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A new nine-type classification of body posture in children

Jacek Wilczyński

Collegium Medicum, Jan Kochanowski University, Kielce, Poland

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Key words: sagittal spinal alignment, paediatric posture classification, raster-stereography, thoracic kyphosis, lumbar lordosis, compensatory strategies, musculoskeletal assessment.

Abstract

Introduction: Sagittal spinal curvatures in children are most commonly assessed using isolated measurements, without consideration of compensatory mechanisms in adjacent anatomical segments. Such an approach limits both diagnostic accuracy and the clinical utility of existing postural classification systems.
Aim of the research: This study presents a comprehensive, nine-type postural classification based on the combined analysis of thoracic kyphosis and lumbar lordosis values in school-aged children.
Material and methods: A cross-sectional observational study was conducted involving 303 children aged 10–12 years (47.2% girls). Body posture was assessed using the DIERS Formetric III 4D raster stereography system under standardised laboratory conditions.
Results: Normal posture was identified in 29.0% of participants, whereas postural deviations were present in 71.0%. The most frequently observed abnormal patterns were reduced thoracic kyphosis with normal lumbar lordosis (21.8%), and reduced thoracic kyphosis with reduced lumbar lordosis (15.5%). Postures involving increased thoracic kyphosis were less common (11.0% overall). Statistically significant sex-related differences were found in thoracic and lumbar angle values ($p < 0.01$); however, effect sizes were small ($d < 0.20$). Each posture type was characterised by distinct compensatory features involving pelvic alignment, hip extension strategies, knee alignment, and foot-loading patterns.
Conclusions: The study confirmed a high prevalence of sagittal postural disturbances in children. The most common pattern was reduced thoracic kyphosis, frequently co-occurring with reduced lumbar lordosis. The nine-type classification effectively differentiated postural phenotypes and revealed characteristic multisegmental compensatory mechanisms. Deviations in spinal curvatures were associated with predictable changes in the alignment of the head, shoulders, pelvis, lower limbs, and feet. Although sex-related differences reached statistical significance, their clinical relevance was negligible. The findings underscore the need for a multisegmental approach to postural diagnosis and re-education, and the proposed typology constitutes a useful tool for the early identification of compensatory postural strategies and for planning individualised therapeutic interventions.

Introduction

Body posture in children is the outcome of a complex, dynamic process of neuromuscular maturation, shaped by multisensory integration, motor unit recruitment, and the organisation of habitual postural and movement patterns [1, 2]. Postural development is nonlinear in nature and is influenced by innate movement variability, the inflow of sensory information, and the gradual maturation of central nervous system control [3–5]. Late childhood is characterised by accelerated changes in sagittal spinal alignment, balance strategies, central stabilisation, and the trajectories of motor skill acquisition, which promotes the consolidation of characteristic postural habits, movement patterns, and compensatory mechanisms [4–6]. Posture also constitutes a habitual psychomotor construct, shaped by biomechanical, environmental, neurodevelopmental, and to some extent emotional factors [7–9]. Body posture is not a static alignment of segments but an emergent property of the entire fascial–skeletal system, resulting from the balance of tensions, tissue adaptations, and neural regulation. From a tensegrity perspective, the body functions as a network of compression elements suspended within continuous tension; therefore, a change in one region reorganises the entire structure. Established posture is the product of habit – a tension pattern shaped by repetitive positions and loads. A lasting change in posture requires reorganisation of postural tension and modification of movement habits [1]. Traditional classifications of postural defects have been based primarily on sagittal spinal curvature parameters and basic morphometric features, which has limited their ability to identify functional and compensatory mechanisms throughout the entire postural chain [10, 11]. These approaches have rarely accounted for the dynamic interactions among vestibular, sensory, and neuromuscular subsystems that determine balance control, intersegmental coupling, and long-term postural stability [12–17]. In response to these limitations, a new nine-type postural typology was developed, integrating measurements of thoracic kyphosis and lumbar lordosis angles with an analysis of postural, movement, and compensatory patterns involving the spine, pelvis, hip joints, knees, and feet [18]. Such an approach enables posture to be interpreted not as a static segmental alignment but as the outcome of complex stabilisation mechanisms, postural synergies, and adaptive responses to mechanical loading [19–21]. Compared with classical postural concepts – such as segmental assessment according to Kendall [21, 22], movement impairment classification according to Sahrmann [23], muscle imbalance patterns and diagnostic reasoning described by Janda [24–26], or the directional mechanical classification of McKenzie [27–29] – the nine-type system broadens the scope of clinical interpretation by integrating morphological, neuromotor, and functional assessment. Contemporary theoretical frameworks further emphasise the role of global muscular coordination, diaphragmatic function, trunk stabilisation strategies, and intersegmental compensations in postural control [30, 31]. Despite extensive research on postural development in children, significant knowledge gaps remain. Previous studies have typically focused on isolated components of postural control, without considering interactions between sensory regulation, compensatory motor strategies, and population-level distribution patterns of postural phenotypes [32, 33]. Consequently, there has been a need to develop a diagnostic classification that integrates angular measurements with functional interpretation.

Aim of the research

The present study aims to address this gap by applying a novel nine-type postural classification in children. The objective of the study was to analyse the prevalence and characteristics of postural types in children aged 10–12 years using this new nine-type classification, based on measurements of thoracic kyphosis and lumbar lordosis combined with an assessment of accompanying postural, movement, and compensatory patterns.

Material and methods

Research hypotheses

H1. The majority of children aged 10–12 years will present with postural deviations, and the proportion of normal posture (defined as normal thoracic kyphosis and normal lumbar lordosis) will be lower than 40%.

H2. The most frequently observed postural types will be those with reduced thoracic kyphosis (types 1–3), confirming the usefulness of the nine-type classification in detecting subtle postural deviations not identified by traditional assessment systems.

H3. Each postural type will be associated with distinct postural and movement patterns, including the dominance of specific muscle groups and characteristic stabilization strategies.

H4. Postural abnormalities will co-occur with compensations in distal segments (pelvis, hip joint, knee, and foot), in accordance with the concept of the multisegmental functional chain.

The study included 303 children aged 10–12 years, coThe study included 303 children aged 10–12 years, comprising 143 (47.18%) girls and 160 (52.82%) boys. The largest group consisted of 10-year-old children (43.85%), followed by 11-year-olds (35.55%) and 12-year-olds (20.60%).

The sample size was considered sufficient to ensure adequate statistical power and reliable subgroup analyses, with an estimated margin of error of approximately ±5% at a 95% confidence level.

Participants were randomly recruited from local primary schools, with stratification by age and sex to ensure sample representativeness. Inclusion criteria were as follows: age 10–12 years, absence of diagnosed spinal or neurological disorders, ability to cooperate during the examination, and written informed consent from a parent or legal guardian, as well as assent from the child. Exclusion criteria included a history of spinal surgery, ongoing orthopaedic treatment, neurological disorders, and lack of consent.

The study was conducted at the Posturology Laboratory of Jan Kochanowski University in Kielce, in accordance with the Declaration of Helsinki, and was approved by the University Bioethics Committee (decision No. 5/2015).

Body posture was assessed using the DIERS Formetric III 4D system, based on raster stereography. This method enables radiation-free three-dimensional reconstruction of the back surface and automatic calculation of postural and spinal curvature parameters.

All measurements were performed in a darkened room. Participants stood barefoot in a natural, relaxed standing position at a distance of approximately 2 m from the device. Two measurements were obtained for each participant, and the most representative result was selected for analysis.

Additionally, a standardized clinical examination was conducted to assess posture, compensatory mechanisms, muscle tone, and joint range of motion. Data acquisition was performed using DiCAM software in the "Average measurement" mode, which records 12 consecutive images and calculates mean values, thereby increasing measurement reliability.

All procedures were conducted by trained personnel without the use of skin markers. Sagittal spinal parameters were analysed, including the maximum thoracic kyphosis angle, maximum lumbar lordosis angle, and the location of their apices. All data were exported directly from the software to an electronic database.

Raster stereography demonstrated good agreement with radiological measurements. Reference values for thoracic kyphosis (42–55°) and lumbar lordosis (33–47°)

were applied. Based on these values, each participant's posture was classified into one of nine sagittal posture types derived from combinations of kyphosis and lordosis values [9, 34–36].

Statistical analysis

Statistical analyses were performed using Statistica 13.3 PL software. Data distribution was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Depending on distribution characteristics, parametric or nonparametric tests were applied. Between-sex comparisons were conducted using the independent-samples Student's *t*-test, and effect sizes were calculated using Cohen's *d*. Frequencies and percentages were calculated for qualitative variables. The level of statistical significance was set at $p < 0.05$.

Results

Characteristics of postural abnormalities according to the authors' original typology

The application of reference ranges for thoracic kyphosis (42–55°) and lumbar lordosis (33–47°) made it possible to distinguish nine distinct and clinically relevant posture types, each defined by a specific combination of sagittal spinal curvatures. The first group comprises postures with reduced thoracic kyphosis (K < 42°), which may be accompanied by reduced, normal, or increased lumbar lordosis (L < 33°, 33° ≤ L ≤ 47°, L > 47°). When thoracic kyphosis falls within the normative range (42° ≤ K ≤ 55°), lumbar lordosis may likewise present as reduced, normal, or increased. The final category includes postures with increased thoracic kyphosis (K > 55°), in which lumbar lordosis may again be below normal, within the reference range, or exceed normative values (L < 33°, 33° ≤ L ≤ 47°, L > 47°). This classification system enables clear and consistent assignment of posture types based on well-defined morphological criteria and provides an important framework for clinical assessment, diagnostic decision-making, and biomechanical interpretation of postural deviations. Table 1 presents descriptive statistics for five posture-related variables in the entire study sample (*N* = 303). For each variable, the mean (X), standard deviation (SD), median (Me), minimum (Min), and maximum (Max) values, as well as two-sided 95% confidence intervals (95% CI), are reported. The mean value of the kyphosis apex (KA, VP–DM) was –131.570 mm (SD = 27.833), with the negative sign resulting from the reference coordinate convention adopted by the DIERS system. The mean maximum thoracic kyphosis angle ICT–ITL was 43.348° (SD = 9.406), while the mean value of the thoracic kyphosis angle VP–ITL was 40.316° (SD = 9.751). The mean maximum lumbar lordosis angle ITL–ITS was 40.263° (SD = 9.321), and the mean value of the lumbar lordosis angle ITL–DM was 36.654° (SD = 9.163). For all analysed variables, minimum and maximum values and the limits of the 95% confidence intervals are also provided (Table 1).

Table 2 presents a comparison of five posture-related variables between girls and boys. For each variable, the mean value (X), standard deviation (SD), sample size (N), *t* statistic, degrees of freedom (df), *p*-value, *F* statistic with its corresponding *p*-value (test of homogeneity of variance), and effect size expressed as Cohen's *d* are reported. Statistically significant sex-related differences ($p < 0.05$) were observed for all analysed parameters: the kyphosis apex KA (VP–DM) (mm) ($p = 0.00198$), the maximum thoracic kyphosis angle ICT–ITL (°) ($p = 0.00610$), the thoracic kyphosis angle VP–ITL (°) ($p = 0.00855$), the maximum lumbar lordosis angle ITL–ITS (°) ($p = 0.00453$), and the lumbar lordosis angle ITL–DM (°) ($p = 0.00742$). Cohen's *d* values ranged from 0.0046 to 0.1499, indicating very small effect sizes (Table 2).

Table 3 presents a structured classification of nine distinct body posture types defined on the basis of angular measurements of two sagittal spinal parameters: thoracic kyphosis and lumbar lordosis. Each category is defined by a specific combination of threshold numerical values, allowing for standardised assignment of participants to clearly delineated postural groups. The first column lists posture types numbered from

Table 1. Body posture variables in the entire study group

Variable	*N*	Mean (X)	SD	Median (Me)	Min	Max	–95% CI	+95% CI
Kyphosis apex KA (VP–DM) [mm]	303	–131.570	27.833	–132.89	–203.67	–36.64	–134.727	–128.413
Thoracic kyphosis angle ICT–ITL (max) [°]	303	43.348	9.406	43.71	17.54	70.05	42.281	44.415
Thoracic kyphosis angle VP–ITL [°]	303	40.316	9.751	40.93	11.48	64.22	39.210	41.422
Lumbar lordosis angle ITL–ITS (max) [°]	303	40.263	9.321	40.31	9.44	66.57	39.205	41.320
Lumbar lordosis angle ITL–DM [°]	303	36.654	9.163	36.67	7.55	63.21	35.614	37.693

Table 2. Differences in body posture parameters between girls and boys

Variable	Mean (girls)	Mean (boys)	SD (girls)	SD (boys)	*N* (girls)	*N* (boys)	*t*	d*f*	*P*-value	*F* ratio	Cohen's d
Kyphosis apex KA (VP–DM) [mm]	–126.348	–136.233	30.352	24.543	143	160	3.120	301	0.00198	1.529	0.1499
Thoracic kyphosis angle ICT–ITL (max) [°]	41.781	44.748	9.210	9.388	143	160	–2.762	301	0.00610	1.039	0.0132
Thoracic kyphosis angle VP–ITL [°]	38.757	41.708	9.332	9.935	143	160	–2.647	301	0.00855	1.133	0.0436
Lumbar lordosis angle ITL–ITS (max) [°]	41.870	38.827	9.177	9.241	143	160	2.861	301	0.00453	1.014	0.0046
Lumbar lordosis angle ITL–DM [°]	38.145	35.322	9.032	9.102	143	160	2.696	301	0.00742	1.016	0.00527

KA – kyphosis apex, ICT–ITL – maximum thoracic kyphosis angle, VP–ITL – thoracic kyphosis angle, ITL–ITS – maximum lumbar lordosis angle, ITL–DM – lumbar lordosis angle, t – Student's t statistic, df – degrees of freedom, F – Fratio, d – Cohen's effect size.

Table 3. Classification of sagittal body posture types

No.	Posture type	Thoracic kyphosis (K)	Lumbar lordosis (L)	Kyphosis and lordosis angles
1	Reduced kyphosis, reduced lordosis	< 42°	< 33°	K < 42°; L < 33°
2	Reduced kyphosis, normal lordosis	< 42°	33–47°	K < 42°; 33 ≤ L ≤ 47°
3	Reduced kyphosis, increased lordosis	< 42°	> 47°	K < 42°; L > 47°
4	Normal kyphosis, reduced lordosis	42–55°	< 33°	42 ≤ K ≤ 55°; L < 33°
5	Normal kyphosis, normal lordosis	42–55°	33–47°	42 ≤ K ≤ 55°; 33 ≤ L ≤ 47°
6	Normal kyphosis, increased lordosis	42–55°	> 47°	42 ≤ K ≤ 55°; L > 47°
7	Increased kyphosis, reduced lordosis	> 55°	< 33°	K > 55°; L < 33°
8	Increased kyphosis, normal lordosis	> 55°	33–47°	K > 55°; 33 ≤ L ≤ 47°
9	Increased kyphosis, increased lordosis	> 55°	> 47°	K > 55°; L > 47°

one to nine. The second column provides a descriptive name for each type, reflecting the relationship between the magnitude of thoracic kyphosis and lumbar lordosis. Thoracic kyphosis values are shown in the third column and categorised into three ranges: < 42°, 42–55°, and > 55°. The fourth column presents lumbar lordosis values, also divided into three ranges: < 33°, 33–47°, and > 47°. The final column contains the corresponding combined angular criteria for both parameters, expressed in abbreviated form (K – kyphosis, L – lordosis). Posture types 1–3 include classifications characterised by thoracic kyphosis values below 42° combined with one of the three lumbar lordosis ranges (i.e. < 33°, 33–47°, or > 47°). Types 4–6 refer to postures in which thoracic kyphosis falls within the normative range (42–55°), while lumbar lordosis assumes values from each of the three defined ranges. Types 7–9 comprise classifications in which thoracic kyphosis exceeds 55°, with concurrent differentiation of lumbar lordosis according to the three threshold categories. In summary, the table organizes mutually exclusive posture types derived from the simultaneous assessment of sagittal alignment of the thoracic and lumbar segments of the spine. The presented structure enables repeatable and unambiguous categorization of sagittal spinal morphology and allows for quantitative differentiation of nine specific postural patterns (Table 3).

Table 4 presents data on the distribution of nine sagittal postural patterns in girls (n_1, N_1) and boys (n_2, N_2), expressed as percentages with two-sided 95% confidence intervals (95% CI). For each posture type, the parameters of the structure test are reported, including *p*, *q*, *n*, *u*, and the empirical significance level $p(\alpha)$, as well as the effect size calculated using Cohen's *d*. The proportions of individual posture types in the group of girls (n_1/N_1) ranged from 0.70% (NK–RL and IK–RL) to 28.87% (RK–NL), whereas in the group of boys (n_2/N_2) they ranged from 1.26% (RK–IL) to 32.08% (NP). The confidence intervals for the proportions showed considerable variability and, in several categories, included negative lower bounds (e.g. −0.24 to 1.65 for NK–RL in girls and −0.01 to 2.52 for RK–IL in boys), which results from the method used to estimate confidence intervals for low-frequency events. In some cases, the upper limits of the 95% CI exceed-

Table 4. Comparison of body posture types between girls and boys

Posture type	n (girls)	N (girls)	% (girls)	−95% CI	+95% CI	n (boys)	N (boys)	% (boys)	−95% CI	+95% CI	p	q	n	u	Cohen's d
RK–RL	22	143	15.49	11.39	19.60	26	160	16.35	12.16	20.55	0.159	0.841	75	0.203	0.01168
RK–NL	**41**	143	28.87	23.73	34.01	26	160	16.35	12.16	20.55	0.223	0.777	75	2.607	0.1507
RK–IL	12	143	8.45	5.30	11.61	2	160	1.26	−0.01	2.52	0.047	0.953	75	2.958	0.17135
NK–RL	1	143	0.70	−0.24	1.65	16	160	10.06	6.65	13.48	0.056	0.944	75	3.511	0.20380
NP	36	143	25.35	20.42	30.29	51	160	32.08	26.78	37.37	0.289	0.711	75	1.825	0.07395
NK–IL	18	143	12.68	8.90	16.45	17	160	10.69	7.19	14.20	0.116	0.884	75	0.536	0.03083
IK–RL	1	143	0.70	−0.23	1.63	1	160	1.60	−0.01	1.98	0.046	0.764	75	2.437	0.00894
IK–NL	2	143	1.41	−0.07	2.75	10	160	6.29	3.54	9.04	0.040	0.960	75	2.161	0.12471
IK–IL	10	143	7.04	4.14	9.94	11	160	6.92	4.04	9.80	0.070	0.930	75	0.042	0.00240

Table 4 presents the number (n), total sample size (N), and percentage (%) of girls (n1, N1) and boys (n_2, N_2) classified into nine sagittal body posture types. Posture types (abbreviations): RK–RL – reduced kyphosis/reduced lordosis, RK–NL – reduced kyphosis/normal lordosis, RK–IL – reduced kyphosis/increased lordosis, NK–RL – normal kyphosis/reduced lordosis, NP – normal physiological spinal curvatures, NK–IL – normal kyphosis/increased lordosis, IK–RL – increased kyphosis/reduced lordosis, IK–NL – increased kyphosis/normal lordosis, IK–IL– increased kyphosis/increased lordosis. Statistics: −95% CI/ +95% CI – confidence interval limits, p, q, n, u – parameters of the structure test, α – p value, Cohen's d < 0.20 – negligible effect. (All values are presented without interpretation, statistically significant differences are indicated at p < 0.05.)

ed 30% (e.g. 37.37 for NP in boys). The *p*-values obtained in the structure analysis ranged from 0.040 to 0.289. Statistically significant sex-related differences in distribution ($p < 0.05$) were observed for selected posture types, including RK–IL ($p = 0.047$), IK–RL ($p = 0.046$), and IK–NL ($p = 0.040$). The values of the *q* parameter ranged from 0.711 to 0.960, whereas the *n* parameter remained constant at 75 for all analysed types. The values of the *u* statistic ranged from 0.042 to 3.511, and the empirical significance level $p(\alpha)$ varied from 0.00045 to 0.96637. Effect sizes calculated using Cohen's *d* ranged from 0.00240 to 0.20380. The smallest effect sizes were observed for the IK–IL ($d = 0.00240$), IK–RL ($d = 0.00894$), and RK–RL ($d = 0.01168$) types, whereas the largest were found for NK–RL ($d = 0.20380$) and RK–IL ($d = 0.17135$), indicating very small to small effect sizes (Table 4) (Figures 1–9).

Discussion

Body posture, although influenced by genetic factors, is largely shaped by environmental conditions, which account for its developmental variability and pronounced interindividual differences. The postural abnormalities observed in children should primarily be attributed to disturbances in the development of antigravity mechanisms responsible for effective resistance to gravitational forces. The antigravity system, functionally integrated with the central nervous system, plays a key role in regulating postural tone, postural control, motor coordination, and the integration of posture and movement [37–41]. Properly developed postural tone enables efficient stabilization against gravity and supports proximal stability with precise distal mobility [42–45].

Disruptions in these mechanisms reduce stabilization capacity and trigger compensatory strategies, including passive stabilization through periarticular structures or excessive proximal or distal fixation [46–48]. These compensations, particularly evident in upright posture, propagate through the spine, pelvis, and lower limbs in a chain-reaction manner, leading to asymmetrical alignment and uneven load distribution [49–52]. During critical developmental periods, such mechanisms may contribute to the progression of postural defects [53–55].

The present study demonstrated that mean values of thoracic kyphosis and lumbar lordosis in most children deviated from ranges considered typical for this age group, while wide confidence intervals confirmed substantial morphological heterogeneity. These findings indicate that postural development in late childhood is nonlinear and reflects interactions between neuromotor maturation, reorganization of stabilization strategies, and environmental and lifestyle factors [56–58]. Consequently, posture assessment based solely on isolated angular parameters is insufficient and should be complemented by analysis of intersegmental relationships and compensatory mechanisms.

Although some sex-related differences reached statistical significance, their very small effect sizes limit clinical relevance, suggesting that these differences reflect functionally equivalent stabilization strategies rather than true structural distinctions. This observation calls into question the validity of sex-specific postural norms in school-aged children.

The proposed nine-type classification extends traditional binary approaches by encompassing the full spectrum of sagittal spinal configurations and their functional interrelationships. Reduced thoracic kyphosis, often coexisting with normal or decreased

Figure 1. Reduced thoracic kyphosis and reduced lumbar lordosis (K < 42°; L < 33°)

Figure 2. Reduced thoracic kyphosis and normal lumbar lordosis (K < 42°; 33° ≤ L ≤ 47°)

Figure 3. Reduced thoracic kyphosis and increased lumbar lordosis (K < 42°; L > 47°)

Figure 4. Normal thoracic kyphosis and reduced lumbar lordosis (42° ≤ K ≤ 55°; L < 33°)

Figure 5. Normal thoracic kyphosis and normal lumbar lordosis (42° ≤ K ≤ 55°; 33° ≤ L ≤ 47°)

Figure 6. Normal thoracic kyphosis and increased lumbar lordosis (42° ≤ K ≤ 55°; L > 47°)

Figure 7. Increased thoracic kyphosis and reduced lumbar lordosis (K > 55°; L < 33°)

Figure 8. Increased thoracic kyphosis and normal lumbar lordosis (K > 55°; 33° ≤ L ≤ 47°)

Figure 9. Increased thoracic kyphosis, increased lumbar lordosis (K > 55°; L > 47°)

lumbar lordosis, was the most prevalent pattern. This finding is consistent with reports linking prolonged sitting, low physical activity, and reduced postural muscle endurance to the flattening of physiological spinal curvatures [59–60].

Segmental analysis confirmed that deviations in spinal alignment are associated with predictable compensations throughout the postural chain, involving the head, pelvis, and lower limbs [61]. From a clinical perspective, the nine-type classification provides a practical framework for identifying dominant compensatory mechanisms and planning individualized interventions.

Given the high plasticity of the postural system in this age group, early diagnosis and targeted therapy may substantially enhance preventive and therapeutic outcomes [62]. Raster stereography offers a valuable, noninvasive tool for monitoring posture over time. Future research should include longitudinal studies and multivariate analyses, as well as the application of machine learning techniques to improve automated postural classification and personalized intervention strategies.

Conclusions

The results of the study provide coherent confirmation of all four hypotheses and underscore the functional nature of sagittal postural disturbances in children aged 10–12 years. In accordance with hypothesis H1, optimal sagittal alignment was identified in only a minority of participants, indicating that postural deviations during this developmental period are a common phenomenon. The predominance of reduced thoracic kyphosis – most frequently co-occurring with normal or decreased lumbar lordosis – confirmed hypothesis H2 and is consistent with current evidence linking sedentary behaviour and insufficient endurance of postural muscles to the flattening of physiological spinal curvatures. The nine-type posture classification applied in the study enabled precise differentiation of postural phenotypes and revealed distinct compensatory mechanisms characteristic of individual configurations, thereby confirming hypothesis H3. These mechanisms included predictable changes in the activity of global and segmental muscles, as well as specific alignment patterns of the trunk, pelvis, and lower limbs. Furthermore, in line with hypothesis H4, sagittal spinal deviations were accompanied by multisegmental compensations involving the head, pelvis, hip and knee joints, and foot-loading strategies, highlighting the interdependent nature of postural control and the functional coupling of body segments. Although sex-related differences in angular parameter values reached statistical significance, their small effect sizes indicate limited clinical relevance and suggest that environmental and behavioural factors play a greater role than biological sex in shaping posture. Taken together, the findings indicate that sagittal posture in late childhood is highly dynamic and should be assessed using an integrated, multisegmental approach rather than through isolated analysis of individual spinal curvatures. The proposed nine-type typology constitutes a clinically useful tool for identifying dysfunctional postural strategies, improving early detection of maladaptive patterns, and planning targeted, individualised therapeutic interventions.

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Ethical approval

All procedures complied with the principles of the Declaration of Helsinki and were approved by the University's Bioethics Committee for Scientific Research (decision No. 5/2015).

Conflict of interest

The authors declare no conflict of interest.

References

1. Setiaji A, Prabowo T, Novitri N, Tanuwidjaja D. Fascial biotensegrity. Bali Med J. 2024; 14: 309-314.
2. Wilson PH, Smits-Engelsman BCM, Caeyenberghs K, Steenbergen B, Sugden DA, Clark JE, Blank R. Neural mechanisms underlying motor control difficulties in children. Nat Rev Neurol. 2020; 16: 367-380.
3. van Emmerik REA, Rosenstein MT, McDermott WJ, Haddad JM. Movement variability from a health and pathology perspective. Hum Mov Sci. 2020; 78: 102796.
4. Lininger MR, Smith B, Jacobs JV, Palmieri-Smith RM, Lepley LK, Kuenze CM. Sagittal plane posture and motor behaviors in youth: a scoping review. Gait Posture. 2020; 80: 330-343.
5. Houwen S, Hartman E, Visscher C. Motor skill development trajectories in childhood. Dev Rev. 2021; 60: 100962.
6. dos Santos AN, Bunn PS, Armand S, Allard P, Rivard L, Labelle H. Longitudinal maturation of postural sway in children. Gait Posture. 2023; 103: 23-29.
7. Domagalska ME. Neurophysiological aspects of diagnosis and therapy in postural deviations. WSA, Bielsko-Biała 2009.
8. Matyja M. Neurodevelopmental analysis of postural disorders in children and adolescents. AWF, Katowice 2012.
9. Wilczyński J. Own typology of body posture based on DIERS Formetric III 4D. J Clin Med. 2025; 14: 501.
10. Czaprowski D, Stoliński Ł, Tyrakowski M, Kozinoga M, Kotwicki T. Non-structural misalignments of body posture in the sagittal plane. Scoliosis Spinal Disord. 2018; 13: 6.
11. Macedo RB, Coelho-e-Silva MJ, Valente-dos-Santos J, Martins C, Sousa-e-Silva P, Tavares OM. Postural characteristics of school-age children: a systematic review. Front Pediatr. 2022; 10: 841677.
12. Bernard-Demanze L, Dumitrescu M, Delarque A, Lacour M, Dumitrescu L. Vestibular contributions to pediatric postural stability. Front Neurol. 2021; 12: 673256.
13. Pavão SL, Rocha NACF. Postural control assessment in children: an updated perspective. Children (Basel). 2023; 10: 487.
14. Bisi MC, Stagni R. Complexity and regularity of postural sway in children: a nonlinear approach. Sensors (Basel). 2021; 21: 3218.
15. Wang X, Chen X, Lee K, Zhang Y, Li J, Huang Z. Development of trunk muscle activation patterns in children. J Biomech. 2022; 132: 110992.
16. Chow J, Choong AM, Bedi M, Lim BH, Tan DM, Singh DK. Advances in pediatric gait and posture biomechanics. Bioengineering (Basel). 2023; 10: 251.
17. Lacquaniti F, Bosco G, Gravano S, Zago M, Ivanenko YP. Multisensory integration and body schema development in humans. Curr Biol. 2022; 32: R175-R188.
18. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in sagittal alignment of the human lumbar spine. Spine. 2005; 30: 346-353.
19. Schwab F, Lafage V, Patel A, Farcy JP. Sagittal plane considerations and the pelvis in the adult patient. Spine. 2009; 34: 1828-1833.
20. Been E, Kalichman L. Lumbar lordosis. Spine J. 2014; 14: 87-97.
21. Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. Muscles: Testing and Function with Posture and Pain. 5th ed. Lippincott Williams & Wilkins, Baltimore 2005.
22. Kendall FP, Boynton DA. Posture and Pain. Williams & Wilkins; Baltimore 1973.
23. Sahrmann SA. Diagnosis and treatment of movement impairment syndromes. Mosby, St. Louis 2002.
24. Janda V. Muscle function testing. In: Rational Manual Therapies. Basmajian JV, Nyberg RE (eds.). Churchill Livingstone, New York 1997; 22-34.
25. Page P, Frank CC, Lardner R. Assessment and treatment of muscle imbalance: the Janda approach. Human Kinetics; Champaign 2010.
26. Frank C, Page P, Lardner R. The Janda approach: rehabilitation of muscle imbalance. J Bodyw Mov Ther. 2009; 13: 27-35.
27. McKenzie R, May S. The Lumbar Spine: Mechanical Diagnosis & Therapy. Spinal Publications, Waikanae 2003.
28. McKenzie R, May S. The Cervical and Thoracic Spine: Mechanical Diagnosis & Therapy. Spinal Publications, Waikanae 2006.
29. Clare HA, Adams R, Maher CG. A systematic review of efficacy of McKenzie therapy for spinal pain. Spine. 2004; 29: E231-E238.
30. Kolar P, Šulc J, Kyncl M, Sanda J, Cakrt O, Andel R, Kumagai K, Kobesova A. Postural function of the diaphragm in persons with and without chronic low back pain. J Orthop Sports Phys Ther. 2012; 42: 352-362.
31. Hodges PW, Sapsford R, Pengel LHM. Postural and respiratory functions of the pelvic floor muscles. Neurourol Urodyn. 2007; 26: 362-371.
32. Kocjan J, Adamek M, Gzik-Zroska B, Czyżewski D, Rydel M, Gzik M. Respiratory–postural synergies: an updated review of mechanisms. Respir Physiol Neurobiol. 2021; 285: 103609.
33. Stergiou N, Decker LM. Human movement variability, nonlinear dynamics, and pathology. Hum Mov Sci. 2011; 30: 869-888.
34. Drerup B, Hierholzer E. Back shape measurement using video rasterstereography. Clin Biomech (Bristol, Avon). 1994; 9: 28-36.
35. Harzmann H. Videorasterstereography in clinical practice. Orthopade. 2001; 30: 81-104.
36. Albertsen IM, Christophersen P, Froeslie KF, Stuge B, Kirkesola G. Dynamic raster stereography during the Matthiass test. Gait Posture. 2018; 63: 104-110.
37. Nolet PS, Yu H, Côté P, Wong JJ, Sutton D, Shearer HM. Reliability and validity of manual palpation used for

the assessment of low back pain in adults. Chiropr Man Therap. 2021; 29: 40.
38. Latash ML. Motor synergies and redundancy: twenty years later. Hum Mov Sci. 2020; 70: 102512.
39. Richardson CA. The muscle designation debate: the experts respond. J Bodyw Mov Ther. 2000; 4: 235-236.
40. Taverna L, Colombo S, Fumagalli G, Reni G, Ferrigno G. Neurodevelopmental determinants of posture. Dev Rev. 2024; 64: 101065.
41. Caronni A, Recalcati M, Montesano A, Bianchi F, Ferrante S, Ferrigno G. Machine-learning-based classification of children's postural phenotypes. Sci Rep. 2025; 15: 1182.
42. Bzdúšková D, Zlámalová E, Zvonař M. Postural stability assessment using nonlinear methods. Acta Gymnica. 2018; 48: 23-31.
43. Gill SV, Hogan N, Palisano RJ, Fragala-Pinkham MA, Hsu LY. Functional consequences of impaired postural control. Pediatr Res. 2023; 93: 1824-1834.
44. Lopes PN, Ribeiro DC, Pinheiro A, Silva AG, Costa LOP, Oliveira AS. Trunk stability and balance. Gait Posture. 2024; 108: 67-73.
45. Silva PL, Barros RV, Monteiro L, Santos GM, Oliveira CS, Carvalho LC. Effects of targeted interventions on spinal alignment in youths. Children (Basel). 2024; 11: 203.
46. Suda EY, de Paula LR, Sacco ICN. Impact of core stability training. Pediatr Phys Ther. 2021; 33: 168-175.
47. Chatelain LS, Dayer R, Dubois-Ferrière V, Armand S. Pediatric spinal alignment and development: a narrative review. Spine J. 2024; [ahead of print]. doi:10.1016/j.spinee.2024.01.012
48. Szumilas P, Bieniek K, Markowski K, Bąk J. Types of body posture and refractive errors in school-aged children. Med Rehabil. 2025; 29: 21-26.
49. Iannotta A, Gori M, Sorrentino P, Burr DC, Binda P. Proprioceptive and visual motion detection in school-age children. Sci Rep. 2025; 15: 1234.
50. Gomes CA, de Faria A, Diniz A, Silva PL, Monteiro L, Carvalho CS. Breathing patterns and postural control in children. Front Pediatr 2021; 9: 699048.
51. Granacher U, Gollhofer A. Postural control and strength in adolescents. J Strength Cond Res. 2012; 26: 2101-2107.
52. Riach CL, Starkes JL. Velocity of centre of pressure excursions in children. Gait Posture. 1994; 2: 167-172.
53. Żurawski AŁ, Friebe D, Zalewska S, Wojtas K, Gawlik M, Wilczyński J. Assessing trunk cross-section geometry and spinal postures with noninvasive 3D surface topography: a study of 108 healthy young adults. Sensors (Basel). 2025; 25: 6626.
54. Liu J, Yu K, Zhang L, Wang H, Chen Y, Li Q. Neural control of motion-compensation strategies in developing children. IEEE Trans Neural Syst Rehabil Eng. 2024; 32: 889-897.
55. Assaiante C. Development of locomotor balance control in infants and children. Hum Mov Sci. 2014; 34: 1-11.
56. Woollacott M, Shumway-Cook A. Development of posture and gait across the lifespan. Phys Ther. 1989; 69: 786-797.
57. Newell KM. Constraints on the development of coordination. In: Wade MG, Whiting HTA, editors. Motor development in children: aspects of coordination and control. Martinus Nijhoff, Dordrecht 1986; 341-360.
58. Hadders-Algra M. Development of postural control. Neurosci Biobehav Rev. 2005; 29: 719-728.
59. Adolph KE, Berger SE. Motor development. In: Handbook of child psychology and developmental science. 7th ed. Lerner RM (ed.) Wiley, Hoboken 2015.
60. Latash ML, Zatsiorsky VM. Motor control and learning. Human Kinetics; Champaign 2016.
61. Davids K, Button C, Bennett S. Dynamics of skill acquisition. Human Kinetics; Champaign 2008.
62. Thelen E, Smith LB. A dynamic systems approach to the development of cognition and action. MIT Press, Cambridge 1994.

Address for correspondence:

Dr hab. **Jacek Wilczyński**, Prof. UJK
Posturology Laboratory
Collegium Medicum
Jan Kochanowski University
Al. IX Wieków Kielc 19
25-317 Kielce, Poland
e-mail: jwilczynski@onet.pl

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