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Sagittal standing posture and relationships with anthropometrics and body composition during childhood

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ABSTRACT

Background: Anthropometry and body composition are plausible influences on pediatric sagittal standing posture. Despite that, the relationship of anthropometrics since birth and body composition with individual postural parameters in children has never been assessed.
Research question: To assess the associations between anthropometrics since birth and body composition parameters, and angles of sagittal standing posture in children.
Methods: The sample included 1021 girls and 1096 boys, evaluated in the population-based birth cohort Generation XXI, Portugal. Weight and height were obtained at birth, 4 and 7 years of age. At age 7, total body less head fat/fat-free mass and bone properties were estimated from whole body dual energy X-ray absorptiometry scans and posture was assessed through right-side photographs during habitual standing with retro-reflective markers placed on body landmarks.
Results: Girls showed increased values of lumbar angle, head and neck flexion, and craniocervical angle with the largest mean (standard deviation) difference in lumbar angle [281.7° (7.4) vs. 276.8° (7.1) in boys, $p < 0.001$]. In both genders, weight and body mass index were weakly associated with lumbar angle: $0.24 \geq r \leq 0.31$ in girls and $0.16 \geq r \leq 0.26$ in boys, all $p < 0.001$. Fat and fat-free mass and bone mineral density were weakly associated with lumbar angle in both genders.
Significance: Our study showed clear postural heterogeneity between girls and boys in early ages. Lumbar angle is likely to be the single most relevant proxy of overall posture based on the associations with the exposures reported in this study.

1. Background

The development of sagittal posture during childhood and adolescence is crucial for the attainment of adult spino-pelvic alignment [1,2]. In turn, sagittal spino-pelvic alignment is associated with back pain and physical disability in adults [3], and sagittal imbalance is the strongest postural predictor of functional loss and dependency in older ages [4].

Anthropometry and body composition are likely to shape pediatric sagittal standing posture [5–8]. Their effects are supposedly related with the natural maturation of the musculoskeletal system in children, with fat leading to plastic changes in muscles, bones and other structures that prevail throughout the life course [5–8]. We have shown that body size since birth is associated with postural patterns defined at 7 years of age [9], where weight and height theoretically regulate the net direction of gravitational forces imposed on the spino-pelvic structures [10]. Furthermore, there is a strong rationale for a relation between bone physical properties and posture, as a result of a shared mechanical environment defined by anthropometrics. We also showed that bone mineral content and density were associated with postural patterns in the same direction of anthropometry, i.e., lower bone mineral density was observed in a flat posture while a hyperlordotic posture showed increased density [11]. However, the relationship of anthropometrics since birth and body composition with individual postural parameters in children has never been evaluated, and it is unknown whether one or more specific angular parameters contribute more strongly to the associations previously observed for postural patterns. Additionally,

Abbreviations: CI, confidence intervals; SD, standard deviation

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differences in sagittal standing posture seem to exist between girls and boys in young adolescence [12,13], as gender-specific relationships between age and postural measures were also observed [2]. Therefore, our aim in this study was to quantify the associations between anthropometrics and body composition parameters, and sagittal standing posture parameters measured at 7 years of age in a population-based birth cohort of children, for both girls and boys.

2. Methods

2.1. Subjects

This study was embedded in the population-based birth cohort Generation XXI, described in detail elsewhere [14,15]. A total of 8647 live born infants were enrolled between April 2005 and August 2006 at all five public maternity units that cover the six municipalities of the metropolitan area of Porto (Northern Portugal). At birth, 91.4% of the invited mothers agreed to participate. Invitations to follow-up evaluations were based on children's date of birth. Four and seven years after birth, 86% and 80% of the cohort's children were re-evaluated, respectively. A specific musculoskeletal assessment was held for a subsample of 2998 children attending the 7-year-old follow-up between December 2012 and August 2013 and without a diagnosis of severe neurological impairment. Of those invited, 80.5% agreed to participate and attended the scheduled assessment in which sagittal posture and bone physical properties were evaluated. We excluded 126 girls and 170 boys due to missing information in at least one of the exposure variables considered in the present work. A final sample of 1021 girls and 1096 boys was analyzed. Ethical approval was obtained from the Ethics Committee of São João Hospital/University of Porto Medical School, and the study protocol was registered with the National Committee for Data Protection.

2.2. Anthropometric variables

Birth weight and recumbent length at birth were retrieved from medical records and ponderal index was computed (weight in grams/length in centimetres^3 * 100) [16]. Anthropometric measurements were collected by trained examiners in further waves of assessment at mean ages (standard deviation, SD) 4.3 (0.3) and 7.4 (0.4). Weight was measured in light indoor clothing to the nearest 0.1 kg using a digital scale (TANITA® at 4 years and Xinyu Electronic Company, Limited at 7 years) and height to the nearest 0.1 cm using a wall stadiometer (SECA®). Body mass index was defined as weight (kg) divided by height squared (m^2).

2.3. Body composition parameters

A Hologic device (Discovery QDR® 4500 W, Hologic Inc., Bedford, MA, USA) was used to measure total-body-less-head fat and fat-free mass. Fat and fat-free mass indices were calculated by dividing fat mass and fat-free mass (kg) by height squared (m^2) [17]. Also, total-body-less-head bone area (cm^2), bone mineral content (BMC, g) and bone mineral density (BMD, g/cm^2) were obtained. As recommended, total-body-less-head rather than total body measurements were used because the head is less responsive to environmental stimuli [18]. Daily calibration of the equipment was conducted using the Hologic Anthropomorphic Spine Phantom, i.e. a quality control tool containing a defined amount of material to originate a stable bone density measurement and allowing to assess and calibrate the ability of the equipment to reproduce that reference measurement. Nine trained radiology technicians were involved in evaluations. Two of the examiners performed 83% of all the whole-body scans.

2.4. Sagittal standing posture

Sagittal standing posture was evaluated by quantitative assessment of photographs of the children's sagittal right view [9], a method validated in other populations with acceptable reproducibility [19–22]. Spherical retro-reflective markers were placed over anatomical landmarks on the right side of the child's body by one of two qualified health professionals: lateral canthus of the eye, tragus, anterior border of the acromium, spinous processes of C7 and T12, anterior superior iliac spine, greater trochanter, lateral epicondyle of the femur and lateral malleolus. Floor markers were used to standardize the placement of the right side of the body 50 cm from the wall. Children were barefoot and wearing underwear or swimwear. Each child was asked to assume their habitual standing position with feet slightly apart, looking straight ahead and moving elbows forward, as previously described in order to standardize position of participants [8,20]. Full-body flash photographs were then acquired with a Canon PowerShot A2300 camera (4608 × 3456 pixels; Canon USA Inc, Arlington, Virginia) attached to a 60-cm-high tripod that was fixed on the floor and placed perpendicularly to the right side of the child's body (distance from the camera: 150 cm). The zoom feature of the camera was not used. The camera was kept at the same height for all children, an option which resulted from a trade-off between perspective error and reproducibility. We opted for a fixed height to ensure the reproducibility of the protocol between children, despite of children's variability in height. Given our large sample size and intensive evaluation schedule, individual adaptation to each child would increase the probability of errors in the remaining dimensions of system positioning and potentially compromise our standardized protocol, which is particularly important in photogrammetry.

We followed the protocol suggested by Perry et al. [20] since it prioritizes the quantification of the relative position of body segments, and therefore, optimizes photographic reliability [20–22]. Angular measures formed by the lines drawn between the anatomical landmarks were obtained using the postural assessment software PAS/SAPO (Laboratory of Biomechanics and Motor Control, Universidade Federal do ABC, SP, Brazil) [19] and using a plumb line with two polystyrene circumferences as reference to allow vertical angle offset during the digitization of photographs (exemplified in Fig. 1). Trunk, lumbar and sway angles (panels F, G and I in Fig. 1) completely characterize thoraco-lumbo-pelvic sagittal alignment in the standing position and were the measures previously used to identify sagittal postural patterns in children [9]. Additionally, head flexion, neck flexion, craniocervical angle, cervicothoracic angle, thoracic flexion and pelvic tilt were also measured. We excluded posture distances from the present analysis due to the magnitude of measurement error related to both inter-rater effects and anthropometrics [20].

2.5. Statistical analysis

Each child was evaluated by only one posture examiner. We assumed random allocation by examiner, meaning that differences in distribution of postural measurements could be attributed to observer effects [23]. Therefore, the mean calibration method considering the measurements of the first examiner as the reference was performed, i.e., adding the difference between means obtained by each examiner to the individual values of each child evaluated by the second examiner [24].

Comparisons of anthropometric and postural parameters between genders were performed using independent samples t-test. Relationships of anthropometric variables, age and body composition parameters with angle measures of sagittal posture were assessed using Pearson's correlation coefficients, and linear regression models were computed to quantify β coefficients and respective 95% confidence intervals (CI). As exposures, we selected anthropometric measurements collected at birth, 4 and 7 years of age. To calculate correlation coefficients, we used only one time point for each exposure at a time,

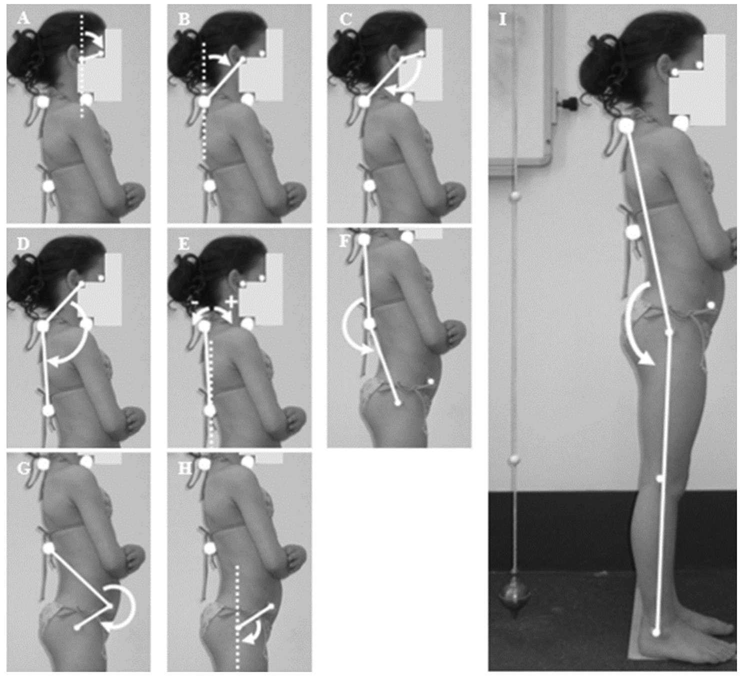

Fig. 1. Definition of angles describing sagittal standing posture: (A) Head flexion; (B) Neck flexion; (C) Craniocervical angle; (D) Cervicothoracic angle; (E) Thoracic flexion; (F) Trunk angle; (G) Lumbar angle; (H) Pelvic tilt; (I) Sway angle. Dashes lines indicate the vertical.

regardless of growth trajectory throughout follow-up. Body composition and angle measures of sagittal posture were collected only at the 7-year follow-up wave. Due to the fact that the follow-ups were not conducted at the same exact chronological age for all children, we opted to account for potential age-related confounding by computing linear regression coefficients adjusted for exact age at the 7-year-old evaluation wave, i.e. the time of outcome assessment. Analyses were performed separately for each wave of assessment (0, 4 and 7 years) and also for each gender. Data were analyzed using STATA® (version 11.1).

3. Results

Girls were born lighter than boys [mean (SD): 3102.6 g (522.6) vs. 3197.6 g (516.5), $p < 0.001$], but showed similar weight at 4 and 7 years of age. However, girls were shorter in all evaluations and consequently showed higher body mass/ponderal index than boys: average differences varying from 0.03 g/cm^3 at birth to 0.42 kg/m^2 at 7 years of age (Table 1).

Girls showed higher fat and lower fat-free mass compared to boys: mean (SD) of 8.5 kg (3.6) vs. 6.9 kg (3.1), $p < 0.001$; and of 14.7 kg (2.3) vs. 15.8 kg (2.3), $p < 0.001$; respectively. While bone area was similar between genders, girls showed lower BMC and BMD (average differences of 8.5 g and 0.01 g/cm^2, respectively).

With respect to angle measures of sagittal standing posture (Table 1), girls showed increased values of lumbar, head and neck flexion, and craniocervical angles with the largest mean (SD) difference in lumbar angle: 281.7° (7.4) vs. 276.8° (7.1), $p < 0.001$. However, girls showed decreased trunk and cervicothoracic angles, thoracic flexion and pelvic tilt, with the largest mean (SD) difference in pelvic tilt: 128.6° (7.1) vs. 132.4° (7.0), $p < 0.001$. Similar sway angles were observed between genders.

3.1. Girls

Table 2 shows the correlations between exposure variables and angular measures of sagittal posture in girls. Weight and body mass index were weakly associated with lumbar angle: $r = 0.24$ and $r = 0.27$ at 4 years, and $r = 0.28$ and $r = 0.31$ at 7 years of age, respectively, all $p < 0.001$. Fat and fat-free mass, BMC and BMD were also weakly but positively associated with lumbar angle: $r = 0.29$, $r = 0.20$, $r = 0.15$, $r = 0.22$, respectively; all $p < 0.001$.

Height and bone area were very weakly associated with cervicothoracic angle: $r = 0.16$ at 4 years and $r = 0.20$ at 7 years (both $p < 0.001$) for height, and $r = 0.18$ ($p < 0.001$) for bone area.

Age was inversely associated with head flexion ($\beta = -5.09$; 95% CI: −6.53 to −3.65), and positively associated with cervicothoracic angle ($\beta = 2.85$; 95% CI: 1.81–3.90); independently of all measurements of weight, all measurements of height, fat and fat-free mass, bone area and BMC (Table 4). Additionally, age was positively associated with sway angle ($\beta = 1.43$; 95% CI: 0.54–2.32).

3.2. Boys

Table 3 shows the correlations between exposure variables and individual angle measures of sagittal posture in boys. As in girls, weight and body mass index were weakly associated with lumbar angle: $r = 0.16$ and $r = 0.22$ at the 4 years follow-up, and $r = 0.21$ and $r = 0.26$ at 7 years of age (respectively), all $p < 0.001$. Fat and fat-free mass were also weakly associated with lumbar angle in boys ($r = 0.24$ and $r = 0.13$, respectively, both $p < 0.001$).

Height and bone area were slightly associated with cervicothoracic angle: $r = 0.17$ at 4 years and $r = 0.23$ at 7 years (both $p < 0.001$) for height, and $r = 0.20$ ($p < 0.001$) for bone area. Additionally, in boys, height was very weakly and inversely associated with neck flexion, an association which became slightly stronger with age up to $r = -0.16$ ($p < 0.001$) at age 7.

Age was inversely associated with head flexion ($\beta = -3.31$; 95% CI: −4.82 to −1.80), and positively associated with cervicothoracic angle ($\beta = 2.77$; 95% CI: 1.77–3.77); independently of all measurements of weight, height, fat and fat-free mass, bone area and BMC (Table 4). Additionally, age was positively associated with sway angle in boys ($\beta = 2.44$; 95% CI: 1.52–3.36).

Table 1
Anthropometric variables, body composition parameters and angles of sagittal standing posture, shown separately for girls and boys.

	All (n = 2117)		Girls (n = 1021)				Boys (n = 1096)				P
	Mean	SD	Mean	SD	Min	Max	Mean	SD	Min	Max	
Birth											
Weight, g	3151.8	521.5	3102.6	522.6	940.0	5200.0	3197.6	516.5	925.0	4460.0	< 0.001
Length, cm	48.6	2.4	48.3	2.4	35.0	54.0	48.9	2.5	36.5	55.5	< 0.001
Ponderal index, 100*(g/cm^3)	2.72	0.27	2.74	0.26	1.52	3.74	2.71	0.27	1.89	5.11	0.017
4 years											
Weight, kg	17.9	2.8	17.9	3.0	11.8	35.4	17.8	2.6	10.4	37.7	0.665
Height, cm	104.9	4.5	104.3	4.5	87.8	120.2	105.4	4.5	91.2	120.7	< 0.001
BMI, kg/m^2	16.17	1.75	16.35	1.98	12.40	28.72	16.00	1.49	11.53	27.40	< 0.001
7 years											
Exact age, years	7.4	0.4	7.4	0.4	6.9	8.6	7.4	0.4	6.9	8.7	0.487
Weight, kg	27.1	5.5	27.3	5.9	16.7	60.5	27.0	5.1	16.9	51.0	0.278
Height, cm	124.6	5.6	124.1	5.5	105.0	142.7	125.1	5.6	107.4	147.9	< 0.001
BMI, kg/m^2	17.38	2.62	17.60	2.84	12.69	32.81	17.18	2.38	12.43	29.86	< 0.001
Fat mass, kg	7.7	3.4	8.5	3.6	2.8	29.2	6.9	3.1	2.4	24.8	< 0.001
Fat-free mass, kg	15.3	2.4	14.7	2.3	9.2	25.6	15.8	2.3	10.0	25.9	< 0.001
FMI, kg/m^2	4.88	1.98	5.43	2.06	1.77	15.82	4.36	1.75	1.66	14.50	< 0.001
FFMI, kg/m^2	9.78	0.95	9.47	0.93	7.31	13.90	10.07	0.88	7.80	13.28	< 0.001
Bone area, cm^2	961.0	64.1	962.8	62.5	778.9	1211.1	959.4	65.6	705.6	1218.1	0.216
BMC, g	595.8	85.8	591.4	85.4	369.3	935.9	599.9	86.0	360.4	966.4	0.022
BMD, g/cm^2	0.62	0.06	0.61	0.06	0.47	0.79	0.62	0.05	0.46	0.81	< 0.001
Trunk angle, °	204.2	6.6	203.7	6.8	176.8	226.7	204.7	6.4	182.1	226.9	0.001
Lumbar angle, °	279.2	7.6	281.7	7.4	257.5	311.1	276.8	7.1	253.5	299.9	< 0.001
Sway angle, °	164.9	4.7	164.9	4.6	151.9	180.6	164.8	4.9	148.7	182.4	0.546
Head flexion, °	74.0	7.7	74.4	7.5	45.4	98.0	73.7	7.8	47.6	101.6	0.033
Neck flexion, °	42.3	4.9	43.3	4.8	29.2	61.8	41.3	4.8	25.5	59.1	< 0.001
Craniocervical angle, °	148.2	8.4	148.8	8.3	121.8	178.3	147.5	8.5	125.2	178.3	< 0.001
Cervicothoracic angle, °	138.6	5.8	137.0	5.7	116.1	167.2	140.1	5.4	115.6	157.2	< 0.001
Thoracic flexion, °	1.1	4.7	0.5	4.6	−17.0	17.7	1.6	4.7	−14.3	16.2	< 0.001
Pelvic tilt, °	130.6	7.3	128.6	7.1	105.0	159.4	132.4	7.0	107.7	153.5	< 0.001

SD, standard deviation; Min, minimum; Max, maximum; BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index; BMC, bone mineral content; BMD, bone mineral density.

Table 2
Correlations (Pearson's coefficient) of anthropometrics variables and body composition parameters with angles of sagittal standing posture, in girls (n = 1021).

	Trunk angle	Lumbar angle	Sway angle	Head flexion	Neck flexion	Craniocervical angle	Cervicothoracic angle	Thoracic flexion	Pelvic tilt
Birth									
Weight	0.10†	0.06	−0.03	0.02	0.05	0.01	−0.01	0.02	0.03
Length	0.09†	0.02	−0.02	0.03	0.03	−0.01	0.00	0.04	0.04
Ponderal index	0.06	0.07*	−0.03	0.01	0.05	0.02	−0.04	0.00	0.01
4 years									
Weight	0.13‡	0.24‡	−0.01	0.06	0.04	−0.03	0.00	0.03	−0.04
Height	0.10†	0.09†	0.02	0.05	−0.11†	−0.11‡	0.16‡	0.07*	−0.02
BMI	0.11‡	0.27‡	−0.03	0.05	0.12‡	0.03	−0.11‡	−0.02	−0.04
7 years									
Exact age (range: 6.9–8.6)	0.05	−0.07*	0.12‡	−0.21‡	−0.12‡	0.12‡	0.22‡	0.16‡	0.03
Weight	0.15‡	0.28‡	−0.04	0.04	0.06*	0.00	−0.04	0.00	−0.02
Height	0.12‡	0.09†	0.03	0.01	−0.13†	−0.09†	0.20‡	0.10†	0.00
BMI	0.13‡	0.31‡	−0.07*	0.05	0.14‡	0.04	−0.16‡	−0.06	−0.02
Fat mass	0.15‡	0.29‡	−0.03	0.03	0.14‡	0.05	−0.11‡	0.00	−0.01
Fat-free mass	0.12‡	0.20‡	−0.03	0.05	−0.06	−0.08†	0.08†	0.02	−0.02
FMI	0.14‡	0.31‡	−0.05	0.03	0.18‡	0.08*	−0.17‡	−0.03	−0.01
FFMI	0.08*	0.22‡	−0.08*	0.08*	0.01	−0.06	−0.05	−0.06	−0.03
Bone area	0.07*	0.03	0.05	−0.01	−0.11‡	−0.06	0.18‡	0.09†	−0.01
BMC	0.09†	0.15‡	0.01	0.02	−0.07*	−0.06*	0.11†	0.05	−0.03
BMD	0.10†	0.22‡	−0.03	0.05	−0.03	−0.06*	0.04	0.00	−0.04

BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index; BMC, bone mineral content; BMD, bone mineral density.

* Significant with $P < 0.05$.

† Significant with $P < 0.01$.

‡ Significant with $P < 0.001$.

Table 3
Correlations (Pearson's coefficient) of anthropometrics variables and body composition parameters with angles of sagittal standing posture, in boys (n = 1096).

	Trunk angle	Lumbar angle	Sway angle	Head flexion	Neck flexion	Craniocervical angle	Cervicothoracic angle	Thoracic flexion	Pelvic tilt
Birth									
Weight	0.04	−0.01	−0.07*	0.00	−0.06	−0.03	0.04	−0.01	0.07*
Length	0.08*	−0.02	−0.08*	0.00	−0.08†	−0.05	0.07*	0.00	0.10†
Ponderal index	−0.04	0.04	−0.02	−0.01	0.02	0.02	−0.04	−0.03	−0.03
4 years									
Weight	0.09†	0.16‡	−0.06*	0.02	−0.06*	−0.06	0.06*	0.01	−0.01
Height	0.09†	0.02	−0.01	0.03	−0.12‡	−0.10†	0.17‡	0.07*	0.06*
BMI	0.05	0.22‡	−0.08†	0.01	0.01	0.00	−0.06	−0.05	−0.07*
7 years									
Exact age (range: 6.9–8.7)	0.01	−0.03	0.20‡	−0.13‡	−0.08†	0.07*	0.23‡	0.18‡	−0.05
Weight	0.12‡	0.21‡	−0.07*	0.00	−0.03	−0.02	0.03	0.00	0.00
Height	0.08†	0.04	0.04	−0.01	−0.16‡	−0.09†	0.23‡	0.10†	0.02
BMI	0.11‡	0.26‡	−0.13‡	0.01	0.06	0.02	−0.11‡	−0.06*	−0.01
Fat mass	0.14‡	0.24‡	−0.12‡	0.01	0.05	0.01	−0.06*	−0.03	0.02
Fat-free mass	0.07*	0.13‡	0.01	−0.01	−0.11‡	−0.06	0.14‡	0.05	−0.02
FMI	0.14‡	0.25‡	−0.14‡	0.01	0.08†	0.03	−0.12‡	−0.05	0.02
FFMI	0.03	0.17‡	−0.04	0.00	−0.02	−0.01	0.00	−0.02	−0.05
Bone area	0.03	0.00	0.04	0.00	−0.15‡	−0.09†	0.20‡	0.08†	0.01
BMC	0.04	0.09†	0.02	−0.01	−0.12‡	−0.07*	0.16‡	0.06*	−0.03
BMD	0.04	0.16‡	0.00	−0.01	−0.09†	−0.05	0.10†	0.03	−0.05

BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index; BMC, bone mineral content; BMD, bone mineral density.
* Significant with $P < 0.05$.
† Significant with $P < 0.01$.
‡ Significant with $P < 0.001$.

Table 4
Linear regression analysis between selected parameters of sagittal standing posture and anthropometrics and body composition parameters at 7 years of age.

	Lumbar angle		Sway angle		Head flexion		Cervicothoracic angle	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Girls (n = 1021)								
Exact age (range: 6.9–8.6)	**−1.94**	**−3.32 to -0.56**	**1.43**	**0.54 to 2.32**	**−5.09**	**−6.53 to −3.65**	**2.85**	**1.81 to 3.90**
Weight	**0.40**	**0.26 to 0.54**	**−0.14**	**−0.22 to −0.05**	0.13	−0.01 to 0.27	**−0.26**	**−0.37 to −0.15**
Height	**0.20**	**0.05 to 0.35**	−0.04	−0.13 to 0.05	**0.17**	**0.02 to 0.32**	0.03	−0.08 to 0.14
BMI	**0.80**	**0.53 to 1.07**	**−0.29**	**−0.46 to −0.11**	0.19	−0.09 to 0.47	**−0.52**	**−0.73 to −0.31**
Fat mass	−0.31	−1.19 to 0.58	**0.65**	**0.08 to 1.21**	−0.52	−1.44 to 0.40	−0.10	−0.77 to 0.57
Fat-free mass	−0.71	−1.68 to 0.27	0.38	−0.24 to 1.01	−0.06	−1.08 to 0.96	0.46	−0.28 to 1.20
Bone area	−0.02	−0.03 to 0.004	0.01	−0.01 to 0.02	−0.02	−0.04 to 0.004	0.01	−0.01 to 0.02
BMC	0.01	−0.01 to 0.03	0.00	−0.02 to 0.01	0.01	−0.01 to 0.03	0.00	−0.02 to 0.01
BMD	8.40	−8.47 to 25.26	−4.12	−14.96 to 6.72	12.43	−5.17 to 30.02	−3.82	−16.57 to 8.94
Boys (n = 1096)								
Exact age (range: 6.9–8.7)	−1.21	−2.54 to 0.12	**2.44**	**1.52 to 3.36**	**−3.31**	**−4.82 to −1.80**	**2.77**	**1.77 to 3.77**
Weight	**0.37**	**0.23 to 0.51**	**−0.18**	**-0.28 to −0.09**	0.05	−0.11 to 0.20	**−0.20**	**-0.31 to −0.10**
Height	**0.18**	**0.03 to 0.33**	−0.03	−0.13 to 0.07	0.07	−0.09 to 0.23	0.07	−0.04 to 0.18
BMI	**0.64**	**0.37 to 0.91**	**−0.38**	**−0.56 to −0.19**	0.05	−0.25 to 0.36	**−0.41**	**−0.62 to −0.20**
Fat mass	0.39	−0.79 to 1.57	0.28	−0.54 to 1.09	0.88	−0.45 to 2.22	−0.07	−0.95 to 0.82
Fat-free mass	0.19	−1.04 to 1.43	0.59	−0.26 to 1.44	0.77	−0.63 to 2.16	0.26	−0.66 to 1.19
Bone area	**−0.03**	**−0.05 to −0.01**	−0.01	−0.02 to 0.01	0.00	−0.02 to 0.03	0.00	−0.01 to 0.01
BMC	**0.02**	**0.002 to 0.04**	0.00	−0.01 to 0.02	0.00	−0.02 to 0.02	0.00	−0.01 to 0.01
BMD	10.16	−4.92 to 25.24	0.10	−10.32 to 10.52	3.37	−13.73 to 20.47	0.08	−11.26 to 11.41

CI, confidence interval; BMI, body mass index; BMC, bone mineral content; BMD, bone mineral density.
Bold type indicates statistical significance.
Weight: adjusted for weight at birth and 4 years-old plus age.
Height: adjusted for length at birth and height at 4 years-old plus age.
BMI: adjusted for ponderal index at birth and BMI at 4 years-old plus age.
Fat: adjusted for all measurements of weight, all measurements of length/height, fat-free mass and age.
Fat-free mass: adjusted for all measurements of weight, all measurements of length/height, fat mass and age.
Bone area: adjusted for all measurements of weight, all measurements of length/height, fat and fat-free mass, BMC and age.
BMC: adjusted for all measurements of weight, all measurements of length/height, fat and fat-free mass, bone area and age.
BMD: adjusted for all measurements of weight, all measurements of length/height, fat and fat-free mass and age.
Age: adjusted for all measurements of weight, all measurements of length/height, fat and fat-free mass, bone area and BMC.

4. Discussion

In both genders, weight and body mass index were positively associated with lumbar angle. Concordantly, bone mineral density was also associated with lumbar angle. Height and bone area were associated with cervicothoracic angle in both genders. Both anthropometrics and body composition parameters were more strongly associated with postural angles in girls, while in boys age was strongly and positively associated with the sway angle, i.e. the anterior displacement of the spine over the hips.

One of the main findings of this study is the clear postural heterogeneity between genders, with girls showing higher lumbar angle since age 7. Evolutionary structural adaptations of the female spine can justify an increased lumbar angle in girls [6,25]. Given that balance was similar between genders, those findings taken together seem to highlight different alignment arrangements in order to obtain the same final balanced spino-pelvis. Concordantly, a gender-specific organization of body segments in young adolescents has been previously suggested [26]. Our study extended these findings to children for the first time, which may imply much earlier differences in biomechanical loads perhaps contributing to the well-known gender differences in pediatric spinal deformities observed in clinical settings. Furthermore, age was positively associated with sway angle, especially in boys, while associations with lumbar angle were stronger for girls. This is in accordance with our previous postural classifications where pattern aggregations of a neutral labelling were different between genders and suggested a predominance of increased lumbar angle in girls and sway back in boys [9].

Among all the individual postural parameters considered, lumbar angle had the strongest unadjusted correlations with anthropometrics and body composition variables. This is in accordance with the key role attributed to lumbar lordosis within the open chain of interdependence between anatomical regions of spino-pelvic sagittal alignment in standing position of asymptomatic adults [5,27], as well as adolescents and children [26,28]. The concept of interdependence between spino-pelvic regions implies that a change in shape or orientation at any anatomical level will affect the shape and orientation of adjacent segments, with lumbar lordosis being the key clinical parameter during spinal deformity and spondylolisthesis surgery planning in order to obtain a balanced and harmonious spino-pelvis [28,29].

In our work, we confirmed body mass index as the characteristic most strongly associated with lumbar angle. A biological effect of body mass index on adult sagittal spino-pelvic alignment is probably related with biomechanical constraints induced by higher body mass during standing posture and gait acquisition in early life, whose influence may deform the sacrum during osseous growth and affect sagittal standing posture [5,6]. Adolescents who remained lighter during childhood had an increased likelihood of showing a flattened lumbar lordosis and, on the contrary, those who were heavier showed a hypercurved lower back [7,8]. In agreement with this mechanical influence of adiposity, our results showed stronger associations for weight than for height, and were also stronger during walking ages (vs. at birth). The same direction of unadjusted correlations was observed for fat and fat-free mass and these associations were stronger for fat mass. Furthermore, a correlation with bone mineral density was also observed. Although research on the associations between bone parameters and sagittal posture is lacking, our previous study [11] showed an inverse relation between bone mineral density and a flattened posture as well as a direct relationship with a hypercurved spine.

Height and bone area were positively associated with cervicothoracic angle and head extension. Despite the lack of research studying the associations of height and bone area with sagittal posture, the observed association can be explained by adaptations to ergonomic mismatch [30]. Taller children need higher thoracic angle combined with head extension to maintain a horizontal gaze. Associations with bone area can be explained by the high collinearity between height and bone area ($r = 0.76$ for girls and $r = 0.79$ for boys; data not shown).

Despite the low age variability in our study, positive associations with age were observed for head extension, cervicothoracic angle and thoracic flexion. This is in accordance with increases in thoracic kyphosis reported to happen during growth [1,2]. However, age and height were also moderately correlated ($r = 0.37$ for girls and $r = 0.33$ for boys; data not shown).

All the correlations reported in this work were weak ($|r| \leq 0.31$), and associations should be viewed in the context of high collinearity between exposure variables which probably even overestimated the individual reported associations. Also, photogrammetry in itself is partially dependent on the anthropometrics of children [20]. Furthermore, in the perspective of our previous findings using standing postural patterns [9,11], the weak correlations observed in this study argue in favor of using patterns as a functional aggregation of overall posture, following the trend of the most recent research [6,8,27].

Our study showed clear postural heterogeneity between girls and boys in early ages denoting different biomechanical loads. Among all postural angles studied, lumbar angle was the most likely to drive the associations previously found between postural patterns and body size and composition [9,11]. Additionally, body mass index was the characteristic most strongly associated with lumbar angle, especially in girls. There was a predominant role of the sway angle especially among boys, in whom it was positively associated with age. However, all the associations were weak and it seems that the study of patterns of sagittal standing posture is of added value compared to isolated postural measures. Nevertheless, if researchers choose to focus on individual angular measures of sagittal standing posture, lumbar and sway angles seem to be the best proxies for overall posture in children on the basis of their relation with anthropometrics and body composition parameters.

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