JHWCR JOURNAL OF HEALTH, WELLNESS AND COMMUNITY RESEARCH 3007-0570

https://doi.org/10.61919/y4m80z91

Review Article

Biomechanical and Developmental Perspectives on Upper Body Postural Adaptations Among School-Aged Children: A Comprehensive Narrative Review

Abdulaziz Atiah Alzaidani[1,2], Chua Siew Kuan[1,3]

[1] School of Physiotherapy, Faculty of Nursing and Applied Science, Lincoln University College, Petaling Jaya, Malaysia
[2] Department of Medical Rehabilitation and Physiotherapy, Children's Hospital, Taif Health Cluster, Taif, Saudi Arabia
3 School of Physiotherapy, Faculty of Medicine, Nursing and Health Sciences, SEGi University, Kota Damansara, Malaysia

*Corresponding author: Chua Siew Kuan, chuasiew@lincoln.edu.my

"Cite this Article" **Received**: 27 March 2026; **Accepted**: 05 May 2026; **Published**: 20 May 2026
Author Contributions: Concept: AAA; Design: AAA, HEF, CSK; Data Collection: AAA; Analysis: HEF, CSK; Drafting: AAA; Critical Revision: HEF, CSK; Final Approval: AAA, HEF, CSK.. **Ethical Approval**: Akhtar Saeed College of Rehabilitation Sciences, Lahore, Pakistan. **Informed Consent**: Written informed consent was obtained from all participants; **Conflict of Interest**: The authors declare no conflict of interest. **Funding**: No external funding; **Data Availability**: Available from the corresponding author on reasonable request; **Acknowledgments**: N/A.

ABSTRACT

Background: Upper-body postural deviations, including forward head posture, thoracic hyperkyphosis, rounded shoulder posture, and altered scapular positioning, are increasingly reported among school-aged children and adolescents. These adaptations emerge during a critical period of skeletal growth, neuromuscular maturation, lifestyle change, and increasing exposure to sedentary behavior. Although age, body mass index (BMI), physical activity, and school-related ergonomic factors have been individually associated with pediatric posture, integrated developmental and biomechanical explanations remain limited. **Objective:** This narrative review aimed to synthesize current evidence on how developmental maturation and BMI-related biomechanical loading influence upper-body postural adaptations, neck–shoulder muscle performance, and postural control in typically developing school-aged children and adolescents aged 6–18 years. **Methods:** A structured narrative literature search was conducted using PubMed, Scopus, and Google Scholar for English-language peer-reviewed studies published between 2010 and 2025. Eligible studies examined head, cervical, thoracic, shoulder, or scapular alignment; neck or shoulder strength; BMI or obesity; physical activity; sedentary behavior; or school-related postural exposures in school-aged populations. Cross-sectional, longitudinal, experimental, interventional, and review studies were considered. Approximately 65 studies were synthesized thematically according to developmental and biomechanical domains; no quantitative pooling or formal risk-of-bias scoring was performed because of methodological heterogeneity. **Results:** Evidence indicates that age-related growth influences cervical alignment, thoracic curvature, shoulder protraction, scapular positioning, and neck–shoulder strength through changing body proportions, spinal maturation, and evolving neuromuscular control. Elevated BMI was associated with anterior mass displacement, increased cervical–thoracic loading, thoracic hyperkyphosis, forward head posture, rounded shoulders, reduced relative muscular strength, and poorer postural stability. Sedentary behavior, screen exposure, low physical activity, asymmetric loading, and inadequate school ergonomics further reinforced maladaptive alignment patterns. **Conclusion:** Upper-body posture in school-aged children reflects a multifactorial interaction between developmental maturation, biomechanical loading, neuromuscular function, and behavioral exposure. Developmentally sensitive screening that integrates posture, BMI or body composition, physical activity, ergonomics, and functional strength assessment may support early prevention and targeted intervention. **Keywords:** Upper-body posture; Forward head posture; Thoracic kyphosis; Shoulder alignment; Scapular positioning; Body mass index; Muscle strength; School-aged children.

INTRODUCTION

Upper-body posture represents the integrated three-dimensional alignment of the head, cervical spine, thoracic spine, scapulae, and shoulder girdle in relation to the body's center of mass and base of support (1). In children and adolescents, this alignment is not fixed but changes continuously in response to skeletal growth, maturation of neuromuscular control, evolving body proportions, lifestyle behaviors, and external mechanical demands (2,3). Optimal postural alignment allows the cervical, thoracic, and scapular musculature to function within efficient length–tension relationships, supporting spinal stability, upper-limb movement, respiratory mechanics, and postural endurance (4). Conversely, deviations such as forward head posture, thoracic hyperkyphosis, rounded shoulders, and altered scapular positioning may increase mechanical stress on spinal and shoulder structures, compromise muscle performance, and contribute to pain, fatigue, reduced physical function, and impaired movement quality during a critical period of musculoskeletal development (5).

The school-age period is particularly important because it coincides with rapid growth, changing spinal curvatures, maturation of sensorimotor control, and increasing exposure to sedentary educational and recreational behaviors. During childhood and adolescence, growth of the spine and limbs may temporarily outpace the development of postural muscle strength and coordination, creating periods of vulnerability to maladaptive alignment patterns (6,7). At the same time, prolonged classroom sitting, digital device use, reduced outdoor activity, and poorly adapted school ergonomics may reinforce sustained cervical flexion, thoracic rounding, and shoulder protraction (8,9). These behavioral exposures do not act in isolation; rather, they interact with biological maturation and neuromuscular development, making upper-body posture a dynamic indicator of both musculoskeletal health and environmental load during growth.

Epidemiological studies indicate that postural deviations are common among school-aged children and adolescents across diverse populations. Large population-based data from China reported a high prevalence of incorrect posture among children and adolescents, with higher rates observed in girls and older age groups (10). Studies from Brazil, Iran, and other settings have similarly reported frequent involvement of the head, shoulder, and spine, including forward head posture, rounded shoulders, and thoracic hyperkyphosis (11–13). Although prevalence estimates vary considerably across regions and measurement methods, the consistency of these findings suggests that upper-body postural deviations represent a widespread pediatric musculoskeletal concern rather than an isolated clinical observation. This variability also highlights the need to interpret posture in relation to age, sex, growth stage, body composition, lifestyle, and assessment technique.

Body mass index and excess adiposity add an important biomechanical dimension to postural development. Children with overweight or obesity may experience altered load distribution, anterior displacement of body mass, increased axial and shear forces, and greater muscular demands for maintaining upright alignment (14,15). These mechanical changes may contribute to forward head posture, increased thoracic curvature, shoulder protraction, altered scapular orientation, and reduced relative neck and shoulder strength, particularly when combined with low physical activity and prolonged sedentary behavior (16,17). However, BMI alone may not fully explain postural variation, because fat distribution, muscle quality, physical fitness, growth stage, sex, and neuromuscular control can modify the relationship between body composition and alignment. Therefore, postural adaptations in children should be understood as multifactorial outcomes rather than as direct consequences of any single risk factor.

Despite a growing body of literature on pediatric posture, existing evidence remains fragmented. Many studies examine isolated outcomes such as craniovertebral angle, thoracic kyphosis, shoulder protraction, scapular asymmetry, muscle strength, or sedentary behavior without integrating these findings into a broader developmental and biomechanical framework. In addition, studies differ substantially in design, population characteristics, posture assessment methods, BMI classifications, and functional measures, limiting direct comparison and making pooled quantitative synthesis difficult. A narrative review is therefore appropriate for this topic because it allows integration of heterogeneous evidence across observational, experimental, biomechanical, developmental, and clinical literature, while emphasizing conceptual relationships and mechanisms rather than estimating a single pooled effect.

This narrative review aims to synthesize current evidence on how developmental maturation and BMI-related biomechanical loading influence upper-body postural adaptations in typically developing school-aged children and adolescents aged 6–18 years. Specifically, it examines age- and BMI-associated changes in forward head posture, thoracic spine curvature, shoulder alignment, scapular positioning, and neck–shoulder muscle strength, while considering the modifying roles of sedentary behavior, physical activity, school ergonomics, and neuromuscular control. By integrating developmental and biomechanical perspectives, this review seeks to clarify mechanisms underlying pediatric upper-body postural adaptations and to inform early screening, prevention, and intervention strategies for promoting long-term musculoskeletal health.

MATERIALS AND METHODS

This narrative review was designed to synthesize developmental and biomechanical evidence on upper-body postural adaptations among typically developing school-aged children and adolescents. The review focused on children aged 6–18 years and examined postural outcomes involving the head, cervical spine, thoracic spine, shoulder girdle, and scapular region, with particular attention to forward head posture, thoracic hyperkyphosis, rounded shoulder posture, scapular positioning, and neck and shoulder muscle performance. A narrative approach was selected because the literature includes heterogeneous study designs, populations, posture-assessment methods, biomechanical outcomes, and developmental variables, making conceptual integration more appropriate than statistical pooling. The synthesis was therefore structured to clarify how age-related maturation, BMI-related loading, lifestyle exposure, and neuromuscular factors interact to influence upper-body alignment during growth.

A structured literature search was conducted using PubMed, Scopus, and Google Scholar to identify peer-reviewed studies published in English between 2010 and 2025. The search focused on developmental, biomechanical, anthropometric, and lifestyle-related determinants of upper-body posture in school-aged children and adolescents. Search terms were combined using Boolean operators and included population terms such as “children,” “adolescents,” and “school-aged”; anthropometric terms such as “body mass index,” “BMI,” “overweight,” and “obesity”; postural terms such as “posture,” “postural alignment,” “forward head posture,” “craniovertebral angle,” “thoracic hyperkyphosis,” “rounded shoulder,” “shoulder alignment,” “scapular positioning,” and “scapular orientation”; and functional terms such as “neck strength,” “shoulder strength,” “muscle endurance,” “postural control,” “physical activity,” “sedentary behavior,” and “school ergonomics.” Reference lists of relevant articles and review papers were also screened to identify additional studies addressing posture, body composition, muscle performance, and biomechanical loading in pediatric populations.

Studies were considered eligible when they examined typically developing children or adolescents within the school-age range and reported evidence relevant to upper-body posture, spinal alignment, shoulder or scapular orientation, neck or shoulder muscle strength, postural control, BMI, obesity, physical activity, sedentary behavior, school-related ergonomic exposure, or developmental maturation. Cross-sectional, longitudinal, experimental, interventional, observational, and review studies were included when they contributed directly to the conceptual understanding of developmental or biomechanical influences on posture. Studies were also considered when they provided clinically relevant information on measurement approaches, including photogrammetry, craniovertebral angle assessment, spinal curvature measurement, acromion-to-wall distance, scapular positioning, dynamometry, endurance testing, or other non-invasive posture and muscle-function assessments.

Studies were excluded when they focused primarily on clinical or pathological populations whose postural adaptations were not representative of typically developing children, including populations with cerebral palsy, neuromuscular disorders, congenital deformities, major orthopedic disease, neurological impairment, or postsurgical conditions. Studies focused exclusively on lower-limb posture, gait mechanics without upper-body postural outcomes, or adult-only samples were not prioritized unless they provided essential biomechanical context directly applicable to the interpretation of pediatric posture. Conference abstracts, theses, editorials, opinion pieces, non-peer-reviewed material, non-English publications, inaccessible full-text articles, and studies with insufficient methodological detail were excluded from the synthesis.

Article selection was guided by relevance to the review objective and by the contribution of each study to one or more prespecified conceptual domains: age-related developmental changes in head posture, thoracic curvature, shoulder alignment, scapular positioning, and neck–shoulder strength; BMI-related biomechanical changes in spinal and shoulder alignment; and behavioral or environmental modifiers such as sedentary behavior, screen exposure, physical activity, backpack carriage, and school ergonomics. Studies were prioritized when they included school-aged participants, reported clearly defined postural or biomechanical outcomes, used recognizable measurement procedures, and contributed evidence to developmental or BMI-related mechanisms. Approximately 65 peer-reviewed studies were included and synthesized narratively.

Data were extracted conceptually rather than statistically. Key information considered during synthesis included author and year, population age range, sample characteristics, study design, geographical setting, BMI or body-composition indicators, postural outcomes, measurement techniques, muscle-strength or endurance outcomes, lifestyle variables, and principal findings relevant to developmental or biomechanical interpretation. Particular attention was given to whether studies examined age-related maturation, sex differences, body composition, obesity, physical fitness, sedentary behavior, or school-related postural exposures. Findings were interpreted according to the direction and consistency of evidence across studies, the developmental stage of participants, the measurement approach used, and the extent to which each study supported either direct pediatric evidence or broader biomechanical inference.

The synthesis followed a thematic and conceptual framework. Evidence was first organized into a developmental perspective, covering age-related adaptations in forward head posture, thoracic spine curvature, shoulder alignment, scapular positioning, and neck and shoulder strength. Evidence was then organized into a biomechanical perspective, focusing on BMI-associated changes in head and cervical alignment, thoracic curvature, shoulder and scapular orientation, and upper-body muscle performance. Within each theme, findings were integrated to identify consistent patterns, contradictory evidence, plausible mechanisms, and clinically relevant implications. Where evidence was heterogeneous, interpretation emphasized conceptual convergence rather than numerical aggregation.

Because of the narrative design, no meta-analysis, pooled effect estimate, formal heterogeneity statistic, publication-bias test, or risk-of-bias scoring system was applied. The included studies varied substantially in design, participant characteristics, posture measurement methods, BMI classification, and functional outcomes, and this heterogeneity supported a narrative synthesis rather than quantitative pooling. The review therefore presents an integrative interpretation of the available evidence, distinguishing observed associations from proposed biomechanical and developmental mechanisms wherever possible. Potential selection bias was addressed by using multiple databases, broad search terms, citation tracking, explicit eligibility criteria, and thematic organization of the evidence, while recognizing that narrative synthesis prioritizes conceptual relevance over exhaustive systematic capture.

RESULTS

Approximately 65 peer-reviewed studies were included in the narrative synthesis. The evidence was organized into two major conceptual domains: developmental adaptations associated with age and maturation, and biomechanical adaptations associated with BMI and body-composition-related loading. Across the included literature, upper-body posture in school-aged children was most commonly assessed through head and cervical alignment, thoracic sagittal curvature, shoulder protraction or rounded shoulder posture, scapular positioning, and neck–shoulder muscle strength or endurance. The synthesis indicated that upper-body postural adaptations are not isolated structural findings but reflect interacting developmental, biomechanical, behavioral, and neuromuscular processes.

The narrative synthesis demonstrated that upper-body posture in school-aged children is shaped by converging developmental and biomechanical influences rather than by a single isolated determinant. Approximately 65 peer-reviewed studies were synthesized across developmental, biomechanical, behavioral, and functional domains.

The strongest and most consistent evidence concerned forward head posture, thoracic hyperkyphosis, rounded shoulder posture, and BMI-related changes in spinal alignment and upper-body muscle performance. Evidence was more heterogeneous for scapular orientation and postural control because studies used different assessment approaches, including craniovertebral angle, thoracic curvature measurement, acromion-to-wall distance, scapular distance, photogrammetry, dynamometry, endurance testing, and observational postural screening.

The developmental evidence indicated that head and cervical posture generally deteriorate with increasing school age. Forward head posture was commonly represented by reduced craniovertebral angle or increased anterior head translation. In school-aged samples, forward head posture was reported in approximately 53.5% of children aged 6–15 years in one postural screening study, while another adolescent study reported a prevalence of approximately 21.3%, with higher values among girls than boys (18,19).

Age-related reductions in craniovertebral angle were particularly evident when younger children were compared with adolescents, suggesting that cervical alignment becomes more vulnerable during later school years (20). This pattern appears to reflect the combined effects of skeletal growth, changing spinal proportions, immature or fatigable postural control, and prolonged flexed-neck behaviors associated with classroom and screen-based activities.

Thoracic curvature showed a consistent developmental pattern across studies. Evidence from healthy pediatric cohorts indicated that thoracic kyphosis increases progressively from childhood into adolescence, with larger cohort findings showing significant age-related increases in thoracic kyphosis and lumbar lordosis across children aged 6–18 years (21,22).

Earlier developmental work also showed that thoracic curvature rises during the growth period, with reported increases from approximately 25° in younger children to more than 35° in older adolescents (23). These findings suggest that increasing thoracic curvature can reflect normal sagittal-plane maturation, but excessive or poorly controlled curvature may become maladaptive when combined with weak spinal extensors, reduced activity, prolonged slumped sitting, or forward head alignment.

Shoulder alignment and scapular positioning also changed across development. Older children and adolescents demonstrated greater acromion-to-wall distance, increased shoulder protraction, and higher prevalence of rounded shoulder posture compared with younger children (24).

Shoulder asymmetry and scapular deviations were reported more frequently during vulnerable growth phases, particularly early school age and puberty, when rapid increases in height and limb length may temporarily disrupt postural control and muscle balance (25). These findings indicate that shoulder posture is closely linked to thoracic alignment: as thoracic kyphosis increases, the scapulae tend to move into greater protraction, anterior tilt, or downward rotation, reinforcing a rounded shoulder pattern.

Age-related changes in neck and shoulder muscle strength followed a more complex pattern. Absolute cervical and shoulder strength generally increased with maturation, reflecting neuromuscular development, increasing muscle mass, and improved motor coordination (26,27).

However, this improvement in absolute strength did not always translate into better postural endurance. Children with forward head posture or rounded shoulders showed reduced cervical and scapular strength in some studies, indicating that postural malalignment may coexist with or contribute to inefficient stabilizer function (28). Therefore, maturation appears to improve strength capacity, while poor alignment, sedentary exposure, and reduced physical activity may compromise the endurance and functional application of that strength.

The BMI-related evidence indicated that elevated BMI and excess adiposity are associated with altered upper-body alignment. Several studies reported that children and adolescents with higher BMI showed smaller craniovertebral angles, greater forward head posture, increased shoulder protraction, and more pronounced thoracic kyphosis compared with normal-weight peers (19-21).

Mechanistically, increased anterior trunk and thoracoabdominal mass may shift the body's center of mass forward, increasing the flexion moment acting on the cervical and thoracic spine. To maintain horizontal gaze and balance, children may adopt compensatory forward head posture, thoracic rounding, and shoulder protraction. The association was not uniform across all studies, suggesting that BMI interacts with body-fat distribution, fitness, maturation, and measurement technique.

Thoracic hyperkyphosis was one of the most clinically relevant BMI-associated outcomes. Comparative evidence showed that children and adolescents with obesity had greater thoracic kyphosis and reduced spinal mobility than normal-weight peers (20). Adolescent data also demonstrated a positive association between BMI and thoracic kyphosis, including in samples with and without scoliosis (22).

These findings support a load-dependent pathway in which anterior trunk mass increases thoracic flexion demand, while reduced extensor endurance and lower physical activity may reduce the capacity to maintain upright alignment. However, some studies indicated that BMI alone may be less informative than regional adiposity, waist circumference, fat-free mass, or overall body composition, suggesting that posture is more closely related to load distribution and muscular capacity than to BMI category alone.

BMI-related shoulder and scapular adaptations were also evident. Children and adolescents with higher BMI tended to show greater shoulder protraction, altered shoulder angles, and increased scapular displacement from the frontal plane (19,23). These findings are biomechanically consistent with anterior trunk loading and thoracic rounding, both of which encourage the scapulae to assume a more protracted and downwardly rotated position.

Muscle imbalance may further reinforce this posture: shortened pectoral musculature, fatigue of thoracic extensors, and reduced activation of the serratus anterior and lower trapezius can limit scapular posterior tilt and upward rotation. Thus, BMI-related shoulder posture appears to reflect both mechanical loading and altered neuromuscular control.

Table 1. Summary Evidence Matrix of Key Studies Included in the Narrative Synthesis

Author / Year	Study Type	Population / Sample	Main Postural or Functional Domain	Key Findings	Evidence Contribution
Yang et al., 2020	Population-based cross-sectional study	595,057 children and adolescents in China	General incorrect posture	Incorrect posture prevalence was 65.3%, with higher rates among girls and older children	Large-scale epidemiological evidence showing high burden of pediatric postural deviations
Batistão et al., 2016	Cross-sectional study	288 children aged 6–15 years	Forward head posture, rounded shoulders, thoracic hyperkyphosis	Forward head posture, rounded shoulders, and thoracic hyperkyphosis were observed in 53.5%, 74.3%, and 30.2% of participants, respectively	Quantifies common upper-body postural deviations in school-aged children

Author / Year	Study Type	Population / Sample	Main Postural or Functional Domain	Key Findings	Evidence Contribution
Abd-Elshafy et al., 2022	Cross-sectional study	288 Egyptian children aged 7–10 years	Forward head posture and trunk extensor endurance	Mean craniovertebral angle was approximately 50°, and forward head posture was associated with reduced back muscle endurance	Links cervical alignment with postural muscle endurance
Szczygieł et al., 2022	Cross-sectional study	Children and adolescents aged 9–15 years	Forward head posture	Adolescents aged 12–15 years showed lower craniovertebral angle than younger children aged 9–11 years	Supports age-related worsening of head alignment
Araychi et al., 2024/2025	Cross-sectional study	Adolescents aged 12–16 years	Forward head posture	Overall forward head posture prevalence was approximately 21.3%, with higher prevalence in girls than boys	Shows sex- and age-related patterning of cervical postural deviation
Camargo et al., 2017	Longitudinal / developmental study	Preschool and school-aged children	Head, thoracic, and shoulder alignment	School-aged children demonstrated greater thoracic curvature and forward acromial displacement than preschool children	Supports developmental transition in postural alignment during early schooling
Tokpınar et al., 2019	Cross-sectional study	Children and adolescents aged 1–16 years	Spinal inclination and sagittal posture	Cervical lordosis tended to decrease with age, whereas thoracic and lumbar curvatures increased	Provides age-related sagittal spinal alignment data
Pesenti et al., 2023	National cohort analysis	1,059 healthy children aged 6–18 years	Spinal sagittal alignment	Thoracic kyphosis and lumbar lordosis increased significantly with age	Strong developmental evidence for progressive spinal curvature changes
Rusek et al., 2021	Observational study	School-aged children during growth	Body composition and posture	Shoulder and scapular deviations were prominent during early school years and puberty	Identifies growth periods vulnerable to postural asymmetry
Li et al., 2024	Cross-sectional survey	Students aged 7–15 years	Rounded shoulder posture	Acromion-to-wall distance and rounded-shoulder prevalence were higher in older children	Supports age-related deterioration in shoulder alignment
Batatolis et al., 2025	Reliability / developmental strength study	Prepubertal and pubertal boys	Cervical muscle strength	Pubertal boys demonstrated higher cervical flexor and extensor strength than prepubertal boys	Shows maturation-related increases in cervical strength

Author / Year	Study Type	Population / Sample	Main Postural or Functional Domain	Key Findings	Evidence Contribution
Mendez-Rebolledo et al., 2022	Cross-sectional strength assessment	Children aged 7–15 years	Upper-limb isometric strength	Shoulder and upper-limb strength increased progressively with age	Supports neuromuscular maturation of shoulder strength
Molina-Garcia et al., 2020	Observational study	Children aged 8–12 years with overweight/obesity	Posture, physical fitness, functional movement	Forward head posture and upper thoracic hyperkyphosis were associated with elevated BMI and reduced fitness	Links BMI, physical fitness, and postural alignment
Bayartai et al., 2022	Comparative study	Children/adolescents with obesity and normal-weight controls	Spinal posture and mobility	Obesity was associated with increased thoracic kyphosis and reduced spinal mobility	Provides biomechanical evidence for obesity-related spinal adaptation
Elsayed et al., 2020	Cross-sectional study	Egyptian adolescents	Craniovertebral and shoulder angles	Higher BMI was associated with smaller craniovertebral and shoulder angles	Supports BMI-related forward head and rounded shoulder patterns
Kasović et al., 2022	Longitudinal study	Children followed over 5 years	Sport participation, fat mass, posture	Increased fat mass and reduced sport participation were associated with poorer posture over time	Longitudinal evidence linking body composition and activity to posture
Valdovino et al., 2019	Comparative adolescent study	Adolescents with and without scoliosis	BMI and thoracic kyphosis	Higher BMI correlated with increased thoracic kyphosis	Supports BMI-related sagittal spinal loading effects
Petrovics et al., 2020/2021	Cross-sectional fitness study	Adolescents with obesity and normal weight	Shoulder muscular strength	Obese adolescents showed lower shoulder muscular performance than normal-weight peers	Links obesity with reduced upper-body muscular function
Domínguez-Barbosa et al., 2025	Body-composition and ultrasound study	Children/adolescents with overweight and obesity	Muscle quality	Greater adiposity was associated with poorer muscle quality and increased intramuscular fat indicators	Supports muscle-quality pathway linking adiposity to postural function

Table 2. Developmental Evidence Synthesis: Age-Related Upper-Body Postural Adaptations

Developmental Domain	Direction of Evidence	Main Postural Adaptation	Proposed Developmental Mechanism	Evidence Strength
Head and cervical alignment	Mostly consistent evidence of worsening alignment with age during school years	Reduced craniovertebral angle and increased forward head posture	Rapid skeletal growth, immature cervical motor control, reduced deep neck flexor endurance, increased sedentary exposure	Moderate
Thoracic curvature	Consistent evidence of age-related increase in thoracic kyphosis	Progressive thoracic rounding and increased sagittal curvature	Growth-related spinal remodeling, vertebral development, reduced extensor endurance, prolonged seated posture	Moderate to strong
Shoulder alignment	Consistent evidence of increasing shoulder	Rounded shoulder posture, forward acromial	Growth-related muscular imbalance, pectoral	Moderate

Developmental Domain	Direction of Evidence	Main Postural Adaptation	Proposed Developmental Mechanism	Evidence Strength
	protraction with age, especially around puberty	displacement, shoulder asymmetry	shortening, delayed scapular stabilizer strength development, unilateral loading	
Scapular positioning	Moderate evidence of maturation-related asymmetry and protraction	Scapular lateralization, anterior tilt, protraction, asymmetry	Pubertal growth, dominant-side loading, schoolbag carriage, reduced postural control	Moderate
Neck and shoulder strength	Consistent evidence of absolute strength increase with age	Increased cervical and shoulder strength during maturation	Neural maturation, increased muscle mass, improved motor coordination	Moderate
Relative postural endurance	Mixed evidence; strength increases with age, but poor posture may reduce endurance	Reduced endurance in children with forward head or rounded shoulder posture	Motor-control inefficiency, fatigue of stabilizers, sedentary behavior	Low to moderate

Table 3. BMI-Related Biomechanical Evidence Synthesis

BMI-Related Domain	Direction of Evidence	Main Postural or Functional Finding	Proposed Biomechanical Pathway	Evidence Strength
Head and cervical posture	Mostly consistent association between elevated BMI and forward head alignment	Smaller craniovertebral angle, increased anterior head translation	Anterior shift in center of mass, increased cervical extensor demand, reduced relative neck endurance	Moderate
Thoracic spine curvature	Generally consistent association between elevated BMI and increased thoracic kyphosis, though some heterogeneity exists	Greater thoracic rounding and reduced spinal mobility	Increased anterior trunk loading, flexion moment at thoracic spine, extensor fatigue, reduced mobility	Moderate
Shoulder alignment	Consistent association between elevated BMI and shoulder protraction	Reduced shoulder angle, greater forward-shoulder posture	Anterior trunk mass, pectoral shortening, scapular stabilizer fatigue, rounded thoracic posture	Moderate
Scapular orientation	Moderate evidence of altered scapular positioning with higher BMI	Scapular lateral displacement, protraction, downward rotation, altered scapulothoracic mechanics	Load redistribution, altered muscle balance, weakness of serratus anterior and lower trapezius	Low to moderate
Neck and shoulder strength	Consistent evidence of reduced relative strength in overweight/obese children and adolescents	Lower relative shoulder strength, reduced endurance, poorer functional performance	Higher body mass demand, intramuscular adiposity, neuromuscular deconditioning, reduced physical activity	Moderate
Postural control	Moderate evidence of poorer balance and postural stability with obesity	Reduced postural complexity and impaired stability	Increased body inertia, altered sensory integration, greater muscular demand	Moderate

Table 4. Integrated Mechanistic Framework Linking Developmental, Biomechanical, and Behavioral Factors

Upstream Factor	Intermediate Mechanism	Primary Postural Outcome	Functional Consequence
Age-related skeletal growth	Changing spinal curvature and body proportions	Increased thoracic kyphosis and compensatory forward head posture	Altered spinal loading and postural control demand
Pubertal growth acceleration	Temporary mismatch between bone growth and muscle strength	Shoulder protraction and scapular asymmetry	Reduced postural endurance and altered shoulder mechanics
Elevated BMI	Anterior center-of-mass displacement and increased axial loading	Forward head posture, thoracic hyperkyphosis, rounded shoulders	Increased cervical and thoracic extensor demand
Increased adiposity	Reduced relative strength and poorer muscle quality	Reduced neck and shoulder stabilizing capacity	Early fatigue and impaired postural maintenance
Prolonged sitting and screen exposure	Sustained cervical flexion and thoracic rounding	Forward head posture and rounded shoulder posture	Muscle imbalance and reduced postural variability
Low physical activity	Reduced strengthening stimulus for postural muscles	Poorer spinal and shoulder control	Reduced functional fitness and endurance
Backpack carriage / asymmetric loading	Unequal shoulder and trunk loading	Shoulder asymmetry and scapular malposition	Altered scapulothoracic rhythm
Poor school ergonomics	Mismatch between furniture, body size, and task demand	Slumped sitting, cervical flexion, thoracic kyphosis	Accumulated mechanical strain

Table 5. Evidence Gradient Across Main Postural Outcomes

Outcome	Developmental Association	BMI Association	Behavioral / Environmental Association	Overall Evidence Pattern
Forward head posture	Moderate evidence of age-related increase, especially in older schoolchildren and adolescents	Moderate evidence linking elevated BMI with smaller craniovertebral angle	Strong conceptual and observational support from screen use and prolonged sitting	Multifactorial outcome with developmental, biomechanical, and behavioral drivers
Thoracic hyperkyphosis	Moderate to strong evidence of progressive increase with age	Moderate evidence linking elevated BMI and anterior trunk loading with greater curvature	Strong support from sedentary posture and reduced activity	Strongly influenced by sagittal growth pattern and mechanical loading
Rounded shoulder posture	Moderate evidence of increasing prevalence with age and puberty	Moderate evidence linking elevated BMI with shoulder protraction	Strong support from sitting, writing, device use, and backpack habits	Closely related to thoracic kyphosis and scapular stabilizer function
Scapular malposition	Moderate developmental evidence, especially around puberty	Low to moderate BMI-related evidence	Moderate evidence from unilateral loading and activity patterns	Evidence is clinically plausible but measurement methods vary
Neck and shoulder strength	Moderate evidence of age-related absolute strength gains	Moderate evidence of reduced relative strength with elevated BMI	Moderate evidence that inactivity and sedentary behavior reduce endurance	Strength increases biologically with age but may be functionally compromised by posture and adiposity
Postural control	Moderate developmental evidence related to maturation	Moderate evidence of impairment with elevated BMI	Moderate evidence from physical inactivity and reduced movement variability	Postural control reflects combined sensory, motor, and mechanical demands

The synthesis also showed that elevated BMI is associated with poorer upper-body muscle performance, particularly when strength is expressed relative to body mass. Obese adolescents demonstrated lower shoulder muscular performance than normal-weight peers, and body fat percentage was inversely associated with normalized upper-extremity strength in broader strength assessments (24,25). Evidence from muscle-quality studies further suggested that greater adiposity may be associated with increased intramuscular fat indicators and reduced contractile efficiency (26).

These findings support a pathway in which excess adiposity increases mechanical demand while simultaneously reducing relative muscular capacity, creating a mismatch between postural load and stabilizing strength. Behavioral and environmental factors modified both developmental and BMI-related postural patterns.

Prolonged sitting, digital device use, reduced sport participation, backpack carriage, and poor school ergonomics were repeatedly linked with forward head posture, thoracic rounding, shoulder protraction, and reduced postural endurance (27,28). Longitudinal evidence suggested that increased fat mass and reduced sport participation were associated with poorer posture over time (19). This indicates that posture during growth is not simply a structural consequence of age or BMI, but a biopsychomechanical outcome shaped by daily exposure, movement variability, physical fitness, and the mechanical demands of the school environment.

Overall, the evidence supports an integrated model in which age-related growth alters spinal curvature, body proportions, muscle strength, and sensorimotor control, while elevated BMI increases mechanical load and reduces relative postural capacity. These developmental and biomechanical influences are further amplified by sedentary behavior, screen exposure, low physical activity, and school-related ergonomic stress.

The most consistent postural outcomes across the reviewed literature were forward head posture, thoracic hyperkyphosis, rounded shoulder posture, and reduced relative neck–shoulder muscle performance. Scapular orientation and postural control were also clinically important, although the evidence was more heterogeneous because of variation in measurement methods and study populations.

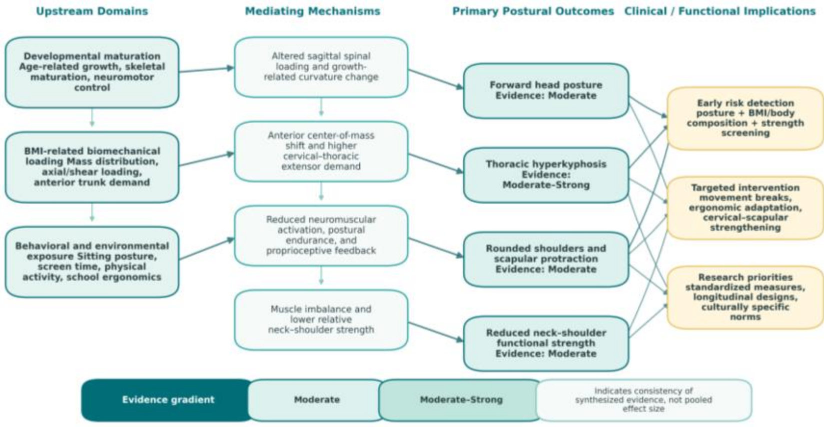

Figure 1. Integrated Evidence-Gradient Framework for Upper-Body Postural Adaptations in School-Aged Children

This figure synthesizes the review's major evidence pathways by showing how developmental maturation, BMI-related biomechanical loading, and behavioral/environmental exposure converge through altered spinal loading, anterior center-of-mass displacement, reduced neuromuscular activation, proprioceptive changes, and muscle imbalance. These pathways map onto four clinically relevant outcomes: forward head posture, thoracic hyperkyphosis, rounded shoulders/scapular protraction, and reduced neck–shoulder functional strength. The evidence-gradient labels distinguish outcomes supported by moderate evidence from those supported by moderate-to-strong evidence, reflecting the narrative synthesis approach requested for publication-ready figures. The conceptual basis is grounded in the review's synthesis that upper-body posture is shaped by developmental maturation, biomechanical loading, and behavioral factors, with BMI-related loading influencing cervical, thoracic, shoulder, and strength outcomes.

DISCUSSION

This narrative review synthesized evidence on how developmental maturation and BMI-related biomechanical loading interact with behavioral and environmental exposures to influence upper-body posture in school-aged children. The principal finding is that postural adaptations such as forward head posture, thoracic hyperkyphosis, rounded shoulder posture, scapular protraction, and reduced relative neck–shoulder muscular performance are best understood as multifactorial outcomes rather than isolated anatomical deviations. Across the reviewed evidence, age-related skeletal growth and neuromuscular maturation appeared to shape sagittal spinal alignment and shoulder-girdle control, while elevated BMI and excess adiposity increased external loading demands on the cervical, thoracic, and scapulothoracic regions. These developmental and biomechanical influences were further modified by sedentary behavior, screen exposure, physical inactivity, backpack carriage, and school ergonomics, indicating that pediatric upper-body posture reflects a dynamic interaction between biological growth and daily mechanical exposure (20–22).

The developmental findings support the concept that childhood and adolescence represent sensitive periods for postural adaptation. Progressive changes in spinal curvature, cervical alignment, and scapular positioning appear to occur alongside growth-related changes in body proportions, muscle strength, proprioceptive control, and motor coordination. Evidence showing age-related increases in thoracic kyphosis and forward head alignment is consistent with the broader understanding that sagittal spinal alignment develops progressively during growth and may become vulnerable during periods of rapid maturation (23,24). However, these adaptations should not be interpreted as uniformly pathological. Some increase in thoracic curvature and change in head–trunk alignment may reflect normal maturation, whereas excessive or persistent deviations may represent maladaptive responses when growth is accompanied by poor postural endurance, insufficient physical activity, or prolonged static positioning. Thus, the clinically important distinction is not simply whether posture changes with age, but whether these changes exceed expected developmental variation and begin to compromise function.

The evidence also indicates that neck and shoulder strength increase with age, but this improvement in absolute strength does not necessarily protect children from poor posture. This apparent paradox may be explained by the difference between absolute force capacity and functional postural endurance. As children mature, increased muscle mass and neural development may improve cervical and shoulder strength; however, habitual forward head posture, thoracic rounding, and shoulder protraction may alter muscle length–tension relationships and increase the sustained demand placed on deep cervical flexors, thoracic extensors, and scapular stabilizers (25,26). Consequently, a child may demonstrate age-appropriate absolute strength while still showing inadequate endurance or inefficient motor control during prolonged sitting, device use, or school tasks. This distinction is important because pediatric postural assessment should include not only static alignment but also functional measures of endurance, strength symmetry, and motor control.

BMI-related findings further reinforce the importance of interpreting posture through a biomechanical lens. Elevated BMI was commonly associated with forward head posture, greater thoracic kyphosis, shoulder protraction, altered scapular orientation, and reduced relative muscular performance. The most plausible mechanism is that increased thoracoabdominal mass shifts the center of mass anteriorly, increasing flexion moments across the cervical and thoracic spine and increasing stabilizing demands on posterior cervical, thoracic, and scapular musculature (27,28). In this context, postural deviations may represent compensatory strategies to maintain gaze, balance, and upright orientation under increased mechanical load. However, the relationship between BMI and posture should not be treated as deterministic. BMI is an indirect measure of body composition and does not distinguish fat mass, lean mass, regional adiposity, or muscle quality. Therefore, children with similar BMI values may show different postural outcomes depending on fitness level, fat distribution, maturation stage, activity exposure, and neuromuscular control.

The relationship between adiposity and upper-body muscle performance is particularly important. Evidence suggests that children and adolescents with overweight or obesity may show reduced relative strength, poorer muscular endurance, and altered postural control compared with normal-weight peers (10,15). Mechanistically, excess adiposity may increase the external load that muscles must support while also reducing relative force production and movement efficiency. Emerging evidence on muscle quality further suggests that intramuscular fat infiltration and altered muscle composition may contribute to reduced contractile efficiency, although this pathway remains less directly established in pediatric postural research than the broader association between obesity and reduced functional fitness (11). Therefore, the interpretation offered here is partly evidence-based and partly mechanistic: the association between elevated BMI and reduced upper-body function is supported by pediatric observational data, while the precise contribution of muscle-quality changes to specific postural deviations requires further longitudinal and imaging-based investigation.

Behavioral and environmental exposures appear to bridge developmental and BMI-related pathways. Prolonged sitting, screen use, reduced sport participation, and low physical activity can reinforce cervical flexion, thoracic rounding, shoulder protraction, and reduced postural variability. These behaviors may also reduce opportunities for strengthening the deep cervical flexors, spinal extensors, scapular retractors, serratus anterior, and lower trapezius. In children with elevated BMI, sedentary behavior may intensify mechanical loading by combining greater body mass with lower relative strength and reduced movement variability. In children undergoing rapid growth, the same exposures may reinforce transient maturational imbalances before neuromuscular control has fully adapted. This convergence helps explain why posture should be viewed as a biopsychomechanical outcome involving growth, load, behavior, and environment rather than as a simple structural defect.

The findings broadly agree with prior literature showing that pediatric postural deviations are common and are associated with age, sex, BMI, physical activity, and sedentary exposure. However, this synthesis advances previous work by integrating developmental and biomechanical explanations into a single framework. Rather than treating forward head posture, thoracic hyperkyphosis, rounded shoulders, scapular malposition, and reduced strength as separate outcomes, the review positions them as interconnected manifestations of altered sagittal loading, muscular imbalance, and neuromuscular adaptation. For example, thoracic hyperkyphosis can encourage compensatory forward head posture to preserve horizontal gaze, while rounded shoulder posture may develop as the scapulae adapt to thoracic rounding and pectoral tightness. Similarly, reduced postural endurance may both contribute to and result from malalignment. This reciprocal interpretation is clinically meaningful because it suggests that interventions targeting one region alone may be less effective than integrated programs addressing cervical, thoracic, scapular, and behavioral components together.

Contradictions across the evidence are also important. Some studies report strong associations between BMI and postural deviations, whereas others suggest that BMI alone has weak or inconsistent relationships with thoracic curvature or forward head posture. These discrepancies are likely explained by differences in posture measurement methods, BMI classification, maturation status, sex distribution, ethnicity, physical activity level, and whether studies assessed total BMI or more specific indicators such as waist circumference, body fat percentage, fat-free mass, or muscle quality. Measurement heterogeneity is especially relevant because craniovertebral angle, forward head distance, thoracic kyphosis angle, acromion-to-wall distance, scapular distance, and photogrammetric indices do not capture identical constructs. Consequently, apparent disagreement between studies may reflect methodological diversity as much as true biological inconsistency. This supports the need for standardized pediatric posture protocols that combine static alignment, dynamic control, body composition, and functional performance.

Several limitations should be considered when interpreting this synthesis. First, the narrative design allowed broad conceptual integration but did not include pooled quantitative estimates, formal risk-of-bias scoring, or meta-analytic assessment of heterogeneity. Therefore, the review is best interpreted as an integrative synthesis of mechanisms and evidence patterns rather than a definitive estimate of effect size. Second, the included studies varied widely in design, with many relying on cross-sectional data; this limits causal inference regarding whether elevated BMI, sedentary behavior, or reduced strength causes postural deviations or whether these factors develop concurrently. Third, heterogeneity in measurement methods and outcome definitions restricts direct comparison across studies. Fourth, the exclusion of non-English literature and the emphasis on peer-reviewed full-text studies may have reduced geographical and cultural breadth. Finally, some mechanistic interpretations, particularly those involving muscle quality, intramuscular adiposity, and long-term structural adaptation, are supported by indirect or emerging evidence and should be distinguished from associations demonstrated directly in school-aged populations.

The clinical implications are substantial. Routine upper-body postural assessment in children should extend beyond visual inspection and include age, maturation stage, BMI or body-composition profile, physical activity level, school behaviors, and functional strength or endurance. Non-invasive tools such as photogrammetry, craniovertebral angle assessment, spinal curvature measurement, acromion-to-wall distance, scapular positioning assessment, and handheld dynamometry may help identify children at higher risk of persistent postural dysfunction. However, interpretation should be developmentally sensitive; the same postural measure may have different clinical meaning in a prepubertal child, a rapidly growing adolescent, and a child with elevated BMI. Screening programs should therefore avoid labeling all deviations as pathological and instead identify patterns associated with functional limitation, pain, reduced endurance, or progressive worsening.

From a school and public health perspective, findings support integrated prevention strategies. Ergonomically appropriate classroom furniture, regular movement breaks, posture education, reduced prolonged static sitting, and structured opportunities for physical activity may reduce cumulative mechanical strain. For children with elevated BMI, interventions should combine general fitness promotion with targeted strengthening of cervical, thoracic, and scapular stabilizers rather than focusing exclusively on weight reduction. For adolescents experiencing rapid growth, programs should emphasize postural awareness, balanced strengthening, flexibility of anterior shoulder and chest musculature, and symmetrical loading habits. These approaches may be particularly useful because many identified mechanisms—sedentary behavior, low postural endurance, poor ergonomic exposure, and neuromuscular deconditioning—are modifiable.

Future research should prioritize longitudinal cohort studies that track posture, body composition, maturation stage, physical activity, muscle strength, and pain or functional outcomes across childhood and adolescence. Such designs are needed to clarify whether postural deviations precede functional impairment or whether they represent adaptive responses to growth and lifestyle exposure. Standardized measurement protocols should be developed for pediatric forward head posture, thoracic kyphosis, rounded shoulders, scapular positioning, and neck–shoulder strength, with normative values stratified by age, sex, maturation stage, and population. Future studies should also compare BMI with more precise body-composition indicators, including waist circumference, body fat percentage, fat-free mass, and muscle-quality measures, to determine which markers best predict postural risk. Finally, intervention trials should evaluate combined ergonomic, behavioral, strengthening, and fitness-based programs, with outcomes extending beyond static posture to include endurance, motor control, pain, respiratory function, participation, and quality of life.

CONCLUSION

Upper-body postural adaptations in school-aged children are shaped by the interaction of developmental maturation, BMI-related biomechanical loading, neuromuscular control, and behavioral exposure. Forward head posture, thoracic hyperkyphosis, rounded shoulder posture, scapular malposition, and reduced relative neck–shoulder functional strength should therefore be interpreted as multifactorial outcomes rather than isolated structural deviations. Age-related growth may alter spinal curvature, shoulder-girdle alignment, and postural control, while elevated BMI and excess adiposity may increase mechanical demand and reduce relative muscular efficiency. These effects are further reinforced by prolonged sitting, digital device use, reduced physical activity, asymmetric loading, and inadequate school ergonomics. Early, developmentally sensitive screening that integrates posture assessment, body-composition indicators, physical activity patterns, and functional strength testing may support timely prevention and intervention. Future research should prioritize longitudinal, culturally diverse, and methodologically standardized studies to establish normative values, clarify causal pathways, and guide evidence-based pediatric postural health strategies.

REFERENCES

1. Molina-Garcia P, Plaza-Florido A, Mora-Gonzalez J, Torres-Lopez LV, Vanrenterghem J, Ortega FB. Role of physical fitness and functional movement in the body posture of children with overweight/obesity. Gait Posture. 2020;80:331-8. doi:10.1016/j.gaitpost.2020.04.001.

2. Ali MG, Abdel Raoof NA, Sedhom MG, Helmy NA, Fawaz HE. Effect of different lumbar lordotic angles on dynamic postural stability in young adults. Fiz Pol. 2020;20(2):142-7. doi:10.56984/8ZG0DC30E.

3. Calcaterra V, Marin L, Vandoni M, Rossi V, Pirazzi A, Grazi R, et al. Childhood obesity and incorrect body posture: impact on physical activity and the therapeutic role of exercise. Int J Environ Res Public Health. 2022;19(24):16728. doi:10.3390/ijerph192416728.

4. Meshgin S, Sheikhhoseini R, Balouchi R. The relationship between upper body posture with physical activity, psychological properties and electronic entertainment using measures in female primary students in Tehran. Iran J Ergon. 2018;6(2):7-15. doi:10.30699/jergon.6.2.7.

5. Azevedo N, Ribeiro C, Machado L. Balance and posture in children and adolescents: a cross-sectional study. Sensors (Basel). 2022;22(13):4973. doi:10.3390/s22134973.

6. Rusek W, Baran J, Leszczak J, Adamczyk M, Baran R, Weres A, et al. Changes in children's body composition and posture during puberty growth. Children (Basel). 2021;8(4):288. doi:10.3390/children8040288.

7. Lee HY, Yong MS. Correlation between forward head posture, round shoulder posture, and muscle activity during the shoulder flexion and abduction task. J Korean Phys Ther. 2023;35(3):83-8. doi:10.18857/jkpt.2023.35.3.83.

8. Đorđević S, Stanković M, Jorgić B, Milenković S, Smailović S, Katanić B, et al. The association of sagittal spinal posture among elementary school pupils with sex and grade. Children (Basel). 2024;11(4):446. doi:10.3390/children11040446.

9. Hendry D, Rohl AL, Rasmussen CL, Zabatiero J, Cliff DP, Smith SS, et al. Objective measurement of posture and movement in young children using wearable sensors and customised mathematical approaches: a systematic review. Sensors (Basel). 2023;23(24):9661. doi:10.3390/s23249661.

10. Annarumma G, Mazza F, Ambrosi A, Keeling E, Fernando F, Sirico F, et al. Sagittal spinal alignment in children and adolescents: associations with age, weight status, and sports participation. Children (Basel). 2025;12(5):659. doi:10.3390/children12050659.

11. Demirci N, Karaca A, Çağlar E, Aksen P, Küçükkubaş N, Çelebi MM, et al. Differences in physical activity, sedentary time, and anthropometric variables among children and adolescents: the TUBON project. Turk J Pediatr. 2024;66(5):511-24. doi:10.24953/turkjpediatr.2024.5300.

12. Moon YJ, Ahn TY, Suh SW, Park KB, Chang SY, Yoon DK, et al. A preliminary diagnostic model for forward head posture among adolescents using forward neck tilt angle and radiographic sagittal alignment parameters. Diagnostics (Basel). 2024;14(4):394. doi:10.3390/diagnostics14040394.

13. Oakley PA, Moustafa IM, Haas JW, Betz JW, Harrison DE. Two methods of forward head posture assessment: radiography vs posture and their clinical comparison. J Clin Med. 2024;13(7):2149. doi:10.3390/jcm13072149.

14. Abd-Elshafy AH, El-Meniawy GH, Abu El Azm WS, El Fakharany MS. The relation of forward head posture with back muscle endurance in primary school children: a cross-sectional study. Bull Fac Phys Ther. 2022;27(1):50. doi:10.1186/s43161-022-00105-8.

15. Ziętek M, Machniak M, Wójtowicz D, Chwałczyńska A. The incidence of body posture abnormalities in relation to the segmental body composition in early school-aged children. Int J Environ Res Public Health. 2022;19(17):10815. doi:10.3390/ijerph191710815.

16. Abelin-Genevois K, Idjerouidene A, Roussouly P, Vital JM, Garin C. Cervical spine alignment in the pediatric population: a radiographic normative study of 150 asymptomatic patients. Eur Spine J. 2014;23(7):1442-8. doi:10.1007/s00586-013-3150-5.

17. Pesenti S, Charles YP, Prost S, Solla F, Blondel B, Ilharreborde B, et al. Spinal sagittal alignment changes during childhood: results of a national cohort analysis of 1,059 healthy children. J Bone Joint Surg Am. 2023;105(9):676-86. doi:10.2106/JBJS.22.00977.

18. Güneş S, Yamak S, Demirhan OE, Sarıkaya AR, Kutlay Ş, Şahinkaya Ş, et al. Relationship of forward head posture with cervical muscle thickness and neck pain-related disability among young adults: a cross-sectional study. Int J Osteopath Med. 2025;57:100770. doi:10.1016/j.ijosm.2025.100770.

19. Willner S, Johnson B. Thoracic kyphosis and lumbar lordosis during the growth period in children. Acta Paediatr Scand. 1983;72(6):873-8. doi:10.1111/j.1651-2227.1983.tb09833.x.

20. Rusnák R, Kolarová M, Aštaryová I, Kutiš P. Screening and early identification of spinal deformities and posture in 311 children: results from 16 districts in Slovakia. Rehabil Res Pract. 2019;2019:4758386. doi:10.1155/2019/4758386.

21. Penha PJ, João SM, Casarotto RA, Amino CJ, Penteado DC. Postural assessment of girls between 7 and 10 years of age. Clinics (Sao Paulo). 2005;60(1):9-16. doi:10.1590/s1807-59322005000100004.

22. Kapo S, Rađo I, Smajlović N, Kovač S, Talović M, Doder I, et al. Increasing postural deformity trends and body mass index analysis in school-age children. Zdr Varst. 2018;57(1):25-32. doi:10.2478/sjph-2018-0004.

23. Mac-Thiong JM, Berthonnaud E, Dimar JR, Betz RR, Labelle H. Sagittal alignment of the spine and pelvis during growth. Spine. 2004;29(15):1642-7. doi:10.1097/01.brs.0000132312.78469.7b.

24. Giglio CA, Volpon JB. Development and evaluation of thoracic kyphosis and lumbar lordosis during growth. J Child Orthop. 2007;1(3):187-93. doi:10.1007/s11832-007-0033-5.

25. Baek CY, Ahn JH, Lee J, Lee HH, Lim WT, Park HK, Kim HD. Effect of digital health corrective posture exercise program on head and shoulder posture in adolescents: a cluster randomized controlled trial. Medicine (Baltimore). 2025;104(12):e41893. doi:10.1097/MD.0000000000041893.

26. Li Y, Zhang S, Li C, Tang Z, Li H, Wang W. Survey on the current status of upper crossed syndrome among students at a special school in Beijing. J Hum Mov Sci. 2024;5(1):88-94. doi:10.23977/jhms.2024.050113.

27. Kasović M, Štefan L, Piler P, Zvonar M. Longitudinal associations between sport participation and fat mass with body posture in children: a 5-year follow-up from the Czech ELSPAC study. PLoS One. 2022;17(4):e0266903. doi:10.1371/journal.pone.0266903.

28. Mandrekar S, Chavhan D, Shyam AK, Sancheti PK. Effects of carrying school bags on cervical and shoulder posture in static and dynamic conditions in adolescent students. Int J Adolesc Med Health. 2019;34(1). doi:10.1515/ijamh-2019-0073.