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Analysis of Risk Factors for Spinal Postural Disorders among Primary School Children

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ABSTRACT

Background: Spinal postural disorders (kyphosis and lordosis) are increasingly prevalent among primary school children during the pre-pubertal phase when the spine remains structurally plastic. Evidence on screen time, physical activity, ergonomics, and nutritional status as simultaneous risk factors remains limited. This study examined their associations and identified the dominant determinant.

Subjects and Method: A cross-sectional study was conducted at an Integrated Islamic Primary School in Bekasi, Indonesia. A total of 240 students aged 9–12 years were enrolled by total sampling. The dependent variable was spinal postural disorder (kyphosis and/or lordosis), assessed by Occiput Wall Distance and Lumbar Wall Distance. Independent variables were screen time, physical activity, learning ergonomics, and nutritional status (BMI-for-age z-score, WHO AnthroPlus). Data were analysed by chi-square, Spearman correlation, multivariable logistic regression, and path analysis (SEM-ML).

Results: Prevalence of spinal postural disorders was 77.5% (kyphosis 55.8%; lordosis 63.3%; both simultaneously 44.2%). High screen time (>2 h/day) was found in 87.5% (mean 4.90±2.10 h/day), 61.7% were physically inactive, and 67.5% had abnormal nutritional status. Multivariable analysis identified BMI (aOR=1.12; 95% CI=1.04 to 1.21; p=0.002), high screen time (aOR=2.18; 95% CI=1.03 to 4.61; p=0.041), and physical inactivity (aOR=2.61; 95% CI=1.27 to 5.35; p=0.009) as independent predictors. Obesity showed the strongest bivariate association (OR=3.80; 95% CI=1.80 to 8.10; p<0.001). Path analysis confirmed BMI as the dominant determinant (total effect=0.38; CFI=1.00; RMSEA=0.00) and physical activity as a partial mediator of the BMI (Sobel z=2.34; p=0.019) and screen time (Sobel z=2.50; p=0.012) pathways.

Conclusion: Obesity, high screen time, and physical inactivity pose a high risk of spinal postural disorders. Weight management, screen time restriction, and increased physical activity are essential.

Keywords: Spinal posture, kyphosis, lordosis, school children, sedentary behavior

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BACKGROUND

Children at primary-school age are in a critical phase of spinal growth, making them particularly susceptible to curvature deviation caused by static postural habits. During this developmental window, excessive sedentary behaviour contributes to the emergence of spinal curvature abnormalities such as kyphosis and lordosis (Dop et al., 2024). Most domestic studies in Indonesia have focused on general health aspects without directly linking exposures to spinal posture (Bull et al., 2020; Hanifah et al., 2023). Yet factors such as physical activity, body-mass index (BMI), and learning ergonomics, specifically school furniture and anthropometry mismatch, have been identified as important determinants of postural development in school children (Castellucci et al., 2017; Brzęk et al., 2017; Maciel et al., 2018).

Screen time is one of the most rapidly growing behavioral exposures among school-aged children worldwide. The proliferation of smartphones, tablets, and digital learning platforms has substantially increased the average daily screen exposure, particularly following the COVID-19 pandemic when remote schooling became widespread (Dop et al., 2024).

From a biomechanical standpoint, prolonged screen use induces a characteristic forward-head posture and cervical flexion, which increases the effective compressive load on the cervical spine from approximately 4.5 kg in the neutral position to as much as 27 kg at 60 degrees of neck flexion (Bridger, 2018). This sustained mechanical stress, when repeated daily over months or years, may contribute to progressive changes in vertebral alignment and the development of thoracic kyphosis. A longitudinal study in Finland involving nearly 1,000 students aged 10–15 years demonstrated that excessive screen time was significantly associated with increased neck and shoulder pain over two years of follow-up (Pirnes et al., 2022). Experimental studies further confirmed that high screen exposure is related to deterioration of postural quality, including a tendency toward kyphosis and lordosis (Dop et al., 2024). A scoping review of smartphone use and postural changes in children and adolescents confirmed that screen use exceeding three hours per day significantly increased the risk of forward head posture (Ellis Sandoval et al., 2025). Despite this growing body of evidence, most studies are conducted in high-income countries, and data from Indonesian urban school settings remain scarce.

Physical activity plays a dual protective role in spinal postural health. First, regular physical activity strengthens the core and postural musculature particularly the transversus abdominis, multifidus, and erector spinae which are essential for maintaining spinal alignment (Grabara and Witkowska, 2024; Mahardhika et al., 2026). Second, physical activity reduces the total daily duration of sedentary postures that are mechanically harmful to the spine. The World Health Organization (WHO, 2020) recommends a minimum of 60 minutes of moderate-to-vigorous physical activity per day for children aged 5–17 years; however, Indonesian national data indicate that approximately 57% of children fail to meet this threshold (Hanifah et al., 2023).

The relationship between physical inactivity and spinal postural disorders has been confirmed in several cross-sectional studies among school-age children across diverse geographical settings (Grabara and Witkowska, 2024; Mrozkowiak et al., 2020), yet the magnitude of association and whether physical activity mediates the effects of other risk factors have not been adequately quantified in the Indonesian context.

School furniture ergonomics represents an often overlooked structural determinant of spinal posture. When desk and chair dimensions do not conform to the child's anthropometric measurements, particularly sitting elbow height and popliteal height, children are compelled to adopt compensatory postures such as trunk flexion, asymmetric weight bearing, and sustained lumbar flexion (Castellucci et al., 2017).

A systematic review of 22 studies reported that furniture mismatch was prevalent in 70–90% of school settings globally and was independently associated with musculoskeletal discomfort and postural deviation (Castellucci et al., 2017). In Indonesia, a study in Karawang found significant mismatch between school furniture and student anthropometry in most primary schools, with associated increases in musculoskeletal complaints (Yanto et al., 2024). The Indonesian Ministry of Health (Ministry of Health of the Republic of Indonesia, 2017) has issued guidelines on ergonomic standards for primary school furniture; however, compliance and its association with objectively measured postural outcomes have not been systematically evaluated.

Nutritional status, particularly overweight and obesity, exerts direct biomechanical effects on spinal alignment. Excess adipose tissue in the abdominal region shifts the body's centre of gravity anteriorly, induces anterior pelvic tilt, and imposes increased axial loading on the lumbar vertebrae, resulting in compensatory hyperlordosis and secondary thoracic kyphosis (Mrozkowiak et al., 2020).

A meta-analysis of more than 84,000 students in Iran reported an overall prevalence of kyphosis of 13.06% and lordosis of 32.59% (Saeidnejad et al., 2021). In Indonesia, prevalence in Makassar reached 21.9% for lordosis and 27% for kyphosis, while in Bandung the prevalence was 30–40% (Maciel et al., 2018). These postural abnormalities are not only an aesthetic concern but also increase the risk of chronic musculoskeletal pain, functional limitation, and reduced quality of life in adulthood (Sedrez et al., 2015). However, few Indonesian studies have examined the contribution of nutritional status to postural disorders using standardised BMI-for-age z-score classifications alongside other behavioural risk factors simultaneously.

The pre-pubertal period, particularly between 9 and 12 years of age, is a crucial window for non-invasive postural detection and intervention because spinal flexibility and growth are still active, meaning deviations such as kyphosis or lordosis remain functional rather than structural (Yan et al., 2020; Zhao et al., 2025). Simple screening methods such as the wall-distance test have demonstrated acceptable reliability for identifying postural deviation (Kaur et al., 2021), but their use in Indonesian primary schools is rarely reported.

The majority of existing studies have examined screen time, physical activity, ergonomics, and nutritional status as isolated risk factors rather than as simultaneous exposures, and no Indonesian study to date has applied both multivariable logistic regression and path analysis to quantify their independent and interrelated contributions to spinal postural disorders.

The novelty of this study lies in its integrative, multi-exposure design, which allows identification not only of independent predictors but also of the mediating role of physical activity in the pathway from screen time and BMI to postural disorder, using structural equation modelling in a large urban primary-school cohort. This study therefore aimed to examine the associations between screen time, physical activity, learning ergonomics, and nutritional status with spinal postural disorders among primary-school children, and to identify the dominant contributing factor.

SUBJECTS AND METHOD

1. Study Design

This analytic cross-sectional study was conducted at an Integrated Islamic Primary School (Sekolah Dasar Islam Terpadu/ SDIT) in Bekasi City, West Java, Indonesia, in March 2026. Bekasi City was selected because of its urban characteristics, high digital-device penetration, and dense school population, providing an ecologically relevant context for examining screen time and ergonomic exposures. Cross-sectional design was chosen to identify risk-factor associations with the outcome at a single time point; causal inference was not intended.

2. Population and Sample

The target population was primary school students aged 9–12 years (Grades 5 and 6) in urban Bekasi. The source population comprised all eligible students enrolled at the study school. Inclusion criteria were: (1) age 9–12 years; (2) active enrolment in Grade 5 or 6; and (3) written informed consent from a parent or guardian and verbal assent from the student. Exclusion criteria were: (1) diagnosed spinal structural abnormality (e.g., scoliosis, congenital vertebral anomaly); (2) history of spinal surgery or fracture; (3) neurological or musculoskeletal condition affecting posture; and (4) incomplete data. Sample size was calculated using the events-per-variable (EPV ≥ 10) formula for multivariable logistic regression: $n = (10 \times k) / p$, where $k = 6$ predictor variables and $p = 0.25$ (estimated prevalence, Saeidnejad et al., 2021), yielding $n = 240$ (Peduzzi et al., 1996; Riley et al., 2020). Total sampling was applied because the school population matched the calculated requirement exactly.

3. Study Variables

The dependent variable was spinal postural disorder, defined as the presence of kyphosis (Occiput-Wall Distance/ OWD >5 cm) and/or lordosis (Lumbar-Wall Distance/ LWD >4 cm). Independent variables were: (1) screen time (high: >2 h/day; low: ≤2 h/day); (2) physical activity (active: PAQ-C score ≥3.00; inactive: <3.00); (3) nutritional status (BMI-for-age z-score classified as underweight, normal, overweight, or obese per WHO 2007 standards; dichotomized as normal vs. abnormal for logistic regression); and (4) learning ergonomics, assessed separately as desk fit (ergonomic vs. non-ergonomic, tolerance ±5 cm from sitting elbow height) and chair fit (ergonomic vs. non-ergonomic, tolerance ±2 cm from popliteal height). Age and sex were included as confounding covariates.

4. Operational Definition of Variables

Spinal postural disorder was defined as the presence of kyphosis and/or lordosis based on standardized wall-standing measurement.

Kyphosis was defined as an Occiput Wall Distance (OWD) greater than 5 cm, measured as the distance from the occiput to the wall while the student stood with heels, buttocks, and scapulae touching the wall (Wiyanad et al., 2018).

Lordosis was defined as a Lumbar Wall Distance (LWD) greater than 4 cm, measured at the deepest point of the lumbar curve in the same standing position (De Carvalho et al., 2010). Students with OWD >5 cm and/or LWD >4 cm were classified as having a spinal postural disorder; those with OWD ≤5 cm and LWD ≤4 cm were classified as normal.

Screen time was defined as the average daily duration (hours per day) a child spent on screen-based activities, including television, smartphone, tablet, digital gaming, and computer or laptop for entertainment, over the past seven days, measured using the Youth Screen Time Survey Literature-Based Version (YSTS-L).

5. Study Instruments

Spinal posture was assessed using a standardized wall-standing protocol. Occiput Wall Distance (OWD), the distance from the occiput to the wall while standing with heels, buttocks, and scapulae touching the wall, was measured with a millimetre-precision ruler to screen for thoracic kyphosis (cut-off: >5 cm) (Wiyanad et al., 2018). Lumbar Wall Distance (LWD), the maximum distance at the deepest lumbar curve to the wall in the same position, was measured with the same instrument to identify lordosis (cut-off: >4 cm) (De Carvalho et al., 2010). Students with OWD >5 cm and/or LWD >4 cm were classified as having a spinal postural disorder; those with OWD ≤5 cm and LWD ≤4 cm were classified as normal.

Screen time was measured using the Youth Screen Time Survey Literature-Based Version (YSTS-L), which records daily duration (hours/day) across five screen-based activities. Screen time was classified as high (>2 h/day) or low (≤2 h/day) per WHO (2020) and American Academy of Pediatrics (2016) recommendations. Physical activity was assessed with the Physical Activity Questionnaire for Older Children (PAQ-C) Indonesian version, adapted and validated by Andriyani et al. (2024; Cronbach's alpha 0.705–0.712). The mean score of 10 items (scale 1–5) was computed; scores ≥3.00 indicated active and <3.00 indicated inactive. Nutritional status was determined from weight (calibrated digital scale) and height (microtoise) measurements, with BMI-for-age z-scores calculated using WHO *AnthroPlus* software (WHO 2007 reference). Learning ergonomics was evaluated by direct measurement of desk height versus sitting elbow height, and chair seat height versus popliteal height, using a calibrated tape measure and an observation checklist validated against Ministry of Health ergonomics guidelines (Ministry of Health of the Republic of Indonesia, 2017; Aiken's V ≥0.80; inter-rater kappa=0.85).

6. Data analysis

Univariate analysis described sample characteristics and exposure prevalences. Bivariate analysis used the chi-square test for categorical associations and Spearman correlation for continuous predictors against OWD and LWD. Prior to logistic regression, assumptions of no severe multicollinearity (VIF <10, confirmed for all variables) and normality of residuals for path analysis were verified. Multivariable binary logistic regression was used to identify independent predictors after controlling for sex and age; model fit was assessed with the Hosmer–Lemeshow test and Nagelkerke R^2. To examine mediation, path analysis was performed using Structural Equation Modelling–Maximum Likelihood (SEM-ML) estimation with the Sobel test for indirect effects. Because the design is cross-sectional, path coefficients represent statistical associations rather than causal pathways. All analyses were conducted in STATA 17; statistical significance was set at $p<0.05$.

7. Research Ethics

Ethical clearance was obtained from the Health Research Ethics Committee, Health Polytechnics, Ministry of Health of Semarang (No. 140/EA/F.XXIII.38/2026).

RESULTS

1. Sample Characteristics of Study Participants

A total of 240 students participated (Table 1). Male students comprised 55.00% (n= 132) and female students 45.00% (n= 108). Most participants were aged 11 years (32.92%), followed by 9 years (30.00%), 10 years (28.33%), and 12 years (8.75%).

Table 1. Sample characteristics (categorical data)

Characteristics	Frequency (n)	Percentage (%)
Sex		
Male	132	55.00
Female	108	45.00
Age (years)		
9	72	30.00
10	68	28.33
11	79	32.92
12	21	8.75
Total	**240**	**100.00**

The prevalence of spinal postural disorders was 77.5% (Table 2). Lordosis was the most frequent disorder (63.3%), followed by kyphosis (55.8%). Among the 186 students with any disorder, 106 (44.2% of the total sample) had both kyphosis and lordosis simultaneously, 28 (11.6%) had kyphosis alone, and 52 (21.7%) had lordosis alone. High screen time (>2 hours/day) was identified in 87.5% of students (mean= 4.90= SD= 2.10 h/day); 61.7% were physically inactive (mean PAQ-C= 2.70; SD= 1.10); 67.5% had abnormal nutritional status; and 81.3% and 65.8% used non-ergonomic desks and chairs, respectively.

Table 2. Distribution of postural disorders and risk-factor exposures (n= 240)

Variable	Frequency (n)	Percentage (%)
Spinal posture		
Kyphosis (OWD >5 cm)	134	55.80
Lordosis (LWD >4 cm)	152	63.30
Postural disorder	186	77.50
Normal posture	54	22.50
Screen time		
High (>2 hours/day)	210	87.50
Low (≤2 hours/day)	30	12.50
Physical activity		
Inactive (<3.00)	148	61.70
Active (≥3.00)	92	38.30
Nutritional status		
Thin	83	34.58
Normal	78	32.50
Overweight	33	13.75
Obese	46	19.17
Desk fit		
Non-ergonomic	195	81.25
Ergonomic	45	18.75
Chair fit		
Non-ergonomic	158	65.83
Ergonomic	82	34.17

2. Bivariate Analysis

Chi-square analysis showed that screen time, physical activity, and nutritional status were significantly associated with spinal postural disorders (Table 3). Spearman correlation confirmed the same direction of association on continuous outcomes: BMI showed moderate positive correlations with OWD (r=0.41; p=0.001) and LWD (r=0.46; p<0.001); PAQ-C showed moderate negative correlations with OWD (r=−0.34; p=0.003) and LWD (r=−0.37; p=0.001), confirming the protective role of physical activity. Ergonomic non-conformity of desks and chairs showed weak but significant positive correlations with both OWD and LWD (r=0.18–0.27; p<0.05). Age was not significantly correlated with either postural measure (Table 4).

Table 3. Bivariate analysis of risk factors for spinal postural disorders

Variable	OR	95% CI	p
Screen time			
High	2.40	1.10–5.10	0.031
Physical activity			
Inactive	2.90	1.40–6.20	0.004
Nutritional status			
Underweight	1.40	0.70–2.90	0.310
Overweight	2.10	0.90–4.90	0.080
Obese	3.80	1.80–8.10	<0.001
Desk fit			
Non-ergonomic	2.28	1.13–4.62	0.020
Chair fit			
Non-ergonomic	1.95	1.05–3.62	0.033

Spearman correlation analysis confirmed the same direction of association on continuous outcomes. BMI showed moderate positive correlations with OWD (r= 0.41; p= 0.001) and LWD (r= 0.46; p<0.001), while PAQ-C showed moderate negative correlations with OWD (r= -0.34; p= 0.003) and LWD (r= -0.37; p= 0.001), confirming the protective role of physical activity. Ergonomic non-conformity of desks and chairs showed weak but significant positive correlations with both OWD and LWD (r=0.18 to 0.27; p<0.05) (Table 4).

Table 4. Spearman correlation between risk factors and OWD/LWD

Variable	OWD r	OWD p	LWD r	LWD p
BMI (z-score)	0.41	0.001	0.46	<0.001
Screen time (hours)	0.29	0.012	0.31	0.008
PAQ-C	-0.34	0.003	-0.37	0.001
Desk tolerance (cm)	0.18	0.041	0.22	0.029
Chair tolerance (cm)	0.21	0.032	0.27	0.015
Age (years)	0.09	0.210	0.11	0.170

3. Multivariate Analysis with Logistic Regression

Multivariable binary logistic regression (Table 5) identified BMI, high screen time, and physical inactivity as independent predictors after adjusting for sex and age. Each one-unit increase in BMI raised the odds of postural disorder by 12% (aOR=1.12; 95% CI=1.04 to 1.21; p=0.002). Children with high screen time had 2.18-

fold higher adjusted odds (aOR=2.18; 95% CI=1.03 to 4.61; p=0.041); physically inactive children had 2.61-fold higher adjusted odds (aOR=2.61; 95% CI=1.27 to 5.35; p=0.009). Ergonomic desk and chair variables, sex, and age were not statistically significant in the adjusted model. The decline in ergonomics' OR from bivariate to multivariable reflects a near-zero-variance ceiling effect (>65–81% non-ergonomic exposure), consistent with the VIF check (all VIF <1.5). The model demonstrated good fit (Nagelkerke R^2=0.47; Hosmer–Lemeshow p=0.742; classification accuracy 84.2%).

Table 5. Multivariable logistic regression on spinal postural disorders

Independent Variables	aOR	95% CI		p
		Lower Limit	Upper Limit	
BMI (per 1-unit increase)	1.12	1.04	1.21	0.002
High screen time (>2 hours/day)	2.18	1.03	4.61	0.041
Physical inactivity (PAQ-C <3.00)	2.61	1.27	5.35	0.009
Non-ergonomic desk	1.51	0.81	2.82	0.180
Non-ergonomic chair	1.69	0.88	3.23	0.110
Male sex	1.38	0.83	2.29	0.210
Age (years)	1.15	0.98	1.35	0.090
N observation= 240				
Nagelkerke R^2 = 0.47 Hosmer–Lemeshow p = 0.742				
Classification Accuracy = 84.20%				

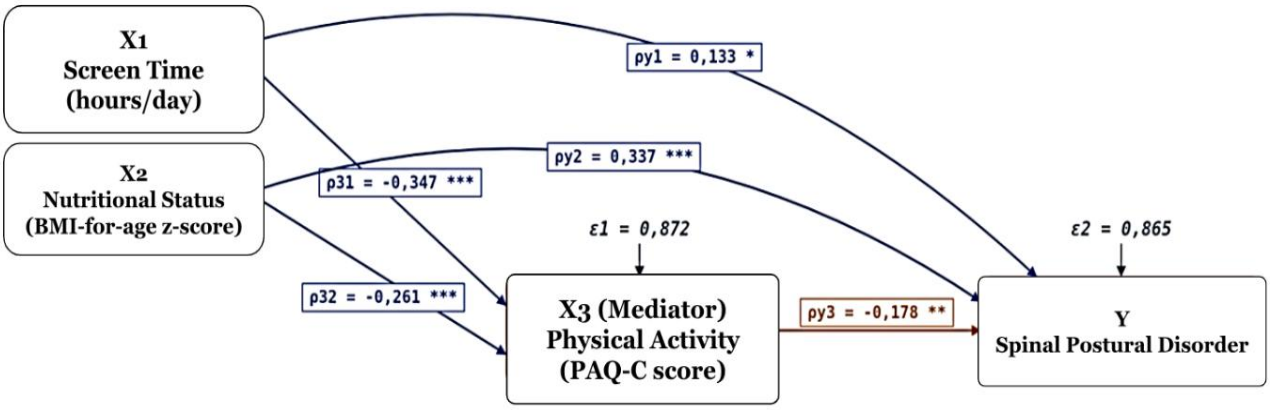

Figure 1. Path analysis model with estimation

4. Multivariate analysis using Path Analysis

a. Structural Model

The structural model (Figure 1) demonstrated that spinal postural disorders were directly influenced by screen time, body mass index (BMI), and physical activity. Screen time and BMI showed positive direct effects on spinal postural disorders, whereas physical activity showed a negative (protective) effect. In addition, screen time and BMI had indirect effects on spinal postural disorders through physical activity, indicating that physical activity partially mediated these associations.

b. Model Fit and Parameter Estimation

Prior to parameter estimation, model fit was evaluated to determine the adequacy of the proposed path model. The initial model included ergonomic variables (desk fit and chair fit); however, these variables were removed during the trimming process because their path coefficients were not statistically significant (desk fit: p=0.275; chair fit: p=0.058). The goodness-of-fit indices indicated an excellent-fitting model, with χ^2(df=2) = 1.82, CFI=1.00, TLI=1.00, RMSEA <0.01, and SRMR=0.02. These findings suggest that the final trimmed model adequately explained the relationships among the study variables.

Table 6 shows that screen time was positively associated with spinal postural disorders (b=0.13; 95%CI=0.03 to 0.23; p=0.012). BMI also had a significant positive direct effect on spinal postural disorders (b=0.34; 95%CI=0.06 to 0.62; p=0.019), whereas physical activity had a significant negative direct effect (b=−0.18; 95%CI=−0.31 to −0.05; p=0.008). Furthermore, physical activity significantly mediated the effects of screen time (b=0.06; 95%CI= 0.01 to 0.11; p=0.012) and BMI (b=0.05; 95%CI=0.01 to 0.09; p=0.019) on spinal postural disorders. Among all predictors, BMI showed the largest total effect (TE=0.38), followed by screen time (TE=0.20), while physical activity remained a protective factor (TE=−0.18).

Table 6. Path analysis on spinal postural disorders (trimmed model)

Dependent Variable		Independent Variable	b	95% CI		p
				Lower Limit	Upper Limit	
Direct effect						
Spinal postural disorder	←	Screen time	0.13	0.03	0.23	0.012
	←	BMI (z-score)	0.34	0.06	0.62	0.019
	←	Physical activity (PAQ-C)	−0.18	-0.31	-0.05	0.008
Indirect effect						
Physical activity (PAQ-C)	←	Screen time	0.06	0.01	0.11	0.012
	←	BMI (z-score)	0.05	0.01	0.09	0.019
Total effect						
Spinal postural disorder	←	Screen time	0.20	0.04	0.36	0.012
	←	BMI (z-score)	0.38	0.06	0.7	0.019
	←	Physical activity (PAQ-C)	−0.18	-0.31	-0.05	0.008

N observation= 240
Goodness of fit: χ^2(df=2)= 1.82
CFI= 1.00; TLI= 1.00; RMSEA <0.01; SRMR= 0.02; CD= 43%

DISCUSSION

This study provides integrative evidence on four modifiable risk factors of spinal postural disorders in pre-pubertal Indonesian primary-school children. The prevalence of postural disorders (77.5%) substantially exceeded the global meta-analytic estimate for kyphosis (13.06%) and lordosis (32.59%) reported by Saeidnejad et al. (2021), but was consistent with Indonesian studies in Bandung (30–40%) and higher than reports from Makassar (kyphosis 27%; lordosis 21.9%). The elevated prevalence likely reflects the combined effect of very high digital exposure (87.5% with screen time >2 h/day; mean 4.90 h/day) and predominantly sedentary school routines (61.7% inactive) in an urban setting. It should be noted that OWD- and LWD-based wall tests are screening tools rather than radiographic measurements; direct comparisons with studies using different assessment methods should therefore be interpreted cautiously.

The significant association between high screen time and postural disorders (aOR=2.18; 95% CI=1.03–4.61; p=0.041) is biomechanically explained by prolonged cervical-flexion posture during digital-device use, which can elevate the effective load on the cervical spine three to five times compared with the normal head weight (Bridger, 2018). This finding aligns with Pirnes et al. (2022) and Ellis Sandoval et al. (2025), who reported that device use exceeding three hours per day significantly increased the risk of forward head posture in school-aged children. In this cohort, the mean screen time of 4.90 h/day substantially exceeded this threshold.

Physical inactivity emerged as a robust independent predictor (aOR=2.61; 95% CI=1.27–5.35; p=0.009) and a partial mediator of both the screen time and BMI pathways, with almost one-third (31.8%) of the total screen-time effect on posture transmitted through reduced physical activity. This dual role positions physical activity as the most strategic leverage point for school-based interventions, in line with WHO (2020) recommendations of at least 60 minutes of moderate-to-vigorous physical activity per day for children aged 5–17 years. Active children develop stronger postural muscles, particularly core muscles (transversus abdominis, multifidus, and erector spinae), which support proper spinal alignment (Grabara and Witkowska, 2024).

Among the studied variables, BMI was the dominant in the path-analysis model (total effect =0.38; 50.7% of total contribution). The mechanism involves increased axial loading on the vertebral column, anterior shift of the body's centre of gravity, anterior pelvic tilt, and compensatory hyperlordosis with secondary thoracic kyphosis (Mrozkowiak et al., 2020). The dose–response association across nutritional categories (overweight OR= 2.10; obesity OR=3.80) supports this biomechanical model. The non-significant category of underweight (OR=1.40; p= 0.310) may reflect a different biomechanical mechanism: relatively lower axial load reduces structural deviation risk despite potential muscle-mass deficit.

Although ergonomic desk and chair fit lost statistical significance in the multivariable model (desk aOR=1.51, p=0.180; chair aOR=1.69, p=0.110), both retained significance in the bivariate analysis and Spearman correlation. The non-significance in the adjusted model most likely reflects a ceiling effect: 81.3% of students used non-ergonomic desks and 65.8% non-ergonomic chairs, creating near-zero variance and limiting the model's ability to estimate risk contrast.

This represents a statistical artefact rather than evidence of biological irrelevance. From a public-health standpoint, the very high prevalence of furniture mismatch supports its relevance as a structural intervention target, particularly given its significance in bivariate analyses and the existing Ministry of Health regulation on school-furniture standards (Ministry of Health of the Republic of Indonesia, 2017).

The limitations of this study include the cross-sectional design that precludes causal inference; the use of self-reported PAQ-C and screen-time logs that may carry recall bias; the absence of direct objective muscle-strength measurement (e.g., Electromyograph); and the single-school setting that limits generalisability. The mediation findings from path analysis should be interpreted as association-based structural patterns, not causal pathways.

Future longitudinal studies in multi-school settings with objective activity monitoring and radiographic confirmation of postural diagnosis are warranted.

Obesity, high screen time, and physical inactivity are independent risk factors for spinal postural disorders in primary-school children, with obesity as the dominant determinant. Integrated school-based interventions, combining active-recess promotion, screen-time regulation, and weight-management programs, should be embedded into the *Usaha Kesehatan Sekolah* (School Health Program) framework, complemented by enforcement of the Ministry of Health regulation on school-furniture ergonomic standards (Ministry of Health of the Republic of Indonesia, 2017). Physical activity represents the most cost-effective single intervention point, as its promotion simultaneously disrupts two risk pathways.

AUTHORS CONTRIBUTION

Zulfa Nadia: Conceptualization, study design, data collection, data management, formal analysis, and original manuscript drafting. Annang Giri Moelyo: Conceptualization, supervision, clinical interpretation of findings, critical review, and manuscript revision. Revi Gama Hatta Novika: Supervision, methodological guidance, and manuscript review and revision. Okid Parama Astirin: Contribution to study design, biological interpretation of results, and manuscript review. Dhoni Akbar Ghozali: Anatomical expertise and consultation, interpretation of spinal anatomy findings, and manuscript review.

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CONFLICT OF INTEREST

There are no conflicts of interest.

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