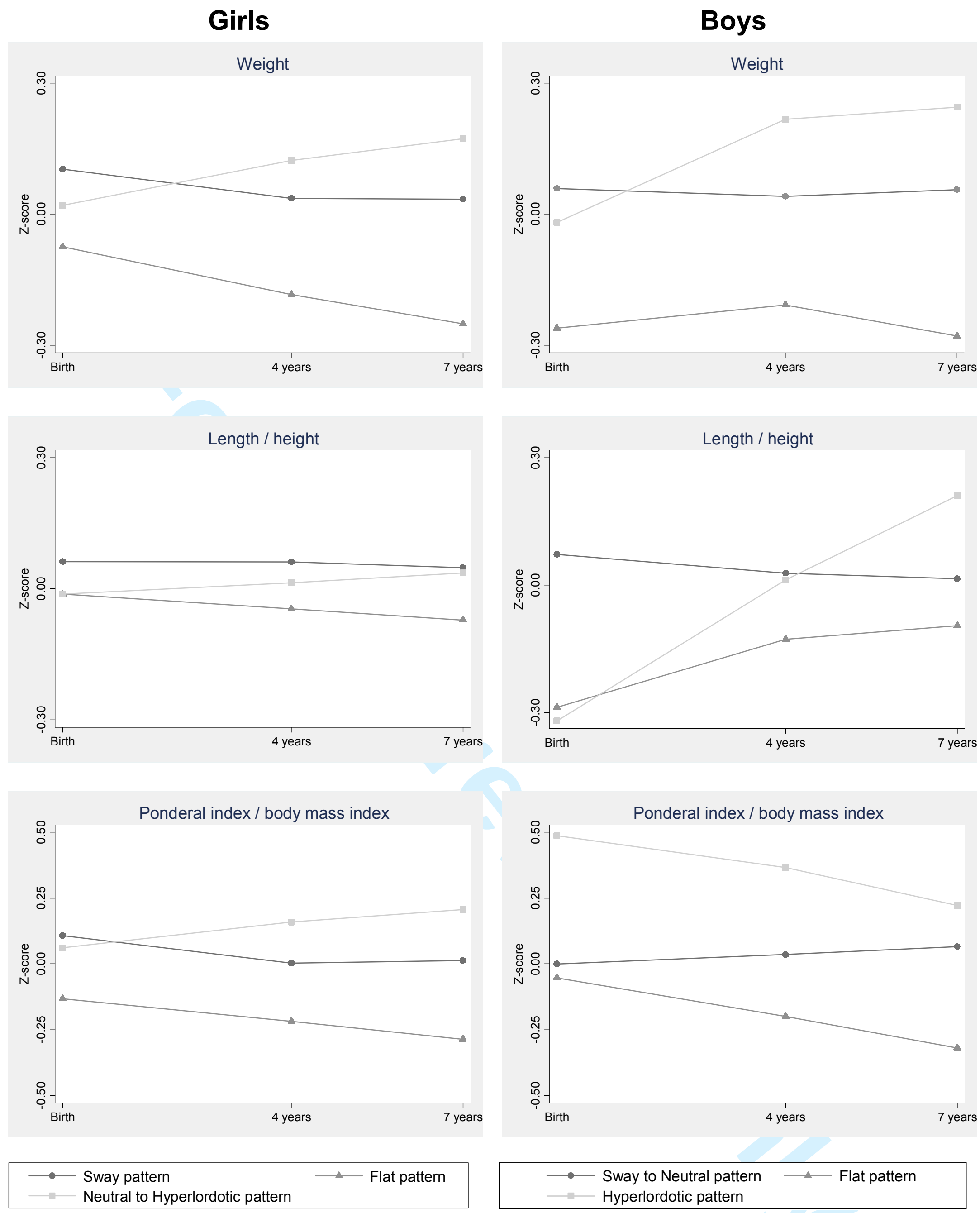
Figure 1 Individual angular measures used to identify sagittal postural patterns (using Mplus latent profile analysis).

Figure 2 Box plots showing the distribution (median, inter-quartile range and range) of each separate postural angle, standardized to have a mean of zero and standard deviation of one, across sagittal standing postural patterns (left panel) and typical members within each pattern (right panel), shown separately for girls and boys.

Figure 3 Standardized cross-sectional means of anthropometric characteristics at birth and ages 4 and 7 years across sagittal standing postural patterns, shown separately for girls and boys.


Girls
Boys
Weight
Length / height
Ponderal index / body mass index
Z-score
Birth
4 years
7 years
Sway pattern
Flat pattern
Neutral to Hyperlordotic pattern
Sway to Neutral pattern
Hyperlordotic pattern

Supplementary material

Table S1 Comparison of Mplus and Mclust sagittal postural patterns assignment, shown separately for girls and boys

		Mplus		
		Sway pattern	**Flat pattern**	**Neutral to Hyperlordotic pattern**
		n (%)	**n (%)**	**n (%)**
Girls, n=1029				
Mclust	Sway pattern	156 (92.9)	42 (11.5)	80 (16.1)
	Flat pattern	12 (7.1)	172 (47.1)	26 (5.2)
	Neutral to Hyperlordotic pattern	0 (0.0)	151 (41.4)	390 (78.6)

		Mplus		
		Sway to Neutral pattern	**Flat pattern**	**Hyperlordotic pattern**
		n (%)	**n (%)**	**n (%)**
Boys, n=1101				
Mclust	Sway to Neutral pattern	643 (73.0)	0 (0.0)	0 (0.0)
	Flat pattern	207 (23.5)	195 (99.0)	2 (8.7)
	Hyperlordotic pattern	31 (3.5)	2 (1.0)	21 (91.3)

Table S2 Postural parameters in sagittal postural patterns, shown separately for girls and boys

	Girls				Boys			
	Sway pattern (n=168, 16.3%)	**Flat pattern (n=365, 35.5%)**	**Neutral to Hyperlordotic pattern (n=496, 48.2%)**		**Sway to Neutral pattern (n=881, 80.0%)**	**Flat pattern (n=197, 17.9%)**	**Hyperlordotic pattern (n=23, 2.1%)**	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**P**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**P**
Trunk angle, °	213.2 (3.5)	202.7 (5.0)	201.2 (5.9)	<0.001	205.9 (5.8)	200.9 (5.4)	189.3 (4.7)	<0.001
Lumbar angle, °	280.4 (4.0)	274.7 (4.5)	287.4 (5.0)	<0.001	276.9 (6.8)	275.0 (6.9)	289.3 (5.8)	<0.001
Sway angle, °	162.2 (3.7)	166.0 (4.5)	165.0 (4.5)	<0.001	163.2 (3.7)	171.9 (3.0)	165.0 (3.9)	<0.001

SD, standard deviation.

Table S3 Associations between standardized anthropometric measures at birth, 4 and 7 years of age and sagittal postural patterns in children assigned to the same pattern in both Mplus and Mclust, shown separately for girls and boys

	Sway pattern	Flat pattern			Neutral to Hyperlordotic pattern		
	OR	OR	95% CI	P	OR	95% CI	P
Girls, n=718							
Weight							
Birth	1	0.72	0.56-0.92	0.010	0.85	0.69-1.04	0.108
4 years	1	0.67	0.46-0.97	0.032	0.98	0.78-1.24	0.867
7 years	1	0.33	0.18-0.61	<0.001	1.06	0.68-1.64	0.796
Length/Height							
Birth	1	0.81	0.61-1.07	0.141	0.85	0.69-1.05	0.127
4 years	1	0.82	0.61-1.09	0.163	0.91	0.73-1.12	0.360
7 years	1	0.78	0.50-1.21	0.265	1.00	0.71-1.39	0.980
Ponderal index/BMI							
Birth	1	0.71	0.56-0.90	0.005	0.91	0.75-1.11	0.372
4 years	1	0.63	0.41-0.96	0.032	1.02	0.78-1.32	0.894
7 years	1	0.31	0.17-0.56	<0.001	1.05	0.69-1.58	0.830
	Sway to Neutral pattern	**Flat pattern**			**Hyperlordotic pattern**		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Boys, n=859							
Weight							
Birth	1	0.72	0.60-0.86	<0.001	0.87	0.49-1.54	0.628
4 years	1	0.78	0.62-0.97	0.027	1.15	0.86-1.54	0.356
7 years	1	0.51	0.35-0.75	0.001	0.99	0.49-2.02	0.979
Length/Height							
Birth	1	0.70	0.59-0.83	<0.001	0.67	0.48-0.93	0.016
4 years	1	0.91	0.75-1.10	0.321	0.99	0.67-1.46	0.945
7 years	1	1.07	0.76-1.52	0.685	2.51	0.79-8.06	0.120
Ponderal index/BMI							
Birth	1	0.94	0.77-1.14	0.506	1.43	1.01-2.01	0.043
4 years	1	0.72	0.56-0.92	0.009	1.23	0.92-1.64	0.169
7 years	1	0.43	0.29-0.65	<0.001	0.74	0.37-1.49	0.403

OR, odds ratio; CI, confidence interval; BMI, body mass index. Odds ratios are per one standard deviation higher anthropometric measure. Estimates at 4 years of age adjusted for birth measurements; estimates at 7 years adjusted for measurements at birth and 4 years.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract; PAGE 1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found; PAGE 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported; PAGE 4
Objectives	3	State specific objectives, including any prespecified hypotheses; PAGE 4
Methods		
Study design	4	Present key elements of study design early in the paper; PAGE 5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection; PAGE 5, 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up; PAGE 5
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed; N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable; PAGE 5, 6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group; PAGE 5, 6
Bias	9	Describe any efforts to address potential sources of bias; PAGE 6
Study size	10	Explain how the study size was arrived at; PAGE 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why; PAGE 6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding; PAGE 6, 7
		(*b*) Describe any methods used to examine subgroups and interactions; N/A
		(*c*) Explain how missing data were addressed; PAGE 5
		(*d*) If applicable, explain how loss to follow-up was addressed; N/A
		(*e*) Describe any sensitivity analyses; N/A
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed; PAGE 5
		(b) Give reasons for non-participation at each stage; PAGE 5
		(c) Consider use of a flow diagram; N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders; PAGE 8
		(b) Indicate number of participants with missing data for each variable of interest; N/A
		(c) Summarise follow-up time (eg, average and total amount); N/A
Outcome data	15*	Report numbers of outcome events or summary measures over time; TABLE 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were

		adjusted for and why they were included; TABLE 2
		(*b*) Report category boundaries when continuous variables were categorized; N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period; N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses; PAGE 10
Discussion		
Key results	18	Summarise key results with reference to study objectives; PAGE 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias, PAGE 15, 16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence; PAGE 13, 14, 15
Generalisability	21	Discuss the generalisability (external validity) of the study results; PAGE 15
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based; PAGE 17

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Associations of anthropometry since birth with sagittal posture at age seven in a prospective birth cohort: the Generation XXI study

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Keywords: Body size, sagittal standing posture, latent profile analysis, musculoskeletal epidemiology, child

Word count: 3506

ABSTRACT

Objectives Adult sagittal posture is established during childhood and adolescence. A flattened or hypercurved spine is associated with poorer musculoskeletal health in adulthood. Although anthropometry from birth onwards is expected to be a key influence on sagittal posture design, this has never been assessed during childhood. Our aim was to estimate the association between body size throughout childhood with sagittal postural patterns at 7 years of age.

Design: Prospective cohort study.

Setting and participants: A subsample of 1029 girls and 1101 boys taking part in the 7-year-old follow-up of the birth cohort Generation XXI (Porto, Portugal) was included. We assessed the associations between anthropometric measurements (weight, height and body mass index) at birth, 4 and 7 years of age and postural patterns at age 7. Postural patterns were defined using latent profile analysis, a probabilistic model-based technique which allows for simultaneously including anthropometrics as predictors of latent profiles.

Results: Postural patterns identified were Sway, Flat and "Neutral to Hyperlordotic" in girls, and "Sway to Neutral", Flat and Hyperlordotic in boys; with flat and hyperlordotic postures representing a straightened and a rounded spine, respectively. In both girls and boys, higher weight was associated with lower odds of a Flat pattern compared to a Sway/"Sway to Neutral" pattern, with stronger associations at older ages: e.g. odds ratios (ORs) were 0.68 (95% CI: 0.53-0.88) per standard deviation (SD) increase in birth weight and 0.36 (95% CI: 0.19-0.68) per SD increase in weight at age 7 in girls, with similar findings in boys. Boys with higher ponderal index at birth were more frequently assigned to the Hyperlordotic pattern compared to the "Sway to Neutral" pattern (OR=1.44 per SD; p=0.043).

Conclusions: Our findings support a prospective sculpting role of body size and therefore of load on musculoskeletal spino-pelvic structures, with stronger associations as children get older.

Strengths and limitations of this study

- This is the first study evaluating the role of anthropometric characteristics from birth through early childhood in shaping standing posture organization in children.
- We assessed a large population-based cohort of 1029 girls and 1101 boys who were followed prospectively up to age seven – the Generation XXI study.
- Postural patterns were defined using a probabilistic, model-based method – latent profile analysis – which included anthropometrics in addition to postural parameters.
- Although photogrammetry is the safest available method for postural evaluation of children, radiograms would have been the gold standard method for curvature measurement.
- Some degree of bias cannot be excluded, since children from the original cohort who were not included in this study were heavier and taller in the 4- and 7-year follow-up evaluations and this could have changed the association between anthropometrics and postural patterns.

INTRODUCTION

Sagittal standing posture evolves with growth and it contributes to the development of pediatric spinal deformities.(1-3) Posture is also crucial in the long term,(4-8) since mature sagittal spino-pelvic alignment is involved in a variety of orthopedic disorders,(2) such as degenerative disease and vertebral listhesis, as well as unspecific back pain and loss of function.(2, 9, 10)

In the first months after birth, profound morphological changes to the pelvis and spine take place.(4, 5, 8) There is an initial verticalization of the pelvis, followed by the rising of the lordotic curve in the lower back as the child begins to assume a sustained upright position, leading the sacrum to a more horizontal position.(4) Then, as walking abilities are acquired, constant dynamic adaptation takes place between pelvis shape, sagittal anatomy of the sacrum and physiologic curves of the spine, all of which gradually develop and interact during growth.(5, 8)

Children's anthropometry is expected to contribute to the mechanical framework of posture modulation, i.e. weight and height modulate gravitational actions and regulate the net direction of forces imposed on the immature spino-pelvic structures.(11) Plastic deformation of bones, discs and other spinal structures can occur,(12-14) as a result of reactive forces by muscles to ensure a stable center of mass.(4, 6, 8)

Overall, there is strong biomechanical support for the hypothesis that children's anthropometric trajectories have the potential to shape postural morphotypes. However, this has never been empirically tested in a pediatric population. Longitudinal, population-based evidence is essential to assess the potential effects of body size in promoting a healthy posture, and also, to identify periods in childhood when prevention and management of weight disorders may be more effective for avoiding long-term musculoskeletal consequences of posture misalignment in later life.

By using prospective data from the Generation XXI birth cohort, our aim was to estimate the associations of body size from birth onwards with sagittal postural patterns at 7 years of age.

METHODS

This study is based on the population-based birth cohort Generation XXI, which has been previously described at length.(15, 16) Briefly, participants were recruited between 2005 and 2006 at five public maternity units serving the six municipalities of the metropolitan area of Porto, Portugal. At birth, 8647 infants were enrolled in the cohort (91.4% of mothers invited agreed to participate). Four and seven years after birth, 69% and 68%, respectively, of all children recruited at birth were reevaluated by face-to-face interviews and physical examinations. During the 7 year-old follow-up, a subsample of 2998 children consecutively assessed between December 2012 and August 2013, and without a diagnosis of severe neurological impairment, was invited for sagittal standing posture evaluation. Of those, 80% agreed to participate and attended the scheduled assessment. After excluding 118 girls and 165 boys with missing information on anthropometrics, 1029 girls and 1101 boys were included in the present analysis. The Generation XXI cohort study was approved by the Ethics Committee of São João Hospital/University of Porto Medical School and complies with the Helsinki Declaration for medical research and with current national legislation, and was also approved by the National Committee of Data Protection. Written informed consent was obtained from all parents or legal guardians.

Birth weight and recumbent length at birth were retrieved from medical records by trained researchers. Ponderal index was then computed (weight in grams/length in centimetres^3 *100).(17) Additionally, weight and height were assessed at mean ages [standard deviation (SD)] 4.3 (0.3) and 7.1 (0.2) years. Weight was measured in light indoor clothing to the nearest 0.1kg using a digital scale (TANITA®) and height to the nearest 0.1cm using a wall stadiometer (SECA®). Body mass index was defined as weight in kilograms divided by height in squared meters.

Sagittal standing posture evaluation in both genders occurred at 7.4 years of age on average (SD: 0.4), 0 to 420 days after the anthropometric evaluation (50% of children evaluated within 61.5 days). Spherical retro-reflective markers were placed over anatomical landmarks on the right-side of the child's body: spinous processes of C7 and T12, anterior superior iliac spine, greater trochanter and lateral malleolus. Children were instructed to rest comfortably in habitual standing position with feet slightly apart, looking straight ahead and moving elbows forward.(18, 19) Floor markers were used to standardize children positioning. Full-body flash photographs of the sagittal right view of children were then acquired, after the examiner judged that the usual upright position had been attained. Angular measures formed by the lines drawn from the anatomical landmarks were obtained using the postural assessment software PAS/SAPO:(20) trunk, lumbar and sway angles (Figure 1). These individual parameters were used to define postural morphotypes through the clustering algorithm Mclust,(21) and a 3-pattern solution was obtained separately for girls and boys.(22) The geometric features (orientation, volume and shape) of the distributions of postural parameters were estimated from the data, and allowed to vary between clusters, or constrained to be the same for all the clusters.(23) We then selected the type of model and number of clusters with the smallest Bayesian Information Criterion (BIC).(24) This clustering procedure was chosen instead of the conventional heuristic methods (13, 19, 25-27) because it has the key advantage of allowing for testing different variances of angle measures within and across clusters.

In this paper, we replicated the 3-pattern solution using the software Mplus version 6.12 (Muthén & Muthén, Los Angeles, CA), because the previously used clustering algorithm in the R package Mclust does not allow joint estimation of postural clusters and their associations with anthropometrics in the same model. This one-step approach was used to account for uncertainty in the assignment of patterns and consequently to obtain unbiased estimates of the association between anthropometrics and posture.(28) Specifically, five latent profile models (different parametrizations of variance-covariance matrices) were tested in Mplus, with a fixed 3-class solution for each gender. We selected the model with the highest concordance (observed agreement) for pattern assignment compared with the solution previously found in Mclust.(22) Overall concordance was 70% in girls and 78% in boys (detailed information provided in online supplementary table S1).

In order to quantify the associations of weight, height/length and body mass/ponderal index at birth, 4 and 7 years of age with postural patterns, we re-ran the selected models simultaneously using multinomial logistic regression (i.e., including anthropometrics as predictors of postural latent profiles). Since the distributions of anthropometric variables change considerably during childhood, weight, height and body mass index were standardized within each age through *z*-score transformations, by subtracting the mean value in the sample from each individual's value and dividing the result by the sample standard deviation; units for associations are presented per SD. Estimates at 4 years of age were adjusted for birth measurements and estimates at 7 years were adjusted for measurements at birth and 4 years of age; i.e., weight estimates were adjusted for previous measurements of weight and similarly for height and body mass index.

RESULTS

There was no association between inclusion in this study and anthropometric characteristics at birth. However, included girls and boys were lighter and shorter at 4- and 7-year-old than those not included{mean differences 95% [confidence intervals (CI)]}: -0.29kg (-0.53;-0.05), -0.40kg (-0.81;0.01), -0.64cm (-1.02;-0.26) and -0.42cm (-0.83;-0.01) in girls, and -0.62kg (-0.83;-0.40), -0.81kg (-1.20;-0.43), -0.84cm (-1.21;-0.46), and -0.53cm (-0.92;-0.13) in boys; respectively.

Identification of postural patterns

Individual angular measures were different between genders (multivariate analysis of variance, $p<0.001$) with the main difference being higher lower trunk inclination/lumbar angle in girls (4.90º, $p<0.001$).

In girls, the selected model was the one restricting variance of angular measures to be the same within patterns (identity covariance matrix) but allowing them to vary across patterns, while homogeneous variance was constrained only across patterns in boys (diagonal matrix). The average latent class probabilities (for the most likely latent class membership) varied between 0.73-0.81 in girls and 0.72-0.86 in boys. Figure 2 displays the features of the three postural patterns (left panel) and a typical member of each pattern (right panel); angular values are provided in online supplementary table S2. The patterns were characterized by: increased trunk angle with backward tilt of the spine over the hips – decreased sway angle (Sway in girls and “Sway to Neutral” in boys given the high gender-specific prevalence of this pattern); straight spine with forward trunk lean – increased sway angle (Flat pattern in both genders); relatively increased lower trunk inclination and intermediate body sway (“Neutral to Hyperlordotic” pattern in girls); or extremely increased lower trunk inclination (Hyperlordotic pattern in boys).

Associations between anthropometry and sagittal posture

Table 1 and Figure 3 show descriptive analyses of the average anthropometric characteristics at birth and ages 4 and 7 years according to participants' most likely class assignment. Odds ratios (OR) and respective 95% CI for the associations between anthropometric traits and posture are shown in Table 2, using the Sway and "Sway to Neutral" patterns as reference given their intermediate overall anthropometric profile.

Girls

Girls with the lowest average weight at all ages belonged more frequently to the Flat pattern at age 7. Higher weight at birth was associated with the Sway pattern, while higher weight at ages 4 and 7 was related with a "Neutral to Hyperlordotic" pattern. Per one SD increase in weight at birth, the odds of a Flat pattern compared to Sway changed by 0.68 (95% CI: 0.53-0.88). This association became stronger with age, with an OR of 0.36 (95% CI: 0.19-0.68) at 7 years of age. The same directions of associations were observed for body mass/ponderal index, with an OR of 0.68 (95% CI: 0.51-0.89) for Flat compared to Sway pattern per SD increase in birth weight and 0.39 (95% CI: 0.21-0.70) per SD increase in weight at 7 years. Lower height was observed in children with the Flat pattern, with mean (SD) height at 7 years of age 122.45cm (4.91) for the Flat, 123.00cm (5.25) for the "Neutral to Sway" and 123.06cm (5.08) for the Sway pattern. Taller girls were 22% to 40% less likely to develop a Flat pattern at 7 years of age ($p \leq 0.080$), but these associations were weaker than those for weight/body mass index.

Boys

As in girls, higher birth weight in boys was associated with the "Sway to Neutral" pattern, while the highest weight thereafter was shown for those assigned to the Hyperlordotic pattern. Per SD increase in weight, the OR for a Flat pattern compared with Sway/Neutral

was 0.66 at birth and 0.33 at 7 years of age. The same decreasing trend for the Flat type was observed in body mass/ponderal index with the OR being stronger than for weight. Boys who were born with higher ponderal index were more likely to have the Hyperlordotic pattern (OR=1.44 per 0.27g/cm^3; p=0.043). Regarding length/height, boys showing a "Sway to Neutral" pattern were born 0.97 cm longer, but those assigned to a Hyperlordotic pattern reach a similar stature at 4 years old, and were 1.04 cm taller at 7 years of age, while shorter boys at birth were more likely to show a Flat pattern [OR=0.65 per SD (2.47cm); p=0.001].

Sensitivity analysis

Similar associations between anthropometry and sagittal posture were observed after restricting the sample to children assigned to the same postural pattern in both Mplus and Mclust (online supplementary table S3). Additionally, sensitivity analyses excluding twins (girls: n=46; boys: n=49) and children born small or large for gestational age(29) (small: n=153, large: n=45 in girls; small: n=155, large: n=27 in boys), and also including adjustment for gestational age at birth, did not change the previous overall patterns of associations. Furthermore, socioeconomic conditions at birth were not clearly associated with postural patterns at 7 years of age (maternal education: p=0.163 in girls and p=0.074 in boys; household income: p=0.436 in girls and p=0.038 in boys), and therefore we opted not to include them as confounders of the relationships between anthropometrics and postural patterns.

Table 1 Anthropometric characteristics at birth and ages 4 and 7 years according to sagittal standing postural patterns, shown separately for girls and boys

	All	Sway pattern	Flat pattern	Neutral to Hyperlordotic pattern
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Girls, n=1029				
Weight				
Birth, g	3102.1 (521.3)	3155.7 (507.5)	3063.1 (539.3)	3112.5 (511.2)
4 years, kg	17.9 (3.0)	18.0 (3.3)	17.3 (2.7)	18.3 (3.1)
7 years, kg	25.9 (5.4)	26.1 (5.7)	24.6 (4.6)	26.9 (5.6)
Length/Height, cm				
Birth	48.2 (2.3)	48.4 (2.1)	48.2 (2.5)	48.2 (2.3)
4 years	104.3 (4.5)	104.6 (4.5)	104.1 (4.4)	104.4 (4.6)
7 years	122.8 (5.1)	123.1 (5.1)	122.4 (4.9)	123.0 (5.3)
Ponderal index/BMI				
Birth, $100^*(g/cm^3)$	2.74 (0.26)	2.77 (0.26)	2.71 (0.26)	2.76 (0.27)
4 years, kg/m^2	16.36 (1.99)	16.36 (2.21)	15.92 (1.78)	16.67 (2.00)
7 years, kg/m^2	17.08 (2.67)	17.11 (2.79)	16.31 (2.30)	17.63 (2.75)
	All	**Sway to Neutral pattern**	**Flat pattern**	**Hyperlordotic pattern**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Boys, n=1101				
Weight				
Birth, g	3198.9 (516.1)	3229.3 (491.0)	3064.1 (600.0)	3189.3 (519.0)
4 years, kg	17.8 (2.6)	17.9 (2.6)	17.3 (2.3)	18.4 (1.6)
7 years, kg	25.8 (4.7)	26.0 (4.8)	24.5 (3.9)	26.9 (4.1)
Length/Height, cm				
Birth	48.9 (2.5)	49.1 (2.3)	48.2 (3.1)	48.2 (2.9)
4 years	105.3 (4.5)	105.5 (4.5)	104.8 (4.6)	105.4 (3.3)
7 years	123.9 (5.3)	123.9 (5.4)	123.3 (5.3)	125.0 (5.4)
Ponderal index/BMI				
Birth, $100^*(g/cm^3)$	2.71 (0.27)	2.71 (0.27)	2.70 (0.28)	2.85 (0.36)
4 years, kg/m^2	16.00 (1.49)	16.06 (1.52)	15.71 (1.32)	16.55 (1.26)
7 years, kg/m^2	16.70 (2.19)	16.85 (2.24)	16.00 (1.79)	17.19 (1.98)

SD, standard deviation; BMI, body mass index.

Table 2 Associations between standardized anthropometric measures at birth, 4 and 7 years of age and sagittal postural patterns, shown separately for girls and boys

	Sway pattern	Flat pattern			Neutral to Hyperlordotic pattern		
	OR	OR	95% CI	P	OR	95% CI	P
Girls, n=1029							
Weight							
Birth	1	0.68	0.53-0.88	0.003	0.83	0.64-1.07	0.154
4 years	1	0.53	0.35-0.79	0.002	1.32	0.84-2.07	0.228
7 years	1	0.36	0.19-0.68	0.002	1.89	0.87-4.10	0.110
Length/Height							
Birth	1	0.78	0.61-1.01	0.056	0.84	0.67-1.05	0.133
4 years	1	0.76	0.57-1.02	0.070	0.93	0.70-1.24	0.618
7 years	1	0.60	0.34-1.06	0.080	1.20	0.38-3.76	0.751
Ponderal index/BMI							
Birth	1	0.68	0.51-0.89	0.005	0.92	0.72-1.18	0.534
4 years	1	0.49	0.30-0.78	0.003	1.34	0.81-2.21	0.249
7 years	1	0.39	0.21-0.70	0.002	1.63	0.89-2.97	0.111
	Sway to Neutral pattern	**Flat pattern**			**Hyperlordotic pattern**		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Boys, n=1101							
Weight							
Birth	1	0.66	0.51-0.87	0.003	0.92	0.56-1.51	0.745
4 years	1	0.62	0.35-1.09	0.099	1.93	1.43-2.60	<0.001
7 years	1	0.33	0.11-0.99	0.048	1.88	0.90-3.92	0.092
Length/Height							
Birth	1	0.65	0.50-0.84	0.001	0.70	0.49-0.998	0.049
4 years	1	0.86	0.65-1.14	0.300	1.00	0.59-1.72	0.993
7 years	1	1.39	0.70-2.74	0.349	2.33	1.10-4.98	0.028
Ponderal index/BMI							
Birth	1	0.93	0.73-1.19	0.566	1.44	1.01-2.04	0.043
4 years	1	0.51	0.25-1.03	0.061	2.08	1.34-3.25	0.001
7 years	1	0.23	0.11-0.51	<0.001	1.50	0.88-2.56	0.139

OR, odds ratio; CI, confidence interval; BMI, body mass index.
Odds ratios are per one standard deviation higher anthropometric measure. Estimates at 4 years of age adjusted for birth measurements; estimates at 7 years adjusted for measurements at birth and 4 years.

DISCUSSION

In this population-based birth cohort we analyzed the associations of anthropometrics at different ages during childhood with sagittal posture at 7 years of age. In both genders, children who remained lighter had an increased likelihood of a Flat posture, and this relationship became stronger with increasing age. Concordantly, being heavier at 4 and 7 years old was associated with a posture characterized by increased lower trunk inclination/lumbar angle: “Neutral to Hyperlordotic” in girls and Hyperlordotic in boys. Shorter girls tended to present a Flat posture and taller boys a Hyperlordotic pattern.

This is the first study evaluating the role of anthropometric characteristics from birth and throughout childhood in shaping standing posture organization. Our findings showed that adiposity was inversely related with a flattened spine, and concordantly, directly associated with a hyperlordotic posture. Only one other research group evaluated the relation between anthropometrics and patterns of standing posture before skeletal maturity is reached(13, 19) and cross-sectional analyses have shown that 14-year-old adolescents with a Flat pattern had the lowest weight/body mass index, while those in the Hyperlordotic pattern were the fattest.(19) Similarly, children in the Flat pattern less frequently belonged to ascending, high or very high trajectories of body size defined from 3 to 14 years of age, while those in the Hyperlordotic pattern were at higher risk of showing overweight trajectories.(13)

Classification systems of sagittal standing posture have been attempted in young adolescent girls(26) and boys(25, 27). However, different procedures for the definition of postural parameters preclude comparisons with our work. Particularly, children have been classified using a three-point Likert scale of uncorrected posture based on the horizontal deviations of four body landmarks in respect to a vertical line(27) and three global patterns (based on three angles with respect to the vertical) with different magnitude of spinal curves being observable within each pattern.(25, 26) Our approach was to model postural patterns following three criteria: a) to use postural parameters as continuous variables as a better representation of the natural spectrum of posture, b) to search for variants comparable with those published in adolescents and adults, in a life course perspective, and c) to use a model-based method that allowed for testing different variances of angle measures within and across clusters. Nevertheless, our patterns are comparable to those published by Dolphens *et al*,(25, 26) at least regarding the suggested global alignment classifications: neutral, sway-back and leaning-forward. In comparison to our classification and focusing on their features regarding the sway angle those would to some extent correspond to the Neutral, Sway and Flat patterns, respectively.

Our results during childhood are also consistent with cross-sectional findings in adult populations(12, 14, 30) suggesting that higher adiposity levels during the development of posture is crucial for the shape and orientation of the spino-pelvic unit, and implying a role of anthropometrics at early ages in shaping overall postural patterns during adulthood. In adults, both a flattened or hypercurved posture generally represent a poor postural health status on the basis of their relation with back pain,(31, 32) and also by contributing to the etiology of pattern-specific spine pathologies, such as discopathy and vertebral listhesis, respectively.(11, 33, 34) In contrast with later stages of life,(13, 14, 19, 30, 33) a neutral labelling was not considered appropriate to characterize postural patterns in children, but non-ideal patterns were already differentiated in childhood (Flat and Hyperlordotic) and it seems plausible that they will progressively mature and partially track over the life course. In terms of the clinical interpretation of our findings, we may postulate that low birth weight may contribute to a flat back that then may increase the risk of idiopathic scoliosis,(1) while higher weight at 4 and 7 years of age may contribute to a hyperlordotic posture that then may predispose to Scheuermann's kyphosis.(3)

In both genders, anthropometric characteristics at ages 4 and 7 were more strongly associated with posture at 7 than body size at birth, as reflected by the age-related increase in the magnitude of associations between weight and the Flat pattern, and also the association of weight with increased lumbar curve observed only at ages 4 and 7. Previous studies describing the changes in sagittal posture throughout different stages of growth,(1, 4-8) highlighted the potential effect of morphologic anthropometric-related changes to be stronger during walking ages and potentially having a cumulative mechanical effect over time. Our observations at different ages in childhood support a cumulative result of weight bearing on spino-pelvic structures, and that is the reason why our work focused on children at 7 years old. Although most changes in sagittal posture occur during the first months after birth, with the acquisition of upright position and walking abilities,(4, 5, 8) it is important to allow sagittal curves to develop during growth through the influence of specific anthropometric mechanical environment and allow that different morphotypes could be distinguished within the sample. An additional major concern was to focus on prepubertal children to ensure homogeneity with regard to sexual development.(35)

Although height was associated with postural patterns, associations were generally weaker than for weight. Consequently, the latter seems to be the main driver of the direction and magnitude of the associations seen for body mass index; as expected for a mechanical mechanism. However, this was not the case for the Hyperlordotic pattern in boys, where height showed a stronger association with posture than weight. This particular relation between height/length and the Hyperlordotic pattern may be a consequence of an anterior displacement of the center of gravity related to an increased weight of the upper body as the child gets older.(7) In order to reestablish a stable basis of support, the lumbar curve increases by means of higher vertebral growth, reflected in height, and this mechanism seems to be responsible for restoring sagittal balance.(7) In agreement with this hypothesis, the

Hyperlordotic pattern was characterized by a substantially increased lower trunk inclination/lumbar angle. However, this study was not designed to investigate this pattern-specific association and the usefulness of length/height to predict the presence of this particular pattern in school-aged boys deserves future specific exploration. Interestingly, the same average ascending trajectory of weight in the Hyperlordotic pattern in boys was observed for the "Neutral to Hyperlordotic" pattern in girls, even though with less extreme values of weight, which supports a functional aggregation of neutral and hyperlordotic postures in school-aged girls.

Some limitations of this work should be highlighted. Children from the original cohort not included in this study were heavier and taller during the 4- and 7-year follow-up. Bias of our analysis is unlikely, as the association between anthropometry and postural patterns is unlikely to differ between included and excluded children. Although photogrammetry is the safest available method for postural evaluation of children,(14, 18, 36) radiographies directly allow us to measure spinal curvatures and are the gold-standard which would have allowed more robust conclusions. Moreover, despite our efforts to standardize the position of the body and of the arms in particular, enough variability may have remained that could have influenced trunk position and therefore overall sagittal posture. Additionally, the present postural patterns have not yet been reproduced in other samples and therefore future research is needed to confirm validation of the postural classifications. Furthermore, latent profile analysis in Mplus was performed in this study, although Mclust(21) has been previously used for postural pattern identification.(22) Since the two clustering methods use different estimation algorithms,(37) classifications were not completely overlapping (online supplementary table S1). However, the solutions between the two clustering algorithms have been initially compared: while the same 3-pattern solution was obtained in boys, for girls, Mplus suggested two and Mclust three patterns (based on the smallest BIC). Based on patterns' interpretability and also because Mplus solution aggregates two of the three groups suggested by Mclust, we opted to use three class models for both genders in order to replicate the solution provided by Mclust.(22) Despite this, our conclusions should not be meaningfully affected since a good concordance between final models was obtained (≥70%), as well as comparable face validity of patterns (i.e., their postural meaning). Our findings were further supported by sensitivity analysis restricted to children assigned to the same postural pattern in both Mplus and Mclust; as shown in online supplementary table S3.

This is the first study evaluating the association of different measures of anthropometry and posture in children, using a large sample of children recruited from a population-based cohort with considerable variability both in exposure and outcome. Additionally, to examine overall postural patterns instead of isolated parameters is a key advantage because patterns allow a better characterization of overall posture, permitting the analysis to account for the relationships between different anatomical regions.(14, 19, 34) Our work used, for the first time, a probability based posture classification (i.e., considering posterior probabilities of pattern membership), in order to avoid bias in the estimates of associations between anthropometry and postural patterns.(28)

We quantified the associations of early anthropometric features with sagittal posture during childhood and we found that children who were lighter from the time of birth were more likely to develop a flattened posture at 7 years of age, while being heavier was associated with a hyperlordotic posture in both genders. The mechanical load imposed by body size seems to have a cumulative sculpting role throughout the first decade of life, especially after walking abilities are acquired.

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Contributors:

FAA, RL, NA and HB collaborated in the conceptualization, design and acquisition of data. FAA, RL, AJS, JH, NA, KT, LDH and HB collaborated in the analysis and interpretation of data. FAA drafted the initial manuscript. RL, AJS, JH, NA, KT, LDH and HB critically reviewed the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Conflict of Interest:

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data Sharing Statement:

No additional data are available.

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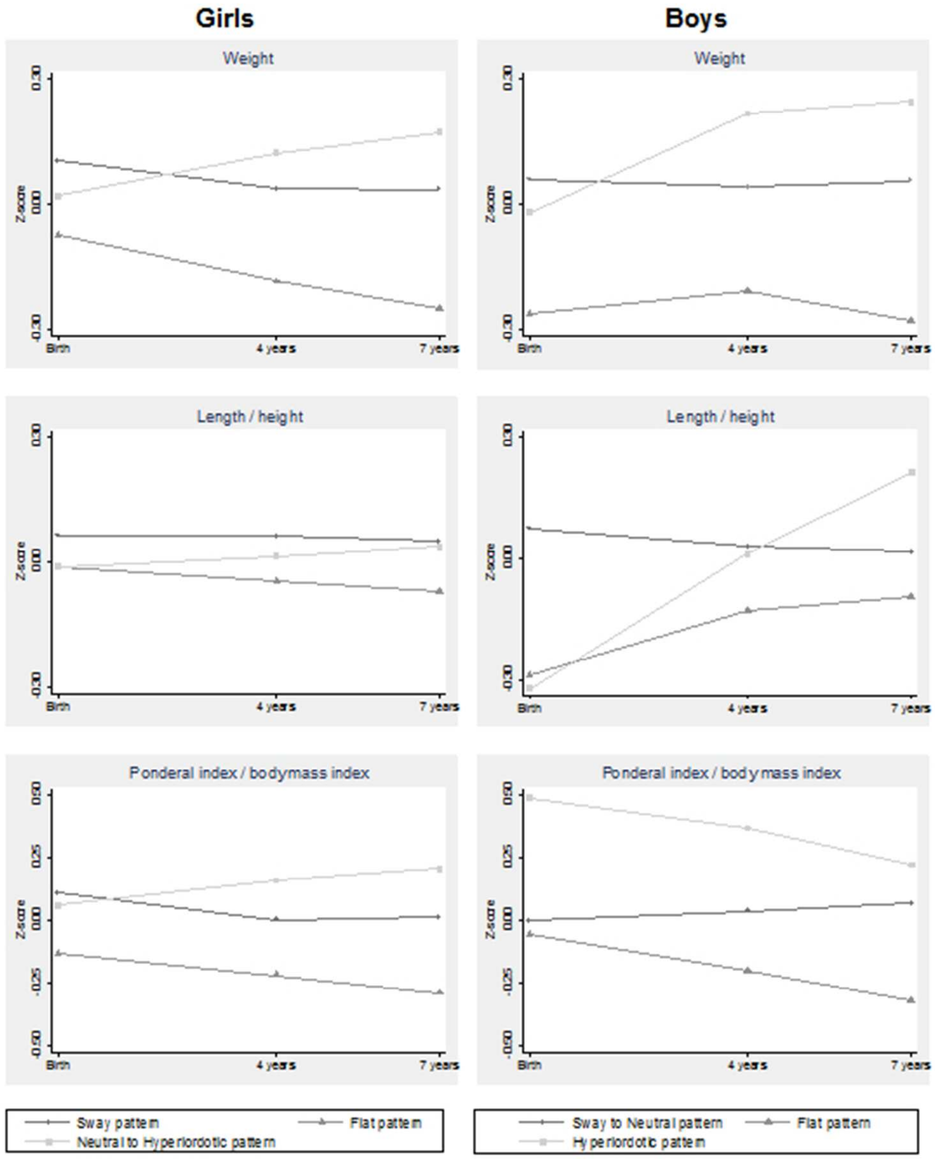
Figure 1 Individual angular measures used to identify sagittal postural patterns (using Mplus latent profile analysis).

Figure 2 Box plots showing the distribution (median, inter-quartile range and range) of each separate postural angle, standardized to have a mean of zero and standard deviation of one, across sagittal standing postural patterns (left panel) and typical members within each pattern (right panel), shown separately for girls and boys.

Figure 3 Standardized cross-sectional means of anthropometric characteristics at birth and ages 4 and 7 years across sagittal standing postural patterns, shown separately for girls and boys.



Standardized cross-sectional means of anthropometric characteristics at birth and ages 4 and 7 years across sagittal standing postural patterns, shown separately for girls and boys.

143x182mm (96 x 96 DPI)

Supplementary material

Table S1 Comparison of Mplus and Mclust sagittal postural patterns assignment, shown separately for girls and boys

		Mplus		
		Sway pattern	**Flat pattern**	**Neutral to Hyperlordotic pattern**
		n (%)	**n (%)**	**n (%)**
Girls, n=1029				
Mclust	Sway pattern	156 (92.9)	42 (11.5)	80 (16.1)
	Flat pattern	12 (7.1)	172 (47.1)	26 (5.2)
	Neutral to Hyperlordotic pattern	0 (0.0)	151 (41.4)	390 (78.6)

		Mplus		
		Sway to Neutral pattern	**Flat pattern**	**Hyperlordotic pattern**
		n (%)	**n (%)**	**n (%)**
Boys, n=1101				
Mclust	Sway to Neutral pattern	643 (73.0)	0 (0.0)	0 (0.0)
	Flat pattern	207 (23.5)	195 (99.0)	2 (8.7)
	Hyperlordotic pattern	31 (3.5)	2 (1.0)	21 (91.3)

Table S2 Postural parameters in sagittal postural patterns, shown separately for girls and boys

	Girls				Boys			
	Sway pattern (n=168, 16.3%)	**Flat pattern (n=365, 35.5%)**	**Neutral to Hyperlordotic pattern (n=496, 48.2%)**		**Sway to Neutral pattern (n=881, 80.0%)**	**Flat pattern (n=197, 17.9%)**	**Hyperlordotic pattern (n=23, 2.1%)**	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**P**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**P**
Trunk angle, º	213.2 (3.5)	202.7 (5.0)	201.2 (5.9)	<0.001	205.9 (5.8)	200.9 (5.4)	189.3 (4.7)	<0.001
Lower trunk inclination/ Lumbar angle, º	280.4 (4.0)	274.7 (4.5)	287.4 (5.0)	<0.001	276.9 (6.8)	275.0 (6.9)	289.3 (5.8)	<0.001
Sway angle, º	162.2 (3.7)	166.0 (4.5)	165.0 (4.5)	<0.001	163.2 (3.7)	171.9 (3.0)	165.0 (3.9)	<0.001

SD, standard deviation.

Table S3 Associations between standardized anthropometric measures at birth, 4 and 7 years of age and sagittal postural patterns in children assigned to the same pattern in both Mplus and Mclust, shown separately for girls and boys

	Sway pattern	Flat pattern			Neutral to Hyperlordotic pattern		
	OR	OR	95% CI	P	OR	95% CI	P
Girls, n=718							
Weight							
Birth	1	0.72	0.56-0.92	0.010	0.85	0.69-1.04	0.108
4 years	1	0.67	0.46-0.97	0.032	0.98	0.78-1.24	0.867
7 years	1	0.33	0.18-0.61	<0.001	1.06	0.68-1.64	0.796
Length/Height							
Birth	1	0.81	0.61-1.07	0.141	0.85	0.69-1.05	0.127
4 years	1	0.82	0.61-1.09	0.163	0.91	0.73-1.12	0.360
7 years	1	0.78	0.50-1.21	0.265	1.00	0.71-1.39	0.980
Ponderal index/BMI							
Birth	1	0.71	0.56-0.90	0.005	0.91	0.75-1.11	0.372
4 years	1	0.63	0.41-0.96	0.032	1.02	0.78-1.32	0.894
7 years	1	0.31	0.17-0.56	<0.001	1.05	0.69-1.58	0.830
	Sway to Neutral pattern	**Flat pattern**			**Hyperlordotic pattern**		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Boys, n=859							
Weight							
Birth	1	0.72	0.60-0.86	<0.001	0.87	0.49-1.54	0.628
4 years	1	0.78	0.62-0.97	0.027	1.15	0.86-1.54	0.356
7 years	1	0.51	0.35-0.75	0.001	0.99	0.49-2.02	0.979
Length/Height							
Birth	1	0.70	0.59-0.83	<0.001	0.67	0.48-0.93	0.016
4 years	1	0.91	0.75-1.10	0.321	0.99	0.67-1.46	0.945
7 years	1	1.07	0.76-1.52	0.685	2.51	0.79-8.06	0.120
Ponderal index/BMI							
Birth	1	0.94	0.77-1.14	0.506	1.43	1.01-2.01	0.043
4 years	1	0.72	0.56-0.92	0.009	1.23	0.92-1.64	0.169
7 years	1	0.43	0.29-0.65	<0.001	0.74	0.37-1.49	0.403

OR, odds ratio; CI, confidence interval; BMI, body mass index. Odds ratios are per one standard deviation higher anthropometric measure. Estimates at 4 years of age adjusted for birth measurements; estimates at 7 years adjusted for measurements at birth and 4 years.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract; PAGE 1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found; PAGE 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported; PAGE 4
Objectives	3	State specific objectives, including any prespecified hypotheses; PAGE 4
Methods		
Study design	4	Present key elements of study design early in the paper; PAGE 5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection; PAGE 5, 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up; PAGE 5
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed; N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable; PAGE 5, 6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group; PAGE 5, 6
Bias	9	Describe any efforts to address potential sources of bias; PAGE 6
Study size	10	Explain how the study size was arrived at; PAGE 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why; PAGE 6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding; PAGE 6, 7
		(*b*) Describe any methods used to examine subgroups and interactions; N/A
		(*c*) Explain how missing data were addressed; PAGE 5
		(*d*) If applicable, explain how loss to follow-up was addressed; N/A
		(*e*) Describe any sensitivity analyses; N/A
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed; PAGE 5
		(b) Give reasons for non-participation at each stage; PAGE 5
		(c) Consider use of a flow diagram; N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders; PAGE 8
		(b) Indicate number of participants with missing data for each variable of interest; N/A
		(c) Summarise follow-up time (eg, average and total amount); N/A
Outcome data	15*	Report numbers of outcome events or summary measures over time; TABLE 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were

		adjusted for and why they were included; TABLE 2
		(*b*) Report category boundaries when continuous variables were categorized; N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period; N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses; PAGE 10
Discussion		
Key results	18	Summarise key results with reference to study objectives; PAGE 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias, PAGE 15, 16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence; PAGE 13, 14, 15
Generalisability	21	Discuss the generalisability (external validity) of the study results; PAGE 15
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based; PAGE 17

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Associations of anthropometry since birth with sagittal posture at age seven in a prospective birth cohort: the Generation XXI study

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Keywords: Body size, sagittal standing posture, latent profile analysis, musculoskeletal epidemiology, child

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ABSTRACT

Objectives Adult sagittal posture is established during childhood and adolescence. A flattened or hypercurved spine is associated with poorer musculoskeletal health in adulthood. Although anthropometry from birth onwards is expected to be a key influence on sagittal posture design, this has never been assessed during childhood. Our aim was to estimate the association between body size throughout childhood with sagittal postural patterns at 7 years of age.

Design: Prospective cohort study.

Setting and participants: A subsample of 1029 girls and 1101 boys taking part in the 7-year-old follow-up of the birth cohort Generation XXI (Porto, Portugal) was included. We assessed the associations between anthropometric measurements (weight, height and body mass index) at birth, 4 and 7 years of age and postural patterns at age 7. Postural patterns were defined using latent profile analysis, a probabilistic model-based technique which allows for simultaneously including anthropometrics as predictors of latent profiles by means of logistic regression.

Results: Postural patterns identified were Sway, Flat and "Neutral to Hyperlordotic" in girls, and "Sway to Neutral", Flat and Hyperlordotic in boys; with flat and hyperlordotic postures representing a straightened and a rounded spine, respectively. In both girls and boys, higher weight was associated with lower odds of a Flat pattern compared to a Sway/"Sway to Neutral" pattern, with stronger associations at older ages: e.g. odds ratios (ORs) were 0.68 (95% CI: 0.53-0.88) per standard deviation (SD) increase in birth weight and 0.36 (95% CI: 0.19-0.68) per SD increase in weight at age 7 in girls, with similar findings in boys. Boys with higher ponderal index at birth were more frequently assigned to the Hyperlordotic pattern (OR=1.44 per SD; p=0.043).

Conclusions: Our findings support a prospective sculpting role of body size and therefore of load on musculoskeletal spino-pelvic structures, with stronger associations as children get older.

Strengths and limitations of this study

- This is the first study evaluating the role of anthropometric characteristics from birth through early childhood in shaping standing posture organization in children.
- We assessed a large population-based cohort of 1029 girls and 1101 boys who were followed prospectively up to age seven – the Generation XXI study.
- Postural patterns were defined using a probabilistic, model-based method – latent profile analysis – which included anthropometrics in addition to postural parameters.
- Although photogrammetry is the safest available method for postural evaluation of children, radiograms would have been the gold standard method for curvature measurement.
- Some degree of bias cannot be excluded, since children from the original cohort who were not included in this study were heavier and taller in the 4- and 7-year follow-up evaluations and this could have changed the association between anthropometrics and postural patterns.

INTRODUCTION

Sagittal standing posture evolves with growth and it contributes to the development of pediatric spinal deformities.(1-3) Posture is also crucial in the long term,(4-8) since mature sagittal spino-pelvic alignment is involved in a variety of orthopedic disorders,(2) such as degenerative disease and vertebral listhesis, as well as unspecific back pain and loss of function.(2, 9, 10)

In the first months after birth, profound morphological changes to the pelvis and spine take place.(4, 5, 8) There is an initial verticalization of the pelvis, followed by the rising of the lordotic curve in the lower back as the child begins to assume a sustained upright position, leading the sacrum to a more horizontal position.(4) Then, as walking abilities are acquired, constant dynamic adaptation takes place between pelvis shape, sagittal anatomy of the sacrum and physiologic curves of the spine, all of which gradually develop and interact during growth.(5, 8)

Children's anthropometry is expected to contribute to the mechanical framework of posture modulation, i.e. weight and height modulate gravitational actions and regulate the net direction of forces imposed on the immature spino-pelvic structures.(11) Plastic deformation of bones, discs and other spinal structures can occur,(12-14) as a result of reactive forces by muscles to ensure a stable center of mass.(4, 6, 8)

Overall, there is strong biomechanical support for the hypothesis that children's anthropometric trajectories have the potential to shape postural morphotypes. However, this has never been empirically tested in a pediatric population. Longitudinal, population-based evidence is essential to assess the potential effects of body size in promoting a healthy posture, and also, to identify periods in childhood when prevention and management of weight disorders may be more effective for avoiding long-term musculoskeletal consequences of posture misalignment in later life.

By using prospective data from the Generation XXI birth cohort, our aim was to estimate the associations of body size from birth onwards with sagittal postural patterns at 7 years of age.

METHODS

This study is based on the population-based birth cohort Generation XXI, which has been previously described at length.(15, 16) Briefly, participants were recruited between 2005 and 2006 at five public maternity units serving the six municipalities of the metropolitan area of Porto, Portugal. At birth, 8647 infants were enrolled in the cohort (91.4% of mothers invited agreed to participate). Four and seven years after birth, 69% and 68%, respectively, of all children recruited at birth were reevaluated by face-to-face interviews and physical examinations. During the 7 year-old follow-up, a subsample of 2998 children consecutively assessed between December 2012 and August 2013, and without a diagnosis of severe neurological impairment, was invited for sagittal standing posture evaluation. Of those, 80% agreed to participate and attended the scheduled assessment. After excluding 118 girls and 165 boys with missing information on anthropometrics, 1029 girls and 1101 boys were included in the present analysis. The Generation XXI cohort study was approved by the Ethics Committee of São João Hospital/University of Porto Medical School and complies with the Helsinki Declaration for medical research and with current national legislation, and was also approved by the National Committee of Data Protection. Written informed consent was obtained from all parents or legal guardians.

Birth weight and recumbent length at birth were retrieved from medical records by trained researchers. Ponderal index was then computed (weight in grams/length in centimetres^3 *100).(17) Additionally, weight and height were assessed at mean ages [standard deviation (SD)] 4.3 (0.3) and 7.1 (0.2) years. Weight was measured in light indoor clothing to the nearest 0.1kg using a digital scale (TANITA®) and height to the nearest 0.1cm using a wall stadiometer (SECA®). Body mass index was defined as weight in kilograms divided by height in squared meters.

Sagittal standing posture evaluation in both genders occurred at 7.4 years of age on average (SD: 0.4), 0 to 420 days after the anthropometric evaluation (50% of children evaluated within 61.5 days). Spherical retro-reflective markers were placed over anatomical landmarks on the right-side of the child's body: spinous processes of C7 and T12, anterior superior iliac spine, greater trochanter and lateral malleolus. Children were instructed to rest comfortably in habitual standing position with feet slightly apart, looking straight ahead and moving elbows forward.(18, 19) Floor markers were used to standardize children positioning. Full-body flash photographs of the sagittal right view of children were then acquired, after the examiner judged that the usual upright position had been attained. Angular measures formed by the lines drawn from the anatomical landmarks were obtained using the postural assessment software PAS/SAPO:(20) trunk, lumbar and sway angles (Figure 1). These individual parameters were used to define postural morphotypes through the clustering algorithm Mclust,(21) and a 3-pattern solution was obtained separately for girls and boys.(22) The geometric features (orientation, volume and shape) of the distributions of postural parameters were estimated from the data, and allowed to vary between clusters, or constrained to be the same for all the clusters.(23) We then selected the type of model and number of clusters with the smallest Bayesian Information Criterion (BIC).(24) This clustering procedure was chosen instead of the conventional heuristic methods (13, 19, 25-27) because it has the key advantage of allowing for testing different variances of angle measures within and across clusters.

In this paper, we replicated the 3-pattern solution using the software Mplus version 6.12 (Muthén & Muthén, Los Angeles, CA), because the previously used clustering algorithm in the R package Mclust does not allow joint estimation of postural clusters and their associations with anthropometrics in the same model. This one-step approach was used to account for uncertainty in the assignment of patterns and consequently to obtain unbiased estimates of the association between anthropometrics and posture.(28) Specifically, five latent profile models (different parametrizations of variance-covariance matrices) were tested in Mplus, with a fixed 3-class solution for each gender. We selected the model with the highest concordance (observed agreement) for pattern assignment compared with the solution previously found in Mclust.(22) Overall concordance was 70% in girls and 78% in boys (detailed information provided in online supplementary table S1).

In order to quantify the associations of weight, height/length and body mass/ponderal index at birth, 4 and 7 years of age with postural patterns, we re-ran the selected models simultaneously using multinomial logistic regression (i.e., including anthropometrics as predictors of postural latent profiles). Since the distributions of anthropometric variables change considerably during childhood, weight, height and body mass index were standardized within each age through *z*-score transformations, by subtracting the mean value in the sample from each individual's value and dividing the result by the sample standard deviation; units for associations are presented per SD. Estimates at 4 years of age were adjusted for birth measurements and estimates at 7 years were adjusted for measurements at birth and 4 years of age; i.e., weight estimates were adjusted for previous measurements of weight and similarly for height and body mass index.

RESULTS

There was no association between inclusion in this study and anthropometric characteristics at birth. However, included girls and boys were lighter and shorter at 4- and 7-year-old than those not included{mean differences 95% [confidence intervals (CI)]}: -0.29kg (-0.53;-0.05), -0.40kg (-0.81;0.01), -0.64cm (-1.02;-0.26) and -0.42cm (-0.83;-0.01) in girls, and -0.62kg (-0.83;-0.40), -0.81kg (-1.20;-0.43), -0.84cm (-1.21;-0.46), and -0.53cm (-0.92;-0.13) in boys; respectively.

Identification of postural patterns

Individual angular measures were different between genders (multivariate analysis of variance, $p<0.001$) with the main difference being higher lower trunk inclination/lumbar angle in girls (4.90º, $p<0.001$).

In girls, the selected model was the one restricting variance of angular measures to be the same within patterns (identity covariance matrix) but allowing them to vary across patterns, while homogeneous variance was constrained only across patterns in boys (diagonal matrix). The average latent class probabilities (for the most likely latent class membership) varied between 0.73-0.81 in girls and 0.72-0.86 in boys. Figure 2 displays the features of the three postural patterns (left panel) and a typical member of each pattern (right panel); angular values are provided in online supplementary table S2. The patterns were characterized by: increased trunk angle with backward tilt of the spine over the hips – decreased sway angle (Sway in girls and “Sway to Neutral” in boys given the high gender-specific prevalence of this pattern); straight spine with forward trunk lean – increased sway angle (Flat pattern in both genders); relatively increased lower trunk inclination and intermediate body sway (“Neutral to Hyperlordotic” pattern in girls); or extremely increased lower trunk inclination (Hyperlordotic pattern in boys).

Associations between anthropometry and sagittal posture

Table 1 and Figure 3 show descriptive analyses of the average anthropometric characteristics at birth and ages 4 and 7 years according to participants' most likely class assignment. Odds ratios (OR) and respective 95% CI for the associations between anthropometric traits and posture are shown in Table 2, using the Sway and "Sway to Neutral" patterns as reference given their intermediate overall anthropometric profile.

Girls

Girls with the lowest average weight at all ages belonged more frequently to the Flat pattern at age 7. Higher weight at birth was associated with the Sway pattern, while higher weight at ages 4 and 7 was related with a "Neutral to Hyperlordotic" pattern. Per one SD increase in weight at birth, the odds of a Flat pattern compared to Sway changed by 0.68 (95% CI: 0.53-0.88). This association became stronger with age, with an OR of 0.36 (95% CI: 0.19-0.68) at 7 years of age. The same directions of associations were observed for body mass/ponderal index, with an OR of 0.68 (95% CI: 0.51-0.89) for Flat compared to Sway pattern per SD increase in birth weight and 0.39 (95% CI: 0.21-0.70) per SD increase in weight at 7 years. Lower height was observed in children with the Flat pattern, with mean (SD) height at 7 years of age 122.45cm (4.91) for the Flat, 123.00cm (5.25) for the "Neutral to Sway" and 123.06cm (5.08) for the Sway pattern. Taller girls were 22% to 40% less likely to develop a Flat pattern at 7 years of age ($p \leq 0.080$), but these associations were weaker than those for weight/body mass index.

Boys

As in girls, higher birth weight in boys was associated with the "Sway to Neutral" pattern, while the highest weight thereafter was shown for those assigned to the Hyperlordotic pattern. Per SD increase in weight, the OR for a Flat pattern compared with Sway/Neutral

was 0.66 at birth and 0.33 at 7 years of age. The same decreasing trend for the Flat type was observed in body mass/ponderal index with the OR being stronger than for weight. Boys who were born with higher ponderal index were more likely to have the Hyperlordotic pattern (OR=1.44 per 0.27g/cm^3; p=0.043). Regarding length/height, boys showing a “Sway to Neutral” pattern were born 0.97 cm longer, but those assigned to a Hyperlordotic pattern reach a similar stature at 4 years old, and were 1.04 cm taller at 7 years of age, while shorter boys at birth were more likely to show a Flat pattern [OR=0.65 per SD (2.47cm); p=0.001].

Sensitivity analysis

Similar associations between anthropometry and sagittal posture were observed after restricting the sample to children assigned to the same postural pattern in both Mplus and Mclust (online supplementary table S3). Additionally, sensitivity analyses excluding twins (girls: n=46; boys: n=49) and children born small or large for gestational age(29) (small: n=153, large: n=45 in girls; small: n=155, large: n=27 in boys), and also including adjustment for gestational age at birth, did not change the previous overall patterns of associations. Furthermore, socioeconomic conditions at birth were not clearly associated with postural patterns at 7 years of age (maternal education: p=0.163 in girls and p=0.074 in boys; household income: p=0.436 in girls and p=0.038 in boys), and therefore we opted not to include them as confounders of the relationships between anthropometrics and postural patterns.

Table 1 Anthropometric characteristics at birth and ages 4 and 7 years according to sagittal standing postural patterns, shown separately for girls and boys

	All	Sway pattern	Flat pattern	Neutral to Hyperlordotic pattern
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Girls, n=1029				
Weight				
Birth, g	3102.1 (521.3)	3155.7 (507.5)	3063.1 (539.3)	3112.5 (511.2)
4 years, kg	17.9 (3.0)	18.0 (3.3)	17.3 (2.7)	18.3 (3.1)
7 years, kg	25.9 (5.4)	26.1 (5.7)	24.6 (4.6)	26.9 (5.6)
Length/Height, cm				
Birth	48.2 (2.3)	48.4 (2.1)	48.2 (2.5)	48.2 (2.3)
4 years	104.3 (4.5)	104.6 (4.5)	104.1 (4.4)	104.4 (4.6)
7 years	122.8 (5.1)	123.1 (5.1)	122.4 (4.9)	123.0 (5.3)
Ponderal index/BMI				
Birth, 100*(g/cm^3)	2.74 (0.26)	2.77 (0.26)	2.71 (0.26)	2.76 (0.27)
4 years, kg/m^2	16.36 (1.99)	16.36 (2.21)	15.92 (1.78)	16.67 (2.00)
7 years, kg/m^2	17.08 (2.67)	17.11 (2.79)	16.31 (2.30)	17.63 (2.75)

	All	Sway to Neutral pattern	Flat pattern	Hyperlordotic pattern
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Boys, n=1101				
Weight				
Birth, g	3198.9 (516.1)	3229.3 (491.0)	3064.1 (600.0)	3189.3 (519.0)
4 years, kg	17.8 (2.6)	17.9 (2.6)	17.3 (2.3)	18.4 (1.6)
7 years, kg	25.8 (4.7)	26.0 (4.8)	24.5 (3.9)	26.9 (4.1)
Length/Height, cm				
Birth	48.9 (2.5)	49.1 (2.3)	48.2 (3.1)	48.2 (2.9)
4 years	105.3 (4.5)	105.5 (4.5)	104.8 (4.6)	105.4 (3.3)
7 years	123.9 (5.3)	123.9 (5.4)	123.3 (5.3)	125.0 (5.4)
Ponderal index/BMI				
Birth, 100*(g/cm^3)	2.71 (0.27)	2.71 (0.27)	2.70 (0.28)	2.85 (0.36)
4 years, kg/m^2	16.00 (1.49)	16.06 (1.52)	15.71 (1.32)	16.55 (1.26)
7 years, kg/m^2	16.70 (2.19)	16.85 (2.24)	16.00 (1.79)	17.19 (1.98)

SD, standard deviation; BMI, body mass index.

Table 2 Associations between standardized anthropometric measures at birth, 4 and 7 years of age and sagittal postural patterns, shown separately for girls and boys

	Sway pattern	Flat pattern			Neutral to Hyperlordotic pattern		
	OR	OR	95% CI	P	OR	95% CI	P
Girls, n=1029							
Weight							
Birth	1	0.68	0.53-0.88	0.003	0.83	0.64-1.07	0.154
4 years	1	0.53	0.35-0.79	0.002	1.32	0.84-2.07	0.228
7 years	1	0.36	0.19-0.68	0.002	1.89	0.87-4.10	0.110
Length/Height							
Birth	1	0.78	0.61-1.01	0.056	0.84	0.67-1.05	0.133
4 years	1	0.76	0.57-1.02	0.070	0.93	0.70-1.24	0.618
7 years	1	0.60	0.34-1.06	0.080	1.20	0.38-3.76	0.751
Ponderal index/BMI							
Birth	1	0.68	0.51-0.89	0.005	0.92	0.72-1.18	0.534
4 years	1	0.49	0.30-0.78	0.003	1.34	0.81-2.21	0.249
7 years	1	0.39	0.21-0.70	0.002	1.63	0.89-2.97	0.111
	Sway to Neutral pattern	**Flat pattern**			**Hyperlordotic pattern**		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Boys, n=1101							
Weight							
Birth	1	0.66	0.51-0.87	0.003	0.92	0.56-1.51	0.745
4 years	1	0.62	0.35-1.09	0.099	1.93	1.43-2.60	<0.001
7 years	1	0.33	0.11-0.99	0.048	1.88	0.90-3.92	0.092
Length/Height							
Birth	1	0.65	0.50-0.84	0.001	0.70	0.49-0.998	0.049
4 years	1	0.86	0.65-1.14	0.300	1.00	0.59-1.72	0.993
7 years	1	1.39	0.70-2.74	0.349	2.33	1.10-4.98	0.028
Ponderal index/BMI							
Birth	1	0.93	0.73-1.19	0.566	1.44	1.01-2.04	0.043
4 years	1	0.51	0.25-1.03	0.061	2.08	1.34-3.25	0.001
7 years	1	0.23	0.11-0.51	<0.001	1.50	0.88-2.56	0.139

OR, odds ratio; CI, confidence interval; BMI, body mass index.
Odds ratios are per one standard deviation higher anthropometric measure. Estimates at 4 years of age adjusted for birth measurements; estimates at 7 years adjusted for measurements at birth and 4 years.

DISCUSSION

In this population-based birth cohort we analyzed the associations of anthropometrics at different ages during childhood with sagittal posture at 7 years of age. In both genders, children who remained lighter had an increased likelihood of a Flat posture, and this relationship became stronger with increasing age. Concordantly, being heavier at 4 and 7 years old was associated with a posture characterized by increased lower trunk inclination/lumbar angle: "Neutral to Hyperlordotic" in girls and Hyperlordotic in boys. Shorter girls tended to present a Flat posture and taller boys a Hyperlordotic pattern.

This is the first study evaluating the role of anthropometric characteristics from birth and throughout childhood in shaping standing posture organization. Our findings showed that adiposity was inversely related with a flattened spine, and concordantly, directly associated with a hyperlordotic posture. Only one other research group evaluated the relation between anthropometrics and patterns of standing posture before skeletal maturity is reached(13, 19) and cross-sectional analyses have shown that 14-year-old adolescents with a Flat pattern had the lowest weight/body mass index, while those in the Hyperlordotic pattern were the fattest.(19) Similarly, children in the Flat pattern less frequently belonged to ascending, high or very high trajectories of body size defined from 3 to 14 years of age, while those in the Hyperlordotic pattern were at higher risk of showing overweight trajectories.(13)

Classification systems of sagittal standing posture have been attempted in young adolescent girls(26) and boys(25, 27). However, different procedures for the definition of postural parameters preclude comparisons with our work. Particularly, children have been classified using a three-point Likert scale of uncorrected posture based on the horizontal deviations of four body landmarks in respect to a vertical line(27) and three global patterns (based on three angles with respect to the vertical) with different magnitude of spinal curves being observable within each pattern.(25, 26) Our approach was to model postural patterns following three criteria: a) to use postural parameters as continuous variables as a better representation of the natural spectrum of posture, b) to search for variants comparable with those published in adolescents and adults, in a life course perspective, and c) to use a model-based method that allowed for testing different variances of angle measures within and across clusters. Nevertheless, our patterns are comparable to those published by Dolphens *et al*,(25, 26) at least regarding the suggested global alignment classifications: neutral, sway-back and leaning-forward. In comparison to our classification and focusing on their features regarding the sway angle those would to some extent correspond to the Neutral, Sway and Flat patterns, respectively.

Our results during childhood are also consistent with cross-sectional findings in adult populations(12, 14, 30) suggesting that higher adiposity levels during the development of posture is crucial for the shape and orientation of the spino-pelvic unit, and implying a role of anthropometrics at early ages in shaping overall postural patterns during adulthood. In adults, both a flattened or hypercurved posture generally represent a poor postural health status on the basis of their relation with back pain,(31, 32) and also by contributing to the etiology of pattern-specific spine pathologies, such as discopathy and vertebral listhesis, respectively.(11, 33, 34) In contrast with later stages of life,(13, 14, 19, 30, 33) a neutral labelling was not considered appropriate to characterize postural patterns in children, but non-ideal patterns were already differentiated in childhood (Flat and Hyperlordotic) and it seems plausible that they will progressively mature and partially track over the life course. In terms of the clinical interpretation of our findings, we may postulate that low birth weight may contribute to a flat back that then may increase the risk of idiopathic scoliosis,(1) while higher weight at 4 and 7 years of age may contribute to a hyperlordotic posture that then may predispose to Scheuermann's kyphosis.(3)

In both genders, anthropometric characteristics at ages 4 and 7 were more strongly associated with posture at 7 than body size at birth, as reflected by the age-related increase in the magnitude of associations between weight and the Flat pattern, and also the association of weight with increased lumbar curve observed only at ages 4 and 7. Previous studies describing the changes in sagittal posture throughout different stages of growth,(1, 4-8) highlighted the potential effect of morphologic anthropometric-related changes to be stronger during walking ages and potentially having a cumulative mechanical effect over time. Our observations at different ages in childhood support a cumulative result of weight bearing on spino-pelvic structures, and that is the reason why our work focused on children at 7 years old. Although most changes in sagittal posture occur during the first months after birth, with the acquisition of upright position and walking abilities,(4, 5, 8) it is important to allow sagittal curves to develop during growth through the influence of specific anthropometric mechanical environment and allow that different morphotypes could be distinguished within the sample. An additional major concern was to focus on prepubertal children to ensure homogeneity with regard to sexual development.(35)

Although height was associated with postural patterns, associations were generally weaker than for weight. Consequently, the latter seems to be the main driver of the direction and magnitude of the associations seen for body mass index; as expected for a mechanical mechanism. However, this was not the case for the Hyperlordotic pattern in boys, where height showed a stronger association with posture than weight. This particular relation between height/length and the Hyperlordotic pattern may be a consequence of an anterior displacement of the center of gravity related to an increased weight of the upper body as the child gets older.(7) In order to reestablish a stable basis of support, the lumbar curve increases by means of higher vertebral growth, reflected in height, and this mechanism seems to be responsible for restoring sagittal balance.(7) In agreement with this hypothesis, the

Hyperlordotic pattern was characterized by a substantially increased lower trunk inclination/lumbar angle. However, this study was not designed to investigate this pattern-specific association and the usefulness of length/height to predict the presence of this particular pattern in school-aged boys deserves future specific exploration. Interestingly, the same average ascending trajectory of weight in the Hyperlordotic pattern in boys was observed for the "Neutral to Hyperlordotic" pattern in girls, even though with less extreme values of weight, which supports a functional aggregation of neutral and hyperlordotic postures in school-aged girls.

Some limitations of this work should be highlighted. Children from the original cohort not included in this study were heavier and taller during the 4- and 7-year follow-up. Bias of our analysis is unlikely, as the association between anthropometry and postural patterns is unlikely to differ between included and excluded children. Although photogrammetry is the safest available method for postural evaluation of children,(14, 18, 36) radiographies directly allow us to measure spinal curvatures and are the gold-standard which would have allowed more robust conclusions. Moreover, despite our efforts to standardize the position of the body and of the arms in particular, enough variability may have remained that could have influenced trunk position and therefore overall sagittal posture. Additionally, the present postural patterns have not yet been reproduced in other samples and therefore future research is needed to confirm validation of the postural classifications. Furthermore, latent profile analysis in Mplus was performed in this study, although Mclust(21) has been previously used for postural pattern identification.(22) Since the two clustering methods use different estimation algorithms,(37) classifications were not completely overlapping (online supplementary table S1). However, the solutions between the two clustering algorithms have been initially compared: while the same 3-pattern solution was obtained in boys, for girls, Mplus suggested two and Mclust three patterns (based on the smallest BIC). Based on patterns' interpretability and also because Mplus solution aggregates two of the three groups suggested by Mclust, we opted to use three class models for both genders in order to replicate the solution provided by Mclust.(22) Despite this, our conclusions should not be meaningfully affected since a good concordance between final models was obtained (≥70%), as well as comparable face validity of patterns (i.e., their postural meaning). Our findings were further supported by sensitivity analysis restricted to children assigned to the same postural pattern in both Mplus and Mclust; as shown in online supplementary table S3.

This is the first study evaluating the association of different measures of anthropometry and posture in children, using a large sample of children recruited from a population-based cohort with considerable variability both in exposure and outcome. Additionally, to examine overall postural patterns instead of isolated parameters is a key advantage because patterns allow a better characterization of overall posture, permitting the analysis to account for the relationships between different anatomical regions.(14, 19, 34) Our work used, for the first time, a probability based posture classification (i.e., considering posterior probabilities of pattern membership), in order to avoid bias in the estimates of associations between anthropometry and postural patterns.(28)

We quantified the associations of early anthropometric features with sagittal posture during childhood and we found that children who were lighter from the time of birth were more likely to develop a flattened posture at 7 years of age, while being heavier was associated with a hyperlordotic posture in both genders. The mechanical load imposed by body size seems to have a cumulative sculpting role throughout the first decade of life, especially after walking abilities are acquired.

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Contributors:

FAA, RL, NA and HB collaborated in the conceptualization, design and acquisition of data. FAA, RL, AJS, JH, NA, KT, LDH and HB collaborated in the analysis and interpretation of data. FAA drafted the initial manuscript. RL, AJS, JH, NA, KT, LDH and HB critically reviewed the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Conflict of Interest:

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data Sharing Statement:

No additional data are available.

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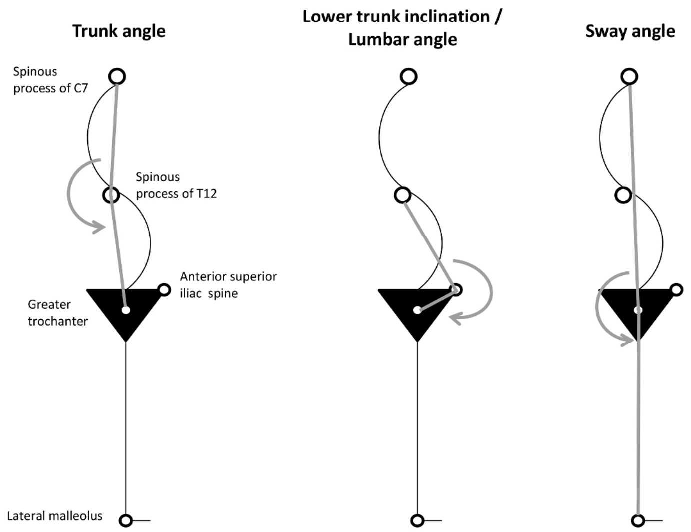
Figure 1 Individual angular measures used to identify sagittal postural patterns (using Mplus latent profile analysis).

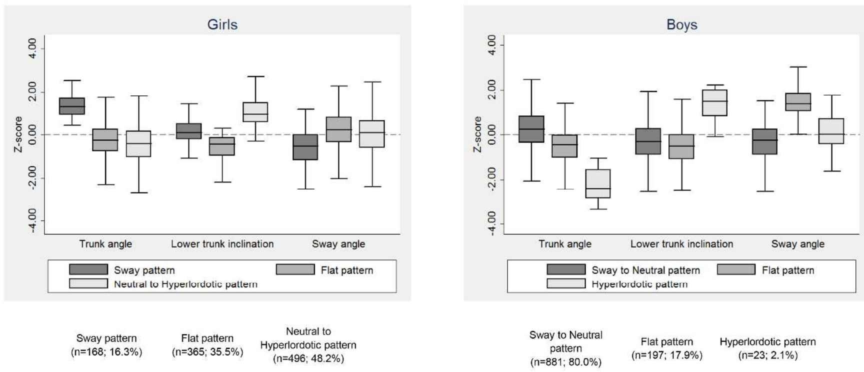
Figure 2 Box plots showing the distribution (median, inter-quartile range and range) of each separate postural angle, standardized to have a mean of zero and standard deviation of one, across sagittal standing postural patterns, shown separately for girls and boys.

Figure 3 Standardized cross-sectional means of anthropometric characteristics at birth and ages 4 and 7 years across sagittal standing postural patterns, shown separately for girls and boys.



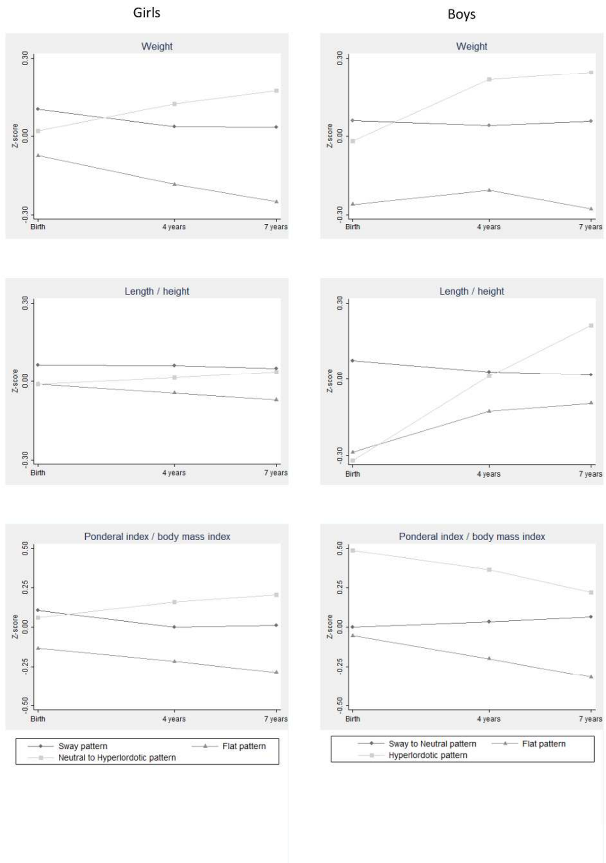
Individual angular measures used to identify sagittal postural patterns (using Mplus latent profile analysis).

254x190mm (300 x 300 DPI)



Box plots showing the distribution (median, inter-quartile range and range) of each separate postural angle, standardized to have a mean of zero and standard deviation of one, across sagittal standing postural patterns, shown separately for girls and boys.

338x190mm (300 x 300 DPI)



Standardized cross-sectional means of anthropometric characteristics at birth and ages 4 and 7 years across sagittal standing postural patterns, shown separately for girls and boys.

190x338mm (300 x 300 DPI)

Supplementary material

Table S1 Comparison of Mplus and Mclust sagittal postural patterns assignment, shown separately for girls and boys

		Mplus		
		Sway pattern	Flat pattern	Neutral to Hyperlordotic pattern
		n (%)	n (%)	n (%)
Girls, n=1029				
Mclust	Sway pattern	156 (92.9)	42 (11.5)	80 (16.1)
	Flat pattern	12 (7.1)	172 (47.1)	26 (5.2)
	Neutral to Hyperlordotic pattern	0 (0.0)	151 (41.4)	390 (78.6)
		Mplus		
		Sway to Neutral pattern	**Flat pattern**	**Hyperlordotic pattern**
		n (%)	**n (%)**	**n (%)**
Boys, n=1101				
Mclust	Sway to Neutral pattern	643 (73.0)	0 (0.0)	0 (0.0)
	Flat pattern	207 (23.5)	195 (99.0)	2 (8.7)
	Hyperlordotic pattern	31 (3.5)	2 (1.0)	21 (91.3)

Table S2 Postural parameters in sagittal postural patterns, shown separately for girls and boys

	Girls				Boys			
	Sway pattern (n=168, 16.3%)	Flat pattern (n=365, 35.5%)	Neutral to Hyperlordotic pattern (n=496, 48.2%)		Sway to Neutral pattern (n=881, 80.0%)	Flat pattern (n=197, 17.9%)	Hyperlordotic pattern (n=23, 2.1%)	
	Mean (SD)	Mean (SD)	Mean (SD)	P	Mean (SD)	Mean (SD)	Mean (SD)	P
Trunk angle, º	213.2 (3.5)	202.7 (5.0)	201.2 (5.9)	<0.001	205.9 (5.8)	200.9 (5.4)	189.3 (4.7)	<0.001
Lower trunk inclination/ Lumbar angle, º	280.4 (4.0)	274.7 (4.5)	287.4 (5.0)	<0.001	276.9 (6.8)	275.0 (6.9)	289.3 (5.8)	<0.001
Sway angle, º	162.2 (3.7)	166.0 (4.5)	165.0 (4.5)	<0.001	163.2 (3.7)	171.9 (3.0)	165.0 (3.9)	<0.001

SD, standard deviation.

Table S3 Associations between standardized anthropometric measures at birth, 4 and 7 years of age and sagittal postural patterns in children assigned to the same pattern in both Mplus and Mclust, shown separately for girls and boys

	Sway pattern	Flat pattern			Neutral to Hyperlordotic pattern		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Girls, n=718							
Weight							
Birth	1	0.72	0.56-0.92	0.010	0.85	0.69-1.04	0.108
4 years	1	0.67	0.46-0.97	0.032	0.98	0.78-1.24	0.867
7 years	1	0.33	0.18-0.61	<0.001	1.06	0.68-1.64	0.796
Length/Height							
Birth	1	0.81	0.61-1.07	0.141	0.85	0.69-1.05	0.127
4 years	1	0.82	0.61-1.09	0.163	0.91	0.73-1.12	0.360
7 years	1	0.78	0.50-1.21	0.265	1.00	0.71-1.39	0.980
Ponderal index/BMI							
Birth	1	0.71	0.56-0.90	0.005	0.91	0.75-1.11	0.372
4 years	1	0.63	0.41-0.96	0.032	1.02	0.78-1.32	0.894
7 years	1	0.31	0.17-0.56	<0.001	1.05	0.69-1.58	0.830
	Sway to Neutral pattern	**Flat pattern**			**Hyperlordotic pattern**		
	OR	**OR**	**95% CI**	**P**	**OR**	**95% CI**	**P**
Boys, n=859							
Weight							
Birth	1	0.72	0.60-0.86	<0.001	0.87	0.49-1.54	0.628
4 years	1	0.78	0.62-0.97	0.027	1.15	0.86-1.54	0.356
7 years	1	0.51	0.35-0.75	0.001	0.99	0.49-2.02	0.979
Length/Height							
Birth	1	0.70	0.59-0.83	<0.001	0.67	0.48-0.93	0.016
4 years	1	0.91	0.75-1.10	0.321	0.99	0.67-1.46	0.945
7 years	1	1.07	0.76-1.52	0.685	2.51	0.79-8.06	0.120
Ponderal index/BMI							
Birth	1	0.94	0.77-1.14	0.506	1.43	1.01-2.01	0.043
4 years	1	0.72	0.56-0.92	0.009	1.23	0.92-1.64	0.169
7 years	1	0.43	0.29-0.65	<0.001	0.74	0.37-1.49	0.403

OR, odds ratio; CI, confidence interval; BMI, body mass index. Odds ratios are per one standard deviation higher anthropometric measure. Estimates at 4 years of age adjusted for birth measurements; estimates at 7 years adjusted for measurements at birth and 4 years.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract; PAGE 1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found; PAGE 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported; PAGE 4
Objectives	3	State specific objectives, including any prespecified hypotheses; PAGE 4
Methods		
Study design	4	Present key elements of study design early in the paper; PAGE 5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection; PAGE 5, 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up; PAGE 5
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed; N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable; PAGE 5, 6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group; PAGE 5, 6
Bias	9	Describe any efforts to address potential sources of bias; PAGE 6
Study size	10	Explain how the study size was arrived at; PAGE 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why; PAGE 6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding; PAGE 6, 7
		(*b*) Describe any methods used to examine subgroups and interactions; N/A
		(*c*) Explain how missing data were addressed; PAGE 5
		(*d*) If applicable, explain how loss to follow-up was addressed; N/A
		(*e*) Describe any sensitivity analyses; N/A
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed; PAGE 5
		(b) Give reasons for non-participation at each stage; PAGE 5
		(c) Consider use of a flow diagram; N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders; PAGE 8
		(b) Indicate number of participants with missing data for each variable of interest; N/A
		(c) Summarise follow-up time (eg, average and total amount); N/A
Outcome data	15*	Report numbers of outcome events or summary measures over time; TABLE 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were

		adjusted for and why they were included; TABLE 2
		(*b*) Report category boundaries when continuous variables were categorized; N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period; N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses; PAGE 10
Discussion		
Key results	18	Summarise key results with reference to study objectives; PAGE 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias, PAGE 15, 16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence; PAGE 13, 14, 15
Generalisability	21	Discuss the generalisability (external validity) of the study results; PAGE 15
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based; PAGE 17

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.