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Associations of Physical Activity, Sedentary Behavior, and Body Mass Index with Abnormal Posture among Primary School Students: A Cross-sectional Study

This cross-sectional study examined the relationships among physical activity (PA), sedentary behavior (SB), body mass index (BMI), and postural abnormalities in 305 sixth-grade students from urban and rural schools in Shenyang, China. Standardized assessments and mediation analyses were employed. The findings revealed alarming public health concerns, with 84.26% of students showing suspected scoliosis, 51.8% being overweight or obese, and 88.5% engaging in more than two hours of sedentary behavior per day. PA was negatively correlated with both BMI ($r = -0.462$, $p < 0.01$) and postural abnormalities ($r = -0.513$, $p < 0.01$), whereas SB showed positive correlations with BMI ($r = 0.375$, $p < 0.01$) and postural abnormalities ($r = 0.586$, $p < 0.01$). Mediation analysis indicated that PA and SB partially mediated the association between BMI and postural abnormalities. The total effect of BMI (0.059) was partitioned into a direct effect (0.026, 44.07%) and indirect effects through PA (0.015, 25.42%), SB (0.013, 22.03%), and the sequential pathway PA→SB (0.005, 8.48%). These findings suggest that BMI affects postural health not only through direct mechanical loading but also indirectly by reducing PA and increasing SB. The study highlights the urgent need for integrated school-based interventions that promote active lifestyles, reduce sedentary time, and manage body weight to prevent postural abnormalities in children.

Keywords: physical activity, sedentary behavior, body mass index, abnormal body posture, scoliosis, high shoulder, pelvic obliquity, primary school students

Introduction

Abnormal body posture has emerged as a globally prevalent yet frequently overlooked health issue among children and adolescents, with steadily rising prevalence observed in both developed and developing countries over the past decade [1]. Proper posture, defined as the ability to maintain optimal musculoskeletal alignment during both static and dynamic activities, serves as a critical indicator of healthy growth and development [2]. This alignment ensures appropriate biomechanical function, facilitates efficient movement patterns, and prevents premature degenerative changes in joint structures. The developing musculoskeletal system during childhood and adolescence exhibits remarkable plasticity, rendering this developmental period particularly vulnerable to postural deviations while simultaneously offering excellent responsiveness to corrective interventions.

The transformation of modern lifestyles has fundamentally altered physical activity patterns among youth, creating environmental conditions highly conducive to the development of postural problems. Contemporary children encounter an environment characterized by increasingly sedentary behaviors, significantly reduced physical activity levels, and various nutritional challenges that collectively contribute to the rising prevalence of postural abnormalities [3]. Traditional outdoor physical play has been largely replaced by screen-based entertainment, while educational environments have become increasingly sedentary, demanding prolonged sitting with minimal postural variation. Recent epidemiological investigations in China reveal alarming rates of postural abnormalities among youth, with studies indicating that over two-thirds of children and adolescents exhibit multiple postural issues of varying severity [4]. This represents a significant departure from historical norms and underscores the rapidity with which this public health challenge has emerged in rapidly developing regions.

Substantial research evidence has consistently identified physical activity (PA), sedentary behavior (SB), and body mass index (BMI) as key modifiable factors influencing postural development. Longitu-

dinal studies demonstrate that higher PA levels correlate strongly with improved postural outcomes and can serve as a protective factor against the development of abnormalities [5, 6]. Conversely, prolonged sedentary time contributes to gradual spinal misalignment and progressive musculoskeletal deterioration through multiple physiological pathways, including reduced lumbar muscle activity, altered spinal alignment, and connective tissue adaptation [7–9]. The relationship between body weight and postural health demonstrates particular complexity, with elevated BMI identified as a significant risk factor for postural abnormalities. Overweight children show substantially higher prevalence of spinal deviations and musculoskeletal imbalances [10, 11], creating a challenging cycle wherein weight difficulties contribute to postural problems, which in turn further reduce activity levels, thereby exacerbating weight issues.

In today's increasingly competitive educational landscape, students face substantial academic pressures that lead to significantly prolonged study time and corresponding sedentary behavior. The average student now spends between 8–10 hours daily in seated positions for academic activities, creating unprecedented sustained loading on developing spinal structures. Meanwhile, the widespread proliferation of smart electronic devices and the rapid normalization of online learning have further increased screen-based sedentary behavior among students, adding recreational screen time to already extended educational sitting. Under these circumstances, students often unconsciously adopt poor sitting and reclining postures that minimize immediate discomfort at the expense of long-term postural health [7]. Over time, these improper postures become habitual, subtly yet profoundly affecting muscular and joint balance through neurological adaptation and connective tissue remodeling.

The physiological consequences of sustained poor posture are both significant and multifaceted. Prolonged maintenance of improper postures results in uneven joint loading, creating asymmetrical stress distribution across joint surfaces and spinal segments. Contemporary research confirms that low physical activity levels and high BMI represent significant independent and interactive factors in the development of postural abnormalities [8]. The relationship between weight status and postural health appears to follow a U-shaped curve, as both underweight and overweight children demonstrate increased susceptibility to spinal problems compared to normal-weight peers [12], suggesting that optimal postural development requires appropriate nutritional status and body composition.

Postural development is influenced not only by weight status but also by the type and quality of physical activity undertaken. Physical activity patterns demonstrate sport-specific effects, with certain sports like basketball and volleyball associated with increased postural deviations through asymmetrical training loads and repetitive movement patterns, while others like gymnastics promote more symmetrical posture through balanced muscular development [13]. Adolescence represents a critical period for postural development due to rapid growth and hormonal influences, with gender-specific maturation patterns influencing the timing and manifestation of postural issues.

Given the multifactorial nature of postural abnormalities, comprehensive intervention approaches are essential that simultaneously address weight management, physical activity promotion, and sedentary behavior reduction [14]. This integrated understanding represents a significant advancement beyond single-intervention approaches that have demonstrated limited long-term effectiveness. Despite the concerning prevalence of postural issues, substantial grounds for optimism exist, as children and adolescents are in a critical stage of growth and development where postural abnormalities are both preventable and correctable. Early identification and effective intervention during initial stages of abnormality can lead to significant improvement and often complete resolution, particularly when addressing functional rather than structural changes.

This study aims to systematically examine the complex relationships among PA, SB, BMI, and postural abnormalities in school-aged children using comprehensive assessment methods and advanced statistical approaches. By elucidating these relationships and their underlying mechanisms, this research seeks to provide robust evidence for targeted intervention strategies that can be implemented across multiple settings including schools, communities, and healthcare facilities. The ultimate goal is to contribute to the development of effective public health approaches that can reverse current trends and promote optimal postural health for future generations of children and adolescents.

Methods and materials

1 Study Design and Participants

This cross-sectional study was conducted in Shenyang, China to investigate the relationships between physical activity, sedentary behavior, BMI, and postural abnormalities among primary school students. A

multi-stage random sampling method was adopted to ensure representativeness. Initially, four primary schools were systematically selected from both urban and rural districts, accounting for socioeconomic and environmental diversity. From these schools, 305 sixth-grade students were included in the final analysis, achieving a high response rate of 94.4%. All participants satisfied predefined inclusion criteria: (1) enrollment in the sixth grade, (2) voluntary participation with informed parental consent, (3) completion of all assessment components, including questionnaires and physical measurements, and (4) absence of physical limitations or medical conditions that could influence posture or physical activity capacity. This rigorous approach ensured the reliability and validity of the study findings.

2 Measures and Procedures

2.1 Literature Review Methodology

This study conducted a comprehensive literature search across multiple academic databases, including CNKI, Wanfang, Web of Science, PubMed, and Chaoxing Qikan. The search utilized key terms and their derivatives related to: (1) primary school students, children and adolescents; (2) BMI, overweight, obesity; (3) physical activity; and (4) body posture. Both Chinese and English search terms were employed. The systematic literature review enabled the collection and synthesis of relevant domestic and international research. This process helped to clarify current developments in the field, define the research direction and framework, and establish the theoretical foundation for this study. Through critical analysis of existing literature, the study identified research gaps and theoretical perspectives that informed the development of the research methodology and analytical approach.

2.2 Physical Activity Assessment

Physical activity was assessed using the Physical Activity Questionnaire for Adolescents (PAQ-A). Although the PAQ-A was originally developed for adolescents (≥12 years), its applicability was verified in our sample of sixth-grade students (approx. 11-12 years) through pilot testing and reliability analysis, which demonstrated good internal consistency (Cronbach's α = 0.82). The instrument includes 9 items assessing activity frequency and intensity over the previous 7 days on a 5-point Likert scale. The total mean score was categorized into low (1-2), moderate (2-3), and high (>3) activity levels for subsequent analysis [11].

2.3 Sedentary Behavior Evaluation

Sedentary behavior was quantified using the Chinese Adolescent Sedentary Activity Questionnaire (ASAQ-CN), a culturally adapted instrument that demonstrates robust psychometric properties in previous validation studies. This comprehensive tool captures time allocation across five conceptually distinct behavioral domains: screen-based activities (television viewing, computer use, tablet/smartphone engagement), cultural pursuits (instrument practice, stationary hobbies, arts and crafts), transportation modalities (motorized travel time), educational activities (homework completion, supplementary classes), and social interactions (seated conversations, telephone communication). The questionnaire comprises 12 specific items that require respondents to estimate time expenditure in hours for each sedentary activity during both weekdays and weekend days. The scoring methodology involves systematic aggregation of reported hours across all items to compute total daily sedentary time. Particular attention was devoted to training research assistants in standardized administration procedures to minimize recall bias and enhance data accuracy. Participants received detailed instructions with concrete examples to facilitate accurate estimation of time allocation. The instrument's established reliability and validity in previous epidemiological investigations [15] supports its appropriateness for the current study's objectives, providing a comprehensive assessment of sedentary behavior patterns beyond simple screen time metrics.

2.4 Postural Measurements

Postural abnormalities were assessed according to the standardized protocols specified in the national standard "Testing Indicators and Methods for Postural Abnormalities in Children and Adolescents" (2022). The assessment included three key indicators: shoulder asymmetry (measured as bilateral difference in acromion height), pelvic tilt (assessed by height differential of anterior superior iliac spines), and spinal curvature (evaluated using Adams forward bending test with a scoliometer). All evaluators received standardized training prior to data collection. Test-retest reliability was examined with 50 participants at a one-week interval, showing high reproducibility across all measures (all reliability coefficients $R \geq 0.829$, $p < 0.001$),

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with an overall mean reliability of R = 0.861 (see Table 1 for detailed reliability statistics). These results support the consistency of the postural assessment protocol and justify the use of initial measurements in subsequent analyses [16].

2.5 Anthropometric Data

Anthropometric measurements were obtained following standardized protocols using carefully calibrated instruments to ensure data precision. Height was measured to the nearest 0.1 centimeter using a portable stadiometer (Seca 213, Germany), with participants standing barefoot in the Frankfurt horizontal plane position. Weight was assessed to the nearest 0.1 kilogram using a digital scale (TANITA HD-390, Japan), with participants wearing lightweight clothing and removing shoes and heavy accessories. All measurements were conducted in duplicate, and average values were used for analysis. If the two measurements differed by more than 0.5 cm for height or 0.5 kg for weight, a third measurement was obtained. Body mass index (BMI) was calculated using the standard formula: weight in kilograms divided by height in meters squared (kg/m^2). The measurement environment was controlled for consistency, with all assessments conducted in private, well-lit rooms at participating schools. Research staff underwent standardized training to ensure uniform measurement techniques and minimize inter-observer variability, following established anthropometric measurement guidelines.

2.6 Statistical Analysis

Data were analyzed using SPSS 22.0. Descriptive statistics were used to summarize sample characteristics, and independent samples t-tests along with chi-square tests were conducted to examine differences between groups. Pearson correlation analysis was applied to assess bivariate relationships among key variables, with the significance level set at $p < 0.05$. To further investigate the underlying mechanism, a hierarchical regression analysis was performed using Model 6 of the PROCESS macro, which allows testing of sequential mediation pathways. This model was specifically chosen to examine the chain mediation effect of physical activity and sedentary time in the relationship between BMI and postural abnormalities, while controlling for gender and geographical origin.

Results and Discussion

This study provides a comprehensive analysis of the interrelationships between modifiable lifestyle factors and postural health in school-aged children. The findings reveal a complex network of associations that underscore the multifactorial nature of musculoskeletal development during this critical growth period. Our results demonstrate significant correlations between physical activity (PA), sedentary behavior (SB), body mass index (BMI), and various postural abnormalities, with important implications for clinical practice and public health interventions.

1 The Multifaceted Protective Effects of Physical Activity

The strong negative correlation between PA and postural abnormalities ($r = -0.513$, $p < 0.01$) highlights the crucial role of regular exercise in promoting musculoskeletal health. This relationship can be understood through several interconnected mechanisms. First, PA contributes to the development of adequate muscle strength and endurance, particularly in the core stabilizer muscles including the transversus abdominis, multifidus, and oblique muscles. These muscles form a natural "corset" that provides essential dynamic stabilization for the spine during both static postures and movement activities [4, 5]. The strengthening of these muscular supports helps maintain proper spinal alignment and reduces the load on passive spinal structures.

Second, PA enhances neuromuscular control and proprioceptive acuity through continuous feedback mechanisms between muscle spindles, joint receptors, and the central nervous system. This improved sensorimotor integration enables more precise postural adjustments and promotes better body awareness, allowing children to self-correct their posture before significant deviations occur [5]. The variety of movement patterns experienced during different physical activities also plays a vital role in preventing the development of muscular imbalances that often underlie postural abnormalities.

The differential protective effects of PA across various postural measures deserve particular attention. PA showed the strongest negative correlation with spinal curvature ($r = -0.308$), suggesting that activities involving multi-directional movements, such as swimming, gymnastics, and team sports, may be especially beneficial for maintaining spinal health. These activities promote symmetrical development of paraspinal

muscles and encourage full range of motion in all spinal planes. The correlation with uneven shoulders ($r = -0.351$) indicates that upper body exercises and activities promoting scapular stability might be particularly important for preventing shoulder asymmetries.

2 The Compounding Risks of Sedentary Behavior

The robust positive correlation between SB and postural abnormalities ($r = 0.586$, $p < 0.01$) represents a significant public health concern, especially considering that 88.52% of participants exceeded recommended SB limits. The biomechanical consequences of prolonged sitting are particularly detrimental to developing musculoskeletal systems. When children maintain flexed spinal positions for extended periods during electronic device use or studying, their spinal structures experience sustained asymmetric loading. This can lead to viscoelastic "creep" in intervertebral discs and spinal ligaments, reducing their ability to maintain proper alignment and absorb physiological loads [17, 18].

The varying strength of correlations between SB and different postural abnormalities provides insights into specific risk patterns. The strong association with uneven shoulders ($r = 0.440$) suggests that screen-based activities often involve asymmetrical postures, such as tilting the head to hold a phone or leaning to one side while watching television. These habitual positions can lead to muscular imbalances between the dominant and non-dominant sides, particularly affecting the upper trapezius and levator scapulae muscles. The relatively weaker correlation with pelvic tilt ($r = 0.166$) indicates that this particular abnormality may be more influenced by other factors, such as sitting surface characteristics, chair height, and lower body muscle flexibility.

The timing and pattern of SB also merit consideration. Our finding that weekend SB was significantly higher than weekday SB suggests that unstructured leisure time presents particular risks for postural health. This pattern highlights the importance of addressing recreational screen time and promoting active alternatives during non-school hours. The accumulation of SB throughout the day appears to have cumulative effects on postural muscles, leading to fatigue and reduced capacity to maintain proper alignment.

3 BMI as a Mechanical and Behavioral Mediator

The positive correlation between BMI and postural abnormalities ($r = 0.484$, $p < 0.01$) supports the mechanical loading hypothesis, wherein excess body mass increases stress on developing musculoskeletal structures. The anterior distribution of adipose tissue characteristic of childhood obesity displaces the center of gravity forward, necessitating compensatory postural adjustments including increased lumbar lordosis, anterior pelvic tilt, and forward head posture [19]. These adaptations represent the body's attempt to maintain balance but create abnormal loading patterns that can lead to structural changes over time.

Beyond purely mechanical effects, higher BMI appears to influence posture through multiple indirect pathways. Children with obesity often demonstrate different movement patterns and may avoid certain physical activities due to decreased fitness levels, discomfort during movement, or social factors. This reduced participation in varied physical activities limits opportunities for developing adequate muscle strength, coordination, and proprioceptive skills—all essential components of good postural control [20-21]. Additionally, excess adipose tissue can physically limit joint range of motion and alter normal movement mechanics, further contributing to postural adaptations.

The relationship between BMI and specific postural measures reveals important patterns. The correlation with spinal curvature ($r = 0.313$) suggests that excess weight particularly affects the spine's ability to maintain its natural curves, while the association with pelvic tilt ($r = 0.207$) indicates effects on pelvic positioning and lower body alignment. These findings emphasize the importance of weight management as part of a comprehensive approach to postural health.

4 The Interconnected Risk Triad and Clinical Implications

The intercorrelations among PA, SB, and BMI reveal a self-reinforcing risk triad that creates a complex challenge for intervention strategies. The negative correlation between PA and both SB ($r = -0.363$, $p < 0.01$) and BMI ($r = -0.462$, $p < 0.01$), combined with the positive correlation between SB and BMI ($r = 0.375$, $p < 0.01$), suggests that these factors operate synergistically rather than in isolation. This network effect has crucial implications for clinical practice and intervention design.

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From a clinical perspective, assessment of children with postural abnormalities should include comprehensive evaluation of all three lifestyle factors. The differential strength of associations across various postural measures suggests that targeted intervention approaches may be most effective. For children presenting with spinal curvature issues, exercise programs incorporating multi-planar movements, core stabilization, and activities that promote spinal extension may be particularly beneficial. For those with uneven shoulders, interventions should focus not only on strengthening exercises for the upper back and scapular stabilizers but also on modifying specific sedentary behaviors and workstation ergonomics.

The relatively weaker association between studied factors and pelvic tilt indicates that this particular abnormality may be influenced by other determinants not measured in this study, such as congenital factors, leg length discrepancies, or specific musculoskeletal conditions. This finding highlights the need for thorough individual assessment when addressing pelvic alignment issues.

Table 1

Correlation Analysis of Physical Activity, Sedentary Behavior, BMI, and Postural Abnormalities

Variable	1	2	3	4	5	6	7
BMI	1						
Physical Activity	-.462**	1					
Sedentary Time	.375**	-.363**	1				
Postural Abnormalities	.484**	-.513**	.586**	1			
Uneven Shoulders	.320**	-.351**	.440**	.675**	1		
Pelvic Tilt	.207**	-.236**	.166**	.412**	-0.003	1	
Pinal Curvature	.313**	-.308**	.401**	.650**	.171**	-.146*	1

Note. **Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

5 Mediating Effects of Physical Activity and Sedentary Behavior between BMI and Postural Abnormalities

This study established a mediation model to examine whether physical activity (PA) and sedentary behavior (SB) mediate the relationship between BMI and postural abnormalities in elementary school students, controlling for gender and geographical origin (Fig.). The findings revealed a well-defined path structure: BMI not only directly and positively predicted postural abnormalities ($B = 0.059$, $p < 0.001$) but also exerted influence through three distinct indirect pathways. These include the independent mediating pathway of PA ($B = -0.095 \rightarrow B = -0.154$), the independent mediating pathway of SB ($B = 0.079 \rightarrow B = 0.162$), and the chain mediating pathway of PA → SB ($B = -0.095 \rightarrow B = -0.321 \rightarrow B = 0.162$) (Tab. 2). The persistent significance of BMI's direct predictive effect after incorporating the mediators indicates that PA and SB partially mediate the relationship between BMI and postural abnormalities.

The identified mechanism suggests that BMI influences postural outcomes through multiple channels. Beyond the direct mechanical loading effect, higher BMI indirectly contributes to postural abnormalities by reducing physical activity levels and increasing sedentary time. Specifically, students with elevated BMI tend to participate less in physical activities, and lower PA levels are associated with increased sedentary behavior. Both behavioral patterns independently and synergistically elevate the risk of developing postural abnormalities.

These results underscore the importance of implementing comprehensive intervention strategies for postural abnormalities in elementary school students. Effective approaches should simultaneously address weight management, promote physical activity, and reduce sedentary time. Breaking the observed vicious cycle of "high BMI → low physical activity → high sedentary behavior → postural abnormalities" will contribute to more effective prevention and improvement of postural health in this population.

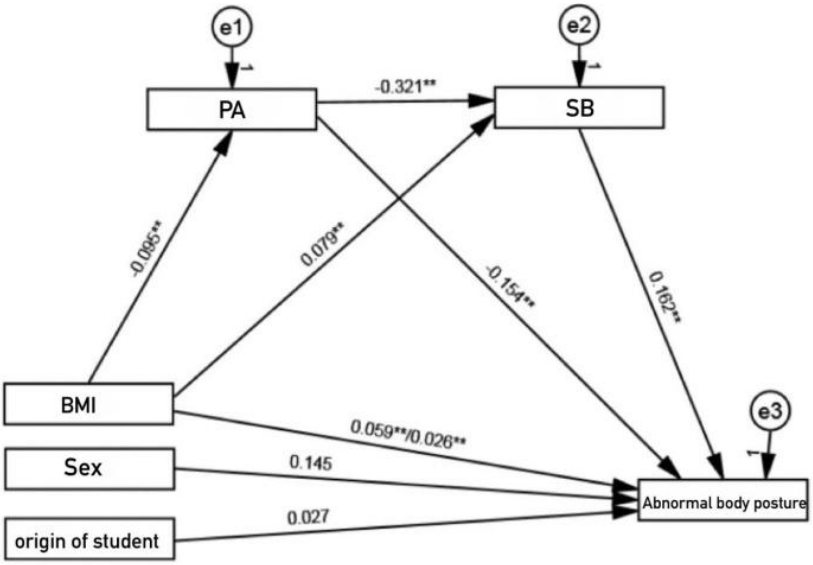

Figure. The Mediating Effect of Physical Activity and Sedentary Behavior on the Relationship Between BMI and Abnormal Body Posture

6 Analysis of the Mediating Effects of Physical Activity and Sedentary Behavior on the Relationship between BMI and Postural Abnormalities

The established chain mediation model reveals a complex network of physiological and behavioral pathways through which BMI influences postural health. The identified pathways demonstrate that the relationship extends beyond simple mechanical loading to encompass intricate behavioral adaptations. The strong negative association between BMI and physical activity (β = -0.413) suggests that increased body mass may create biomechanical constraints that reduce movement efficiency and comfort, thereby discouraging physical activity participation (Tab. 2). This is particularly relevant during the elementary school years when children are developing fundamental movement skills and activity habits. The mediating role of physical activity can be understood through multiple physiological mechanisms. Regular physical activity enhances core muscular strength, particularly in the transversus abdominis, multifidus, and oblique muscles, which provide essential dynamic stabilization for spinal structures. Furthermore, physical activity improves neuromuscular control and proprioceptive acuity through continuous feedback mechanisms between muscle spindles and the central nervous system, enabling more precise postural adjustments and promoting better body awareness.

The positive predictive relationship between BMI and sedentary behavior (β = 0.234) underscores the bidirectional nature of this association. Children with higher BMI may experience increased discomfort during physical activities, leading to greater preference for sedentary pursuits. Simultaneously, prolonged sedentary time contributes to weight gain through reduced energy expenditure, creating a self-perpetuating cycle. The significant positive association between sedentary behavior and postural abnormalities (β = 0.403) can be attributed to the biomechanical consequences of sustained flexed spinal positions during electronic device use and studying, which can lead to viscoelastic "creep" in spinal structures. Notably, the differential effects across various sedentary behavior domains provide insights for targeted interventions. Screen-based activities demonstrated the strongest association with postural abnormalities, particularly affecting shoulder symmetry, while educational sedentary behaviors showed comparatively weaker associations. This pattern suggests that the context and nature of sedentary activities may moderate their impact on postural health.

The quantified mediation effects (PA: 0.015; SB: 0.013; chain: 0.005) provide empirical evidence for developing targeted interventions. The findings suggest that multi-component approaches addressing both weight management and behavioral modifications may yield superior outcomes compared to single-focus interventions. Specifically, programs should aim to break the observed cycle by simultaneously promoting physical activity, reducing recreational screen time, and implementing ergonomic adjustments in school and home environments. For children presenting with postural abnormalities, assessment should include comprehensive evaluation of physical activity patterns, sedentary behaviors, and body composition. The identified pathways suggest that interventions focusing on fundamental movement skill development may be particularly beneficial, as improved motor competence may enhance physical activity participation while reducing

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sedentary time. Additionally, the strong association between weekend sedentary behavior and postural abnormalities highlights the importance of addressing leisure-time activities beyond the school setting.

Table 2

Total Indirect Effects and Mediation Effect Decomposition

Effect Type	Pathway	Effect Size	BootSE	BootLLCI	BootULCI	Propoetio
Direct Effect	BMI⇒Postural Abnormalities	0.026	0.007	0.013	0.040	44.068%
Indirect Effect	BMI⇒PA⇒Postural Abnormalities	0.015	0.004	0.007	0.024	25.424%
	BMI⇒SB⇒Postural Abnormalities	0.013	0.005	0.004	0.023	22.034%
	BMI⇒PA⇒SB⇒Postural Abnormalities	0.005	0.002	0.002	0.009	8.475%
Total Effect	BMI⇒Postural Abnormalities	0.059	0.007	0.045	0.073	

Note. Boot LLCI = lower limit of the 95% confidence interval; Boot ULCI = upper limit of the 95% confidence interval; PA = Physical Activity; SB = Sedentary Behavior. All mediation pathways were tested using bootstrap sampling (n = 5000).

7 Limitations and Future Research Directions

Several limitations of the current study should be acknowledged. The cross-sectional design precludes establishment of causal relationships, and the use of self-reported measures for PA and SB introduces potential recall and social desirability biases. Furthermore, our assessment did not account for several potentially influential confounders, including nutritional status, sleep quality, psychosocial factors, or detailed ergonomic conditions in home and school environments.

Future research should address these limitations through longitudinal designs to establish temporal precedence and better understand the developmental trajectory of these relationships. Incorporation of objective activity monitoring using accelerometers and inclinometers would provide more precise data on activity intensities, patterns, and sitting postures. Investigation of the specific types and contexts of SB most detrimental to postural health would help refine intervention targets. Additionally, research exploring the role of other potential mediators such as muscular endurance, flexibility, and movement competence would provide a more comprehensive understanding of the factors influencing postural health.

Intervention studies testing integrated approaches that simultaneously address PA, SB, and BMI are needed to establish evidence-based guidelines for comprehensive postural health promotion. Such studies should examine not only the efficacy of these interventions but also their implementation in real-world settings such as schools and communities.

Conclusions

This study provides empirical evidence that physical activity (PA), sedentary behavior (SB), and body mass index (BMI) form an interrelated system that jointly influences postural health among school-aged children. The findings clarify the chain mediating effects of PA and SB in the BMI–posture relationship, advancing current understanding of the multifactorial mechanisms underlying postural abnormalities.

The results underscore the importance of integrated rather than single-factor approaches to posture management. Comprehensive strategies should simultaneously promote active lifestyles, reduce sedentary time, and maintain healthy body composition. Schools represent a key platform for implementing such interventions through regular movement breaks, ergonomic classroom designs, and posture education embedded in the curriculum. Family engagement is equally critical, with parents encouraged to model active behavior, set reasonable screen-time limits, and create activity-friendly home environments. Community-level programs offering structured weekend activities can further mitigate sedentary tendencies during leisure time.

Nevertheless, the cross-sectional design restricts causal interpretation. Future longitudinal and interventional studies are needed to validate these pathways and examine long-term outcomes of integrated posture-promoting programs. By emphasizing behavioral and environmental modification during this critical developmental stage, the study provides valuable evidence for multi-level public health strategies to foster healthy postural development among children and adolescents.

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