Rural–urban differences in gross motor coordination and body mass index among Indonesian children aged *7–9 Years*

Diferencias rural–urbanas en la coordinación motora gruesa y el índice de masa corporal en niños indonesios de 7 a 9 años

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Received: 16-04-26
Accepted: 29-05-26

How to cite in APA

Mardiansyah, A., Ramadoni, R., Nurmahmudah, F., Murti, A. T., Marjanto, D. K., & Albana, H. (2026). Rural–urban differences in gross motor coordination and body mass index among Indonesian children aged 7–9 Years. *Retos, 82*, 32-48. https://doi.org/10.47197/retos.v82.119260

Abstract

Introduction: Gross motor coordination is fundamental to children's physical development and is influenced by body mass index and residential context. However, rural–urban differences in the GMC–BMI relationship remain understudied in Indonesian children.
Methodology: A total of 396 children aged 7–9 years from West Sumatra, Indonesia participated in this cross-sectional study. BMI was classified using WHO 2007 standards. GMC was assessed via the KTK3+ battery comprising balance beam, jumping sideways, moving sideways, and eye-hand coordination. MANOVA with post hoc Bonferroni tests and location-specific linear discriminant analyses were conducted.
Results: Rural children significantly outperformed urban peers on BB ($F = 7.474$; $p = .007$; $\eta p^2 = .019$), JS ($F = 26.244$; $p < .001$; $\eta p^2 = .064$), and EHC ($F = 8.508$; $p = .004$; $\eta p^2 = .022$), with the rural advantage widening with age (Age × Location for EHC: $\eta p^2 = .093$). MS showed no significant location effect ($p = .926$). Location-specific LDA revealed that BB was the primary BMI discriminator in rural children ($r = .910$), while JS dominated in urban children ($r = .859$). Critically, 86% of children were underweight or severely underweight, with urban children exhibiting a paradoxically higher severe underweight rate (75.0%) than rural peers (66.3%).
Conclusions: Rural Indonesian children demonstrated superior GMC trajectories across middle childhood. The context-dependent BMI–GMC relationship and the dual burden of undernutrition across both settings demand integrated, location-sensitive physical education and nutritional interventions.

Keywords

Gross motor coordination, BMI, rural–urban, KTK3+, Indonesian children, Physical Education.

Resumen

Introducción: La coordinación motora gruesa es fundamental para el desarrollo físico de los niños y está influenciada por el índice de masa corporal y el contexto residencial. Sin embargo, las diferencias entre zonas rurales y urbanas en la relación entre la coordinación motora gruesa y el IMC siguen siendo poco estudiadas en niños indonesios.
Metodología: Un total de 396 niños de 7 a 9 años de Sumatra Occidental, Indonesia, participaron en este estudio transversal. El IMC se clasificó utilizando los estándares de la OMS 2007. La coordinación motora gruesa se evaluó mediante la batería KTK3+, que comprende equilibrio en barra, saltos laterales, desplazamientos laterales y coordinación óculo-manual. Se realizaron análisis MANOVA con pruebas post hoc de Bonferroni y análisis discriminante lineal específicos por ubicación.
Resultados: Los niños de zonas rurales superaron significativamente a sus pares urbanos en equilibrio en barra ($F = 7.474$; $p = .007$; $\eta p^2 = .019$), saltos laterales ($F = 26.244$; $p < .001$; $\eta p^2 = .064$) y coordinación óculo-manual ($F = 8.508$; $p = .004$; $\eta p^2 = .022$), con una ventaja rural que aumentó con la edad (Edad × Ubicación para coordinación óculo-manual: $\eta p^2 = .093$). Los desplazamientos laterales no mostraron un efecto significativo de la ubicación ($p = .926$). El análisis discriminante lineal específico por ubicación reveló que el equilibrio en barra fue el principal discriminador del IMC en niños rurales ($r = .910$), mientras que los saltos laterales predominaron en niños urbanos ($r = .859$). De manera crítica, el 86% de los niños presentaba bajo peso o bajo peso severo, con los niños urbanos mostrando una tasa paradójicamente mayor de bajo peso severo (75.0%) en comparación con sus pares rurales (66.3%).
Conclusiones: Los niños indonesios de zonas rurales demostraron trayectorias superiores de coordinación motora gruesa durante la niñez media. La relación entre IMC y coordinación motora gruesa dependiente del contexto, así como la doble carga de desnutrición en ambos entornos, exigen intervenciones integradas en educación física y nutrición sensibles a la ubicación.

Palabras clave

Coordinación motora gruesa, BMI, rural–urbano, KTK3+, niños indonesios, Educación Física.

Introduction

Gross motor coordination (GMC) refers to the ability to integrate multiple body movements in a precise, controlled, and efficient manner during locomotive and object manipulation tasks (Biino et al., 2022). As a fundamental dimension of motor competence, GMC plays a critical role in children's physical, cognitive, and psychosocial development. Children with well-developed GMC are more likely to participate in physical activity (PA), demonstrate higher levels of physical fitness, maintain healthier body weight, and experience greater social inclusion among peers (Astuti et al., 2023; Barnett et al., 2016; Stodden et al., 2008). Conversely, poor GMC in childhood has been associated with physical inactivity, lower self-efficacy, social withdrawal, and elevated risk for non-communicable diseases across the lifespan (Canli et al., 2024; Coppens et al., 2019; Rodrigo A. Lima et al., 2021).

From the perspective of Ecological Dynamics, children's gross motor skill development is not solely determined by biological maturation, it is also influenced by the interaction among individual characteristics, task quality, and environmental support (Ramadoni & Adnan, 2026), all of which play a crucial role in facilitating children's successful motor skill development (Newell, 1986; Valadi & Gabbard, 2020). Ecological Dynamics theory further posits that supportive environments can enhance children's engagement in movement experiences that promote motor skill development, including access to play spaces, diverse play equipment, opportunities for social interaction, and the cultivation of a culture that encourages lifelong physical activity (Little & Sweller, 2015). Therefore, differences in motor competence may reflect disparities in environmental opportunities and affordances rather than merely differences in geographical location.

A well-established body of evidence demonstrates that GMC improves progressively with age throughout childhood and adolescence, driven by maturation of the central nervous system, increasing myelination of neural pathways, and accumulated motor experience (D'Hondt et al., 2013; Giuriato et al., 2021). Gender differences in GMC have also been documented, with boys generally outperforming girls on locomotor tasks such as jumping and sprinting, while girls tend to show superior performance on balance-related tasks (Lopes et al., 2018; Mardiansyah et al., 2024) (Lopes et al., 2018; Mardiansyah et al., 2024). These developmental trajectories, however, are not uniform across populations and are substantially shaped by environmental, nutritional, and socioeconomic factors.

Standardised assessment of GMC has advanced considerably with the development and validation of instruments such as the Körperkoordinationstest für Kinder (KTK) (Kiphard & Schilling, 1974, 2007) and its adapted version, the KTK3+ (Coppens et al., 2021). These tools enable age and gender referenced evaluation of motor quotient (MQ) across diverse populations, facilitating cross-national comparisons of GMC development (Biru et al., 2025). Normative data generated from European samples have informed international benchmarks. However, growing evidence highlights the need for region-specific norms that account for cultural, environmental, and health disparities in LMIC contexts (Barnett et al., 2016).

In Indonesia, recent work by Mardiansyah et al. (2023) and Oktarifaldi et al. (2024) established population-specific GMC norms for primary school children aged 7–12 years using the KTK3+. Both boys and girls exhibited consistent age-related GMC improvements, with MQ values broadly within normal classification ranges. These findings were similar by Coppens et al. (2021) from Belgian children, suggesting that basic developmental trajectories of GMC may be cross-culturally robust. However, both Indonesian studies were conducted predominantly in urban or semi-urban settings, leaving the GMC profile of rural Indonesian children (who constitute a substantial proportion of the national population) largely uncharacterised.

A key modifiable determinant of GMC is body composition, particularly BMI (Marmeleira et al., 2017). The relationship between excess body weight and impaired motor coordination is well documented across multiple populations and measurement tools (Almeida et al., 2021; D'Hondt et al., 2013; Giuriato et al., 2019; Mardiansyah et al., 2024). Overweight and obese children consistently demonstrate inferior performance on tasks requiring dynamic balance, bilateral locomotion, and postural control compared to their normal-weight peers. Graf et al. (2004) identified that higher BMI in early childhood is independently associated with poorer GMC and lower endurance capacity, and that this relationship is compounded by inactive leisure behaviours such as prolonged television viewing. Furthermore, Antunes et al. (2015) demonstrated in a large Portuguese sample that the negative association between BMI and

GMC is most pronounced on weight-bearing locomotor tasks, where excess mass creates mechanical disadvantages by shifting the centre of gravity and increasing the muscular demand required to maintain postural stability.

The temporal dynamics of the BMI–GMC relationship are equally important. Lopes et al. (2018) reported a non-linear association between BMI and motor coordination in children aged 6–10 years, suggesting that the detrimental effect of excess weight on GMC intensifies as children progress through middle childhood. Longitudinal evidence further suggests that the relationship between GMC and body weight is bidirectional: poor motor competence may reduce motivation for PA, leading to progressive weight gain, which in turn further impairs GMC, a self-reinforcing negative cycle that has been termed the "developmental spiral of disengagement" (Coppens et al., 2019; Lima et al., 2019; Stodden et al., 2008). Intervening early in this cycle is therefore crucial for supporting healthy motor and weight development trajectories.

In many low- and middle-income countries, including Indonesia, nutritional problems are increasingly characterized by a double burden of malnutrition in which undernutrition coexists with overweight and obesity (Wells et al., 2020). This phenomenon is closely linked to the nutrition transition, where rapid lifestyle and dietary changes occur alongside persistent nutritional inadequacies (Kimenju & Qaim, 2016). Consequently, both overweight and underweight conditions may influence children's motor development trajectories and physical functioning.

While much of the existing literature focuses on the consequences of overweight and obesity on GMC, the impact of underweight (particularly severe underweight) on motor development has received far less systematic attention. Yet in low- and middle-income countries (LMICs) such as Indonesia, undernutrition remains a significant and pervasive public health challenge (Adhyka et al., 2025). The Indonesian Basic Health Survey (RISKESDAS) has documented a dual nutritional burden, approximately 20% of children aged 5–12 years are overweight and 9.2% are obese (Sulistiadi et al., 2023), while simultaneously, stunting and wasting affect substantial proportions of the child population, disproportionately in rural and economically marginalised communities. Undernutrition is associated with reduced muscle mass, impaired neuromuscular function, compromised skeletal development, and lower energy availability, all of which may independently or synergistically impair GMC development (Klein et al., 2023; Lima et al., 2021).

Beyond nutritional status, the rural–urban divide introduces a distinct layer of complexity in understanding GMC development among Indonesian children. Rural environments in Indonesia are characterised by limited school infrastructure (Sulistiadi et al., 2023), fewer organised sport and recreation programmes, lower family incomes, and restricted access to quality physical education. At the same time, rural children may benefit from greater opportunities for unstructured outdoor play, traditional games, and locomotor activities in open natural spaces, all of which are recognised as potent contexts for organic motor skill development (Barnett et al., 2016). Urban children, conversely, may have better access to formal sport and physical education facilities, but face competing pressures from sedentary screen-based leisure, traffic-restricted play environments, and academic demands that can reduce habitual PA (Giuriato et al., 2022; Graf et al., 2004). The net effects of these contrasting contexts on GMC development remain unclear and are likely to differ across age groups, genders, and BMI categories. In addition, other factors such as screen time, a sedentary lifestyle, and fewer opportunities for outdoor play may also contribute to differences in GMC development, particularly among urban children. Increasing exposure to digital media may reduce children's participation in many types of movement-based activities, which are essential for the development of motor skills and physical growth.

Socioeconomic status (SES) is an additional factor that must be considered when evaluating the rural–urban GMC gap. Veldman et al. (2020) demonstrated in a cross-sectional study that lower family income is independently associated with reduced GMC in preschool children, potentially reflecting limited access to movement-rich environments, stimulating toys, and structured PA programmes. In Indonesia, rural communities are disproportionately represented among lower-income households, meaning that observed rural–urban differences in GMC may partially reflect underlying SES gradients rather than geographic location. Disentangling these interrelated influences requires studies that simultaneously assess residential setting, SES, PA habits, and BMI (an approach that remains rare in the Indonesian literature).

Despite growing recognition of GMC as a public health priority, research on motor development in Indonesian children remains limited in both scope and methodological rigour. Most existing studies have been conducted in urban settings, employed non-standardised assessment tools, or failed to stratify findings by rural–urban context or BMI category. Furthermore, the majority of global GMC research originates from high-income countries, where the nutritional, environmental, and socioeconomic profiles of children differ substantially from those prevalent in Indonesia and other LMICs (Barnett et al., 2016). This creates a significant knowledge gap that impedes the development of evidence-based physical education policy and intervention programmes tailored to the specific needs of Indonesian children.

Given these considerations, the present study aimed to compare GMC performance and BMI status between rural and urban primary school children aged 7–9 years in Indonesia and examine the relationship between BMI classification and GMC performance across residential contexts. Rather than assuming directional superiority between environments, the study explored potential differences in GMC and BMI profiles between rural and urban children.

Method

Study Design

This study employed a cross-sectional design to examine rural–urban differences in GMC and BMI among primary school children in West Sumatra, Indonesia. Cross-sectional designs are widely used in paediatric motor development research as they allow efficient characterisation of population-level differences across age, gender, and location at a single point in time The study protocol received ethical approval from the local ethics committee and institutional review board of Universitas Negeri Padang [ethics approval number. Written informed consent was obtained from the parents or legal guardians of all participating children prior to any data collection. Verbal assent was also sought from each child before testing commenced.

Physical education teachers at each school were briefed on the study objectives and cooperated in coordinating testing schedules. On each testing day, anthropometric measurements were taken first in a quiet indoor room, followed by the KTK3+ motor assessment on the school sports field or outdoor area. Children were assessed individually or in small groups of no more than four, ensuring that each child received full attention from the research assistant during their assessment. Testing was conducted between 07:30 am and 12:00 am to avoid the effects of heat fatigue, which is a relevant consideration in the equatorial climate of West Sumatra. Children were encouraged to bring water and were given adequate rest between subtests.

Participants and Sampling

A total of 396 primary school children aged 7–9 years participated in this study, comprising 196 children from rural settings and 200 from urban settings (190 boys, 206 girls). Participants were drawn from public primary schools in rural and urban districts of West Sumatra Province, Indonesia. Schools were selected through purposive cluster sampling, in which rural schools were defined as those located in sub-districts classified as rural (*desa*) according to the Indonesian Central Statistics Agency (BPS) administrative categorisation, and urban schools were those located in sub-districts classified as urban (*kota*). Children were excluded if they had been absent from school for more than two consecutive weeks due to illness in the month preceding testing, had any acute injury at the time of assessment, or if their parents declined to provide consent.

Anthropometric Measurement

All anthropometric assessments were conducted individually in a quiet room at each school on the same day as motor testing, following standardised measurement procedures. Stature was measured to the nearest 0.1 cm using a microtoise/stadiometer with the participant standing without footwear, feet together and flat on the ground, and head positioned in the horizontal plane. Body mass was recorded to the nearest 0.1 kg using a calibrated digital scale, with participants wearing light clothing and no shoes. Each measurement was taken twice and the mean value was used for analysis.

BMI was calculated for all participants using the standard formula: BMI = weight (kg) / height^2 (m^2). Weight status was classified using the WHO 2007 Growth Reference for school-aged children and adolescents, which provides age- and gender-specific BMI-for-age z-score thresholds. Participants were assigned to one of five categories: severely underweight. Underweight, normal weight, overweight, and obese. The WHO 2007 reference was selected in preference to national Indonesian growth charts because it provides internationally comparable BMI classifications and has been validated for use in Indonesian paediatric populations (Sulistiadi et al., 2023).

Gross Motor Coordination Assessment

GMC was assessed using the Körperkoordinationstest für Kinder with third adaptation (KTK3+), an updated version of the original KTK battery developed by (Kiphard & Schilling, 1974). The KTK3+ was validated by (Coppens et al., 2021) in a large Flanders (i.e., the Dutch-speaking part of Belgium) sample (n = 2,271; aged 6–19 years) and has since been adopted in several cross-national studies involving Indonesian children (Mardiansyah et al., 2023, 2024; Oktarifaldi et al., 2024). The KTK3+ retains three subtests from the original KTK (balance beam , jumping sideways and moving sideways, while replacing the hopping-for-height subtest with an eye-hand coordination task (Platvoet et al., 2018), primarily due to safety and time constraints in applied settings. Each subtest was administered according to standardised protocols as follows:

(1) Balance Beam (BB). Children were required to walk backwards along three beams of progressively decreasing width: 6 cm, 4.5 cm, and 3 cm. Each beam was 3 metres in length and elevated 3 cm above the ground. Children completed three trials on each beam, and the total number of steps taken without stepping off the beam was recorded (maximum score: 72 steps across all three beams). Before each trial, children were given one practice attempt to familiarise themselves with the task.

(2) Jumping Sideways (JS). Children stood on one side of a low wooden partition (2 cm high, 60 cm long) and performed rapid bilateral lateral jumps over the partition as many times as possible. Two 15-second trials were administered with a 10-second rest between trials. The total number of successful two-footed jumps across both trials was recorded. A jump was counted as valid only if both feet cleared the partition fully.

(3) Moving Sideways (MS). Two identical wooden boards (25 × 25 cm, elevated 2 cm) were placed side by side on the floor. Children stood on one board, placed the second board to the side, stepped onto it, then retrieved and repositioned the first board, repeating this lateral transfer motion as rapidly as possible for two 20-second trials, with a 10-second rest between trials. The total number of board transfers (each transfer = 1 point) across both trials was recorded.

(4) Eye-Hand Coordination (EHC). Children stood 1 metres from a smooth wall and threw a tennis ball against the wall, catching it with both hands. Two 30-second trials were administered, with a 10-second rest between trials. The total number of successful catches across both trials was recorded. A catch was counted as valid only if the ball was controlled with one hand without being pressed against the body.

Raw scores from each subtest were summed and converted to age- and gender-standardised motor quotient (MQ) values using the normative tables provided by Coppens et al. (2021), where MQ is expressed on a scale with a population mean of 100 and standard deviation of 15. MQ categories are classified as: very good (MQ ≥ 131), good (MQ 116–130), normal (MQ 86–115), below normal (MQ 71–85), and low (MQ ≤ 70). Testing was conducted outdoors on flat, hard-surface areas at each school by a team of trained research assistants who had undergone a standardised two-day training workshop prior to data collection to ensure inter-rater reliability. All assessments were completed in a single session per school.

Data Analysis

All statistical analyses were performed using IBM SPSS Statistics (Version 27.0, IBM Corp., Armonk, NY) and Microsoft Excel (Version 2019). The significance threshold was set at α = .05 for all inferential tests. Descriptive statistics, including means, standard deviations, and frequency distributions were computed for all anthropometric and GMC variables, stratified by location (rural/urban), gender (boys/girls), and age group (7, 8, and 9 years). The Kolmogorov–Smirnov test was used to assess the normality of continuous variables within each subgroup. Levene's test was applied to evaluate the homogeneity of variance assumption.

Linear discriminant analysis (LDA) was conducted to determine the extent to which the four KTK3+ subtest scores could discriminate between children belonging to different WHO BMI categories (severely underweight, underweight, normal weight, overweight, and obese). Canonical discriminant function coefficients were extracted and visualised in a two-dimensional scatter plot (Figure 1). The Wilks' lambda statistic was used to assess the overall significance of group separation, and the standardised canonical discriminant function coefficients were examined to identify the relative contribution of each subtest to group discrimination. A multivariate analysis of variance (MANOVA) was conducted to compare GMC subtest scores and MQ simultaneously between rural and urban children, with age and gender included as covariates to control for their known effects on GMC. Pillai's trace was used as the multivariate test statistic due to its robustness under conditions of unequal sample sizes and mild violations of multivariate normality. Significant multivariate effects were followed by univariate analyses of variance (ANOVAs) for each dependent variable. Post hoc pairwise comparisons were conducted using Tukey's honestly significant difference (HSD) test to identify specific group differences while controlling the familywise error rate. Partial eta-squared (ηp^2) was reported as an index of effect size, with values of .01, .06, and .14 interpreted as small, medium, and large effects, respectively.

Results

Participant Characteristics and Anthropometric Profiles

A total of 396 children completed all assessments and were included in the final analysis (rural: n = 196; urban: n = 200). No participants were excluded due to incomplete data or failure to complete the full KTK3+ battery. The overall sample comprised 190 boys (48.0%) and 206 girls (52.0%), with a mean age of 8.1 ± 0.8 years across the full sample. Table 1 presents descriptive statistics for age, height, weight, and BMI stratified by location, gender, and age category.

Regarding stature, rural boys and girls demonstrated mean heights broadly consistent with WHO 2007 median reference values for their respective ages, while urban children slightly exceeded these reference values across all age groups. This pattern suggests marginally superior linear growth among urban children, potentially reflecting better nutritional conditions or greater access to healthcare in urban settings. Mean heights increased systematically with age in both groups, as expected given the developmental nature of the sample.

For body weight, rural 9-year-olds showed a notably higher mean weight (M = 33.6 ± 8.5 kg) compared to their urban counterparts of the same age (M = 28.2 ± 6.0 kg), despite similar mean heights (rural: 136.7 ± 7.3 cm; urban: 135.0 ± 6.3 cm). This discrepancy contributed to the higher mean BMI observed among rural 9-year-olds (M = 17.8 ± 3.3 kg/m^2) relative to urban 9-year-olds (M = 15.4 ± 2.7 kg/m^2), and likely reflects a greater variability in nutritional status within the rural subsample at this age, as indicated by the larger standard deviation.

MANOVA revealed significant main effects of age on BMI ($F = 8.19$; df = 1; $p < .001$), confirming that BMI increased with advancing age across the full sample ($F = 4.40$; $p < .05$; $\eta p^2 = .024$). A significant main effect of location on BMI was also observed ($F = 10.90$; df = 1; $p < .05$), indicating that rural and urban children differed meaningfully in their BMI profiles. Furthermore, a significant within-group effect was detected ($F = 15.87$; df = 1; $p < .001$), demonstrating that BMI differences between age subgroups were statistically robust within each residential setting. Urban children exhibited a notably stable BMI trajectory across age groups (7 years: M = 15.3 ± 2.9; 8 years: M = 15.4 ± 2.8; 9 years: M = 15.4 ± 2.7 kg/m^2), while rural children showed a more pronounced age-related increase, culminating in the substantially higher mean BMI at 9 years noted above. No significant interaction between age and location was observed for BMI ($p > .05$), suggesting that the age-related increase in BMI followed a broadly parallel trajectory in both settings, albeit at different absolute levels in certain age groups.

Table 1. Means (M) and standard deviations (SD) and sample size for location, gender, age, height, weight, and BMI

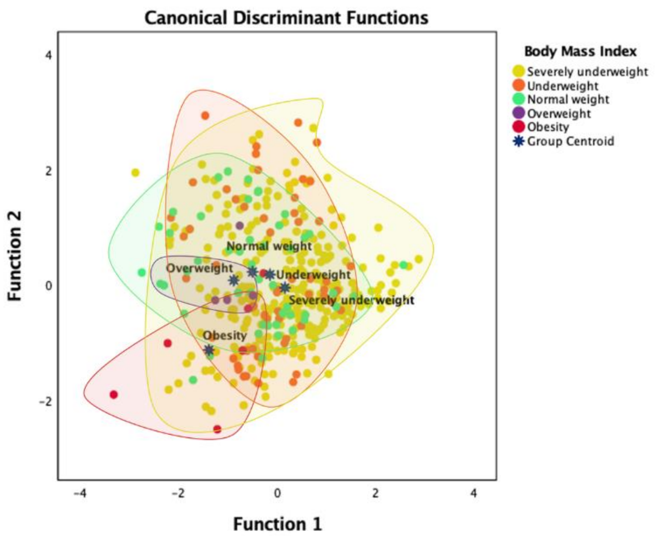
Location	Variables	n	Age, years	Height, cm	Weight, kg	BMI, kg/m²
			M ± SD	M ± SD	M ± SD	M ± SD
Rural	Boys	90	8.1 ± 0.9	129.7 ± 9.1	27.1 ± 7.9	15.8 ± 2.8
	Girls	106	8.0 ± 0.8	127.8 ± 8.5	27.8 ± 7.4	16.8 ± 3.1
	7 years	65	7.2 ± 0.1	122.1 ± 5.8	23.1 ± 4.3	15.4 ± 2.4
	8 years	63	8.4 ± 0.2	126..8 ± 4.6	25.5 ± 4.6	15.8 ± 2.6
	9 years	68	9.3 ± 0.3	136.7 ± 7.3	33.6 ± 8.5	17.8 ± 3.3
	TOTAL	196	8.0 ± 0.8	128.7 ± 8.8	27.5 ± 7.6	16.4 ± 3.0
Urban	Boys	100	8.2 ± 0.9	131.5 ± 7.9	27.1 ± 6.7	15.6 ± 3.2
	Girls	100	8.3 ± 0.8	131.5 ± 8.5	26.3 ± 5.2	15.1 ± 2.4
	7 years	66	7.3 ± 0.1	127.0 ± 7.6	24.7 ± 5.3	15.3 ± 2.9
	8 years	64	8.4 ± 0.1	132.3 ± 8.7	27.1 ± 6.2	15.4 ± 2.8
	9 years	70	9.7 ± 0.2	135.0 ± 6.3	28.2 ± 6.0	15.4 ± 2.7
	TOTAL	200	8.3 ± 0.8	131.5 ± 8.2	26.7 ± 6.0	15.4 ± 2.8

BMI Weight Status Distribution

The distribution of WHO-classified BMI categories across the total sample revealed a striking pattern of nutritional vulnerability (Figure 1). Across the combined sample of 396 children, 71% were classified as severely underweight, 15% as underweight, 12% as normal weight, 1% as overweight, and 2% as obese. Taken together, 86% of all participants fell below the normal weight threshold, while only 3% exceeded it. This distribution deviates markedly from national prevalence estimates reported by Sulistiadi et al. (2023) and suggests that the children sampled in this study (drawn from both rural and urban schools in West Sumatra) represent a population with a substantially elevated burden of undernutrition.

When disaggregated by location, the severely underweight category remained dominant in both settings, though the proportion was notably higher among rural children. Among rural participants, the distribution across BMI categories was as severely underweight (66%), underweight (15%), normal weight (15%), overweight (1%), and obese (3%). Among urban participants, the corresponding distribution was severely underweight (75%), underweight (14%), normal weight (10%), overweight (1%), and obese (1%). These figures reveal an interesting reversal of the expected rural–urban nutritional pattern: urban children in this sample exhibited a higher proportion of severe underweight than their rural counterparts, while rural children showed a comparatively greater proportion of normal weight and obesity. This finding may reflect localised dietary and socioeconomic conditions specific to the West Sumatran communities sampled, and warrants further investigation in future studies with broader geographical coverage.

Figure 1. Canonical discriminant function plot illustrating the discrimination of KTK3+ ability among rural and urban children across five WHO BMI categories (severely underweight, underweight, normal weight, overweight, and obese).



KTK3+ Discrimination Across BMI Categories

LDA was conducted to examine the extent to which KTK3+ subtest scores collectively discriminated between the five WHO BMI categories. For the total sample, the overall discriminant model was statistically significant (Wilks' λ = .889; χ^2 = 46.08; df = 16; p < .001). Four canonical discriminant functions were extracted. Function 1 explained 72.9% of the total between-group variance (eigenvalue = 0.089; canonical correlation = r = .286), and Function 2 explained an additional 26.4% (eigenvalue = 0.032; canonical correlation = r = .177). Together, Functions 1 and 2 accounted for 99.3% of the explained variance, with Functions 3 and 4 contributing negligible variance (0.03% combined). Overall classification accuracy was 70.7% for original grouped cases and 70.5% for cross-validated cases, indicating acceptable discriminant model stability.

The LDA model was statistically significant based on Functions 1 through 4 (Wilks' λ = .889; χ^2 = 46.08; df = 16; p < .001), with only Function 1 contributing meaningful discrimination (eigenvalue = .089; 72.9% of variance; canonical r = .286; p < .001). Function 2 did not reach significance (p = .175). Structure matrix coefficients identified BB (r = .597) and MS (r = .482) as the primary discriminating variables on Function 1, while EHC was the dominant variable on the non-significant Function 2 (r = .858). Group Statistics revealed that obese children consistently scored lowest on BB (M = 39.17), MS (M = 27.50), and EHC (M = 4.67), while severely underweight children demonstrated the highest BB scores (M = 57.98) but among the lowest EHC scores (M = 6.83). Normal-weight children achieved the highest combined EHC performance (M = 10.27). These patterns confirm a task-specific association between BMI status and GMC, weight-bearing locomotor tasks (BB, MS) are most impaired by obesity, while object control performance (EHC) is most strongly associated with nutritional adequacy across the BMI spectrum.

For the rural subsample (n = 196), the discriminant model was significant (Wilks' λ = .849; χ^2 = 31.24; df = 16; p < .05), with Function 1 explaining 74.94% of the variance (eigenvalue = 0.129; r = .338). Overall classification accuracy was 67.35% (cross-validated: 65.82%). For the urban subsample (n = 200), the model was also significant (Wilks' λ = .862; χ^2 = 28.88; df = 16; p < .05), with Function 1 explaining 76.84% of the variance (eigenvalue = 0.119; r = .327). Overall classification accuracy was 75.50% (cross-validated: 74.00%), suggesting that BMI-category-based GMC discrimination was somewhat clearer in the urban group.

Table 2. Eigenvalues and Wilks' Lambda Statistics for Canonical Discriminant Functions Derived from KTK3+ Subtest Scores Across Five BMI Categories.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	.089[a]	72.9	72.9	.286
2	.032[a]	26.4	99.4	.177
3	.001[a]	.6	100.0	.027
4	.000[a]	.0	100.0	.006
Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	.889	46.082	16	.000
2 through 4	.968	12.726	9	.175
3 through 4	.999	.299	4	.990
4	1.000	.016	1	.898

Table 3. Structure Matrix: Pooled Within-Group Correlations Between KTK3+ Subtests and Standardized Canonical Discriminant Functions

Standardized Canonical Discriminant Function Coefficients				
Variables	Function			
	1	2	3	4
Balance Beam	.581	.556	-.135	-.742
Eye-hand Coordination	-.158	-.220	1.180	.228
Jumping Sideways	.785	.073	-.261	.803
Moving Sideways	-.718	.890	-.323	-.102

Table 4. Structure Matrix: Pooled Within-Group Correlations Between KTK3+ Subtests and Standardized Canonical Discriminant Functions.

Structure Matrix				
Variables	Function			
	1	2	3	4
Balance Beam	.597*	.522	.281	-.540
Eye-hand Coordination	-.397	.858*	.045	.325
Jumping Sideways	.066	.400	.894*	.190
Moving Sideways	.482	.478	.012	.734*

Note. Bold values indicate the largest absolute correlation between each variable and any discriminant function. * Largest absolute correlation between each variable and any discriminant function.

Gross Motor Coordination

The Significant main effects were observed for age ($F = 17.84$; $df = 8$; $p < .001$; $\eta p^2 = .158$), gender ($F = 39.29$; $df = 4$; $p < .001$; $\eta p^2 = .292$), and location ($F = 8.45$; $df = 4$; $p < .001$; $\eta p^2 = .081$). In the univariate follow-up tests, significant differences between rural and urban children were found for BB ($F = 7.47$; $df = 1$; $p < .05$; $\eta p^2 = .019$), JS ($F = 26.24$; $df = 1$; $p < .001$; $\eta p^2 = .064$), and EHC ($F = 8.51$; $df = 1$; $p < .05$; $\eta p^2 = .022$). In addition, significant univariate effects were found for all KTK3+ subtests across age ($p < .001$) and gender ($p < .001$). On average, 8-year-old children ($\eta p^2 = .158$) performed better than their 7- and 9-year-old peers. Boys outperformed girls on the JS, MS, and EHC subtests, whereas girls showed better performance on the BB subtest.

Table 5. Summary of Univariate F-Tests for KTK3+

Variables	df	Balance Beam	Jumping Sideways	Moving Sideways	Eye-hand Coordination
Age	2	10.83***	30.57***	16.59***	24.91***
Gender	1	18.96***	21.76***	31.09***	63.22***
Location	1	7.47**	26.24***	0.01	8.51**
Age x Gender	2	3.76*	4.02*	0.05	1.81
Age x Location	2	5.74**	6.73***	9.81***	19.70***
Gender x Location	1	16.98***	0.02	0.21	0.02
Age x Gender x Location	2	4.50*	3.13*	0.818	0.20
R^2		0.20	0.26	0.18	0.31
Adjusted R^2		0.18	0.24	0.15	0.29

Note. * p < .05; ** p < .01; *** p < .001. Dashes (-) indicate interaction terms not included in the final model for those dependent variables.

Motor Quotient

Estimated marginal means from the MANOVA model for BB by age were 7 years ($M = 57.03 \pm 1.01$), 8 years ($M = 60.63 \pm 1.04$), and 9 years ($M = 53.95 \pm 0.98$), confirming a peak at age 8 followed by a decline at age 9 driven by increasing BMI. For JS, estimated marginal means were 7 years ($M = 44.07 \pm 1.06$), 8 years ($M = 55.04 \pm 1.10$), and 9 years (values available from univariate tests), with pairwise Bonferroni comparisons revealing significant differences between all age groups (7 vs. 8: mean difference = −1.45; $p = .041$; 7 vs. 9: mean difference = −3.67; $p < .05$).

By location, estimated marginal means for JS were rural ($M = 61.35 \pm 1.44$) versus urban ($M = 52.71 \pm 1.42$), confirming the significant rural advantage (mean difference = 8.63; $p < .001$). For BB, estimated marginal means were rural ($M = 58.80 \pm 0.84$) versus urban ($M = 55.60 \pm 0.82$). For EHC, the rural group ($M = 8.45 \pm 0.49$) significantly outperformed the urban group ($M = 6.22 \pm 0.48$), with gender-stratified estimates showing rural boys ($M = 11.2 \pm 7.5$) substantially outperforming urban boys ($M = 9.1 \pm 7.2$) and rural girls ($M = 6.1 \pm 6.2$) outperforming urban girls ($M = 4.4 \pm 5.3$).

Table 6. Means (M) and standard deviations (SD) and sample size for individual KTK3+ and the motor quotient by Location, gender and age

			Individual KTK3+ test items				Motor quotient
			BB n steps	JS n jumps	MS n transfer	EHC n catches	
Loc	Variables	n	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD
Rural	Boys	90	58.1 ± 11.4	57.0 ± 13.5	37.9 ± 6.7	11.2 ± 7.5	99.99 ± 15.0
	Girls	106	59.3 ± 11.2	51.2 ± 12.7	34.3 ± 7.1	6.1 ± 6.2	100.02 ± 15.01
	7 years	65	61.4 ± 10.2	44.8 ± 10.1	31.6 ± 5.7	3.0 ± 4.2	90.91 ± 11.44
	8 years	63	61.5 ± 10.3	56.7 ± 10.6	39.2 ± 7.1	9.6 ± 6.7	105.63 ± 14.12
	9 years	68	53.7 ± 11.4	59.8 ± 13.9	37.1 ± 6.4	12.5 ± 7.1	103.42 ± 14.91

	TOTAL	196	58.8 ± 11.2	53.8 ± 13.4	36.0 ± 7.1	8.4 ± 7.3	99.98 ± 14.98
Urban	Boys	100	50.5 ± 14.6	60.1 ± 13.5	38.0 ± 7.1	9.1 ± 7.2	98.94 ± 11.08
	Girls	100	60.6 ± 11.1	44.8 ± 12.5	34.5 ± 7.2	4.4 ± 5.3	92.59 ± 11.72
	7 years	66	52.7 ± 12.6	43.3 ± 10.4	36.0 ± 6.7	6.2 ± 5.7	89.81 ± 10.91
	8 years	64	59.9 ± 14.7	52.4 ± 16.7	37.5 ± 8.7	8.0 ± 7.5	98.99 ± 16.79
	9 years	70	54.2 ± 13.4	47.3 ± 12.5	35.3 ± 6.3	6.2 ± 6.9	91.98 ± 12.72
	TOTAL	200	55.5 ± 13.9	47.6 ± 13.9	36.2 ± 7.3	6.8 ± 6.7	93.51 ± 14.11

Significant interaction effects were confirmed for age × gender ($F = 17.34$; $df = 8, 764$; $p < .001$ multivariate) and age × location ($F = 18.35$; $df = 8, 760$; $p < .001$ multivariate). Univariate tests for the age × group interaction were significant for JS ($F = 26.24$; $df = 2, 384$; $p < .001$; $\eta p^2 = .064$) and EHC ($F = 16.59$; $df = 1, 384$; $p < .001$; $\eta p^2 = .080$), confirming that the rural GMC advantage became more pronounced with age. For gender × location interactions, significant univariate effects were found for BB ($F = 18.96$; $df = 1, 384$; $p < .001$; $\eta p^2 = .047$) and JS ($F = 21.76$; $df = 1, 384$; $p < .001$; $\eta p^2 = .054$).

Table 7. Comparative LDA Results for KTK3+, Location, and BMI.

Variables	Total (N = 369)	Rural (n = 196)	Urban (n = 200)
Model Fit			
Wilks' λ	.889	.849	.862
χ^2	46.08	31.24	28.88
df	16	16	16
p	< .001	.013	.025
Function 1			
Eigenvalue	.089	.129	.119
% of varience	72.9	74.9	76.8
Canoncal r	.286	.338	.327
Primary discriminator (Structure Matrix r)			
Balance Beam	.597	.910	.421
Jumping Sideways	.066	.152	.859
Moving Sideways	.482	.708	.420
Eye-hand Coordination	-.397	-.541	-.651
Classification Accuracy			
Original	70.71%	67.35%	75.50%
Cross-Validated	70.45%	65.82%	74.00%

Discussion

This study examined differences in GMC and BMI between rural and urban children aged 7–9 years in West Sumatra, Indonesia. Children in rural areas demonstrated significantly better GMC performance than their urban peers on the BB and EHC tests, with the rural advantage increasing with age, particularly for EHC. Overall, 86% of the sample was classified as underweight or severely underweight. Interestingly, urban children showed a higher prevalence of severe underweight (75.0%) compared to rural children (66.3%). Furthermore, location-specific LDA results indicated that the subtests distinguishing BMI categories varied by setting. BB was the main discriminator among rural children, whereas JS was more prominent among urban children. This pattern suggests that the relationship between BMI and GMC may operate differently depending on the environmental context.

The findings of this study can also be explained through the perspective of ecological dynamics and environmental affordances. Children living in rural areas in this study appeared to have more diverse opportunities for physical activity through unrestricted access to outdoor play, interaction with various natural terrains (e.g., rice fields, hills, and rivers), and participation in physical activity practices deeply embedded in Indonesian culture. Therefore, differences in GMC may not merely reflect geographical location itself, but rather the availability of movement opportunities and the environmental characteristics that support motor development within a particular setting (Delyana et al., 2024).

The finding that children in rural areas outperformed their urban peers on several KTK3+ subtests contrasts with our initial hypothesis but is consistent with recent studies conducted in Indonesia. For example, Atradinal et al. (2026) and Oktarifaldi et al. (2024), in studies of children in West Sumatra using the same KTK3+ test battery, also reported that children from rural and semi-rural schools demonstrated higher proficiency in gross GMC skills compared to those from urban schools. This advantage has been attributed to greater exposure to unstructured outdoor play and traditional movement practices. However, the findings of Niemistö et al. (2019) do not support the view that greater exposure to outdoor play necessarily leads to better motor skill development among children in Finland, regardless of whether they live in rural or urban areas. This difference may reflect the influence of Finland's national early childhood education curriculum, which is implemented consistently across the country and promotes equitable educational practices, including clear recommendations for PA in early childhood education. In addition, Finnish children generally have a high level of autonomy in their daily movement and are able to access a wide range of environmental opportunities (Kyttä, 1997). As a result, children in Finland may have relatively equal opportunities to develop GMC and to participate in organized sports, regardless of geographic location. In contrast, such equitable access to PA and motor skill development in early childhood has not yet been fully realized in Indonesia. Evidence suggests that children with limited motor skill proficiency can still be found in both rural and urban areas. This highlights an important challenge for policymakers in designing and implementing a national early childhood curriculum that can effectively reach diverse regions across Indonesia.

The better JS performance observed among rural children is consistent with the findings of Mardiansyah et al. (2024), who reported that locomotor (particularly jumping sideways) was significantly associated with routine PA levels and the frequency of outdoor activities among Indonesian primary school children. These activities are generally more common in rural settings. In West Sumatra, traditional children's games such as *engklek*, *lompat tali*, and *gobak sodor* closely reflect the movement demands of bilateral jumps and lateral coordination required in the JS and BB subtests (Suwondo, 1982). As a result, these activities may provide a form of implicit motor skill training that is less frequently experienced by children in urban environments. Graf et al. (2004), in the CHILT Project involving primary school children in Germany, similarly found that children who spent more time in active outdoor recreational activities performed significantly better on tasks related to balance and jumping sideways than their peers whose leisure time was predominantly sedentary. In addition, Côté & Vierimaa (2014) have shown that many professional athletes grew up in small towns/rural, which tend to provide more equitable opportunities for free play as well as access to organized sports (Surya et al., 2012). Overall, the present findings highlight the importance of early childhood as a critical period for GMC development. Children who have greater freedom to engage in play tend to show more positive motor development outcomes (Ryan & Deci, 2017), while access to organized sports can further support motor learning. Together, these factors create a supportive environment that promotes motor development and encourages higher levels of PA among children.

The results of this study also indicate age- and location-related differences in GMC, particularly in the EHC and JS subtests. These findings suggest that GMC tends to improve with age among children in rural areas. Specifically, rural children show a consistent increase in EHC performance from ages 7 to 9, whereas urban children demonstrate improvement up to age 8, followed by a slight decline at age 9. This decline at age 9 may be related to the quality of physical activities in which children engage. Previous research suggests that limited success or enjoyment in age-appropriate activities (e.g., sports and games) can reduce children's motivation to continue participating (Lima et al., 2019). These findings highlight the importance of support from both parents and teachers in maintaining children's engagement in PA. Continuous monitoring of the quality and variety of activities may help prevent disengagement and reduce the likelihood of sedentary behavior (Nurmahmudah et al., 2025).

In addition, the findings reveal differences based on gender and location. The results indicate a cross-pattern in which rural boys significantly outperform their urban counterparts, while urban girls perform slightly better than girls in rural areas. This pattern suggests that the rural advantage in balance-related tasks is largely driven by boys, whereas girls' balance performance appears to be less sensitive to residential context. Coppens et al. (2021) similarly reported that boys performed better on three of the four KTK3+ subtests, while girls showed better performance on the BB test. These findings are consistent with the view that differences in motor performance may be influenced by both sociocultural factors related to participation in PA and underlying biological differences. In the Indonesian context, rural boys are more likely than rural girls to engage in outdoor play (Oktarifaldi et al., 2024), which may help explain why the location-related advantage in BB performance observed in this study appears to be gender-specific.

When compared with the European normative data reported by Coppens et al. (2021), the standardized KTK3+ MQ of rural children in this study appears to be close to international benchmarks, whereas that of urban children is slightly lower. This pattern is consistent with the findings of Mardiansyah et al. (2023), who reported average MQ scores of approximately 98–100 among children in West Sumatra, based on a sample largely drawn from rural areas. These results suggest that the GMC of rural children in West Sumatra is generally comparable to international norms, while urban children may show lower performance relative to both local and international benchmarks.

The findings of the present study, that children living in rural areas outperformed their urban counterparts on several KTK3+ subtests underscores the complex, context-dependent nature of GMC development. From an Ecological Dynamics perspective, these differences may reflect variations in environmental affordances and opportunities for movement, rather than geographical location alone.

One of the key findings of this study is that the primary indicators distinguishing BMI categories differ across residential settings. Among rural children, body weight emerged as the main contributor to LDA Function 1, whereas among urban children, BMI played a more dominant role. These location-specific differences in the relationship between BMI and GMC have not been previously reported in the Indonesian literature and extend the findings of Mardiansyah et al. (2024), who examined the BMI–GMC association in a combined sample without considering residential differences. The prominence of BB as the primary distinguishing factor among rural children can be interpreted within the framework of the biomechanical disadvantage hypothesis proposed by (Walhain et al., 2016). In rural environments, where children are more frequently engaged in outdoor play and activities that require dynamic balance and agility on uneven natural surfaces, performance on balance tasks may be more sensitive to postural instability associated with unfavorable BMI. This may reflect the combined effects of excess body mass or insufficient muscle mass on movement control. Furthermore, the prominent differences observed in the JS subtest are consistent with the findings of Battaglia et al. (2021), who reported that lateral jumping performance is influenced by BMI, particularly among children who are physically inactive and lack specific training. In such cases, the absence of regular bilateral jumping activities may exacerbate performance limitations associated with suboptimal body composition. The higher classification accuracy observed in urban areas in this study further suggests that the relationship between BMI and GMC may be more structured and predictable in urban environments (Umar et al., 2023). This may be due to more consistent patterns of PA among urban children, which could lead to more uniform BMI-related motor performance compared to the more variable conditions typically found in rural contexts.

The high overall prevalence of severe underweight, along with the unexpectedly higher rates observed in urban areas compared to rural areas, challenges the conventional assumption, reflected in national RISKESDAS (Indonesia) data, that malnutrition is primarily a rural issue. Sulistiadi et al. (2023) note that although rural areas generally show a higher average burden of stunting and underweight at the national level, certain urban subdistricts (particularly in densely populated, low-income settings) can exhibit comparable levels of severe underweight. In these contexts, food security may be constrained by factors such as housing and transportation costs. The present findings are consistent with this perspective and suggest that the urban schools included in this study may serve a higher proportion of socioeconomically vulnerable populations. This paradox may be further explained by Abay et al. (2022), who examined how food systems in LMICs are increasingly characterized by the widespread availability of ultra-processed foods that are energy-dense but low in micronutrients. This pattern can contribute to malnutrition among low-income urban families, despite their physical proximity to food markets. In contrast, rural families in West Sumatra (Indonesia) may still have greater access to locally produced traditional foods such as rice, freshwater fish, vegetables, and tropical fruits (which are aligned with Minangkabau dietary practices and may provide more balanced nutritional intake, even under conditions of economic constraint).

The unexpectedly high prevalence of severe underweight among urban children may reflect a form of double vulnerability, whereby children are simultaneously exposed to limited opportunities for physical activity and poor dietary quality associated with the ongoing nutritional transition. Furthermore, Syahrul et al. (2016) reported no significant differences in the prevalence of underweight between boys and girls in urban areas. This finding contrasts with the results of the present study, which revealed that 33% of children in rural areas and 38% of children in urban areas were classified as underweight. These findings suggest that malnutrition in urban settings should not be understood solely in terms of food scarcity, but also in relation to lifestyle changes, reduced physical activity, and broader environmental influences associated with urbanization.

These findings have important implications for physical education practice and public health policy in Indonesia. In rural school settings, physical education teachers should recognize that higher performance in BB, JS, and EHC among rural children likely reflects well-developed motor competence shaped by natural movement environments and engagement in traditional games. These context-specific strengths could be more systematically incorporated into structured physical education programs. In particular, the findings support the integration of traditional movement-based games from West Sumatra (such as *engklek*, *egrang*, and *gobak sodor*) into the physical education curriculum as culturally relevant and cost-effective approaches to promoting motor development.

From a practical perspective, schools can benefit from implementing a hybrid physical education curriculum that combines traditional Indonesian games with structured motor skills development activities (Côté & Vierimaa, 2014). Periodic assessments of GMC can also help teachers identify children who need additional support, particularly those at risk of nutritional problems. Furthermore, school-based interventions that integrate the promotion of physical activity and nutrition education can serve as a more comprehensive strategy for improving children's health and motor development.

At the national policy level, the high prevalence of severe underweight in both rural and urban areas highlights the need to strengthen existing frameworks for monitoring children's health and PA in Indonesia. Addressing malnutrition alongside the growing burden of overweight and obesity should be considered a key priority. The findings of this study support these efforts and further suggest that GMC screening, using validated tools such as the KTK3+, could be integrated into routine school health assessments. This approach may enable earlier identification of children with lower motor competence who could benefit from combined nutritional and PA interventions.

This study has several limitations. Its cross-sectional design does not allow for causal inferences or the examination of longitudinal pathways, for example, whether lower levels of GMC reduce motivation for PA, potentially leading to gradual weight gain, which may in turn further affect GMC over time. In addition, several potentially relevant variables were not assessed, including household income, habitual PA levels, screen time, dietary intake, and sleep quality. Future research should incorporate more comprehensive measures, such as accelerometer-based PA monitoring, validated 24-hour dietary recall, and indicators of family socioeconomic status (e.g., the Family Prosperity Scale), alongside motor assessments. This would enable more advanced analyses, such as structural equation modeling, to better understand the pathways linking residential context, nutritional status, and GMC development. Our study was conducted exclusively in West Sumatra Province, Indonesia. The Minangkabau cultural context (including its matrilineal social structure, distinctive dietary patterns, and children's outdoor play practices) may not fully represent other regions of Indonesia, such as Java, Sunda, Bali, or Eastern Indonesia. Future research should therefore examine cross-cultural variability in motor development across different regions, particularly in LMIC contexts. Multi-province studies in Indonesia are needed to determine whether the rural–urban patterns observed in this study can be generalized at the national level. Furthermore, BMI is unable to distinguish between fat mass and fat-free mass, limiting its utility as a proxy for body composition. Future studies should employ direct measures of body composition, muscle fitness, physical activity, and environmental characteristics to better elucidate the complex relationships among nutritional status, physical fitness, and gross motor competence.

Conclusions

This study highlights significant differences in GMC between rural and urban elementary school children aged 7–9 years in West Sumatra, Indonesia. Children from rural areas consistently outperformed their urban peers on the BB, JS, and EHC subtests, with this advantage increasing with age, particularly in eye–hand coordination. In contrast, MS did not show a significant main effect of location, suggesting that lateral movement performance may be more strongly influenced by age and BMI status than by residential context. Location-specific LDA results further indicate that the relationship between BMI and GMC differs across environments. BB emerged as the primary discriminator among rural children, whereas

JS was more prominent among urban children, suggesting that the BMI–GMC relationship may be context-dependent.

The high prevalence of severe underweight is a major concern, particularly as urban children show higher rates than their rural peers. This finding challenges the common assumption that malnutrition is primarily a rural issue and suggests that current child health policies in Indonesia may place insufficient emphasis on undernutrition alongside overweight and obesity. Our findings highlight the need for physical education programs that are sensitive to both GMC and BMI, especially in urban settings during the critical developmental period of ages 7 to 9. Future research should adopt longitudinal, multi-regional, and socioeconomically stratified designs to better understand causal pathways and to support the development of context-specific motor development programs for Indonesian children. In addition, the findings also suggest that environmental factors, lifestyle, and nutritional transition processes may play an important role in shaping children's GMC across different living locations.

Conflict of interest

Arischo Mardiansyah, Ramadoni, Fitri Nurmahmudah, Astrid Tiara Murti, Damardjati Kun Marjanto, and Hasan Albana declare that they have no conflicts of interest concerning the content of this study.

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