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Biological determinants outweigh the learning environment: a path-analytic model of physical fitness, nutritional status, and motor ability in primary-school children

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ABSTRACT

Motor skills in the middle childhood phase are a critical skill through which one could attain lifelong physical activity; However, their determinants are often examined separately, which "hides" the fact of how biological readiness and the instructional environment together influence movement outcomes. Objective: In this work, the authors represented the direct and indirect impacts of children's motor ability through physical fitness, nutritional status, and the learning environment in such a way that the learning environment was considered as a mediator. Methods: The research was carried out using a cross-sectional, correlational design on 38 fifth-grade pupils at a laboratory primary school in Padang, Indonesia. Physical fitness was measured with the Indonesian Student Fitness and Skill Test (Phase C), nutritional status with body-mass-index-for-age, the learning environment with a validated Likert questionnaire, and motor ability with the Nurhasan Motor Ability Test. Data were analysed through path analysis using ordinary-least-squares regression across three structural models in IBM SPSS Statistics 27, after verifying normality, linearity, and the absence of multicollinearity. Results: Physical fitness is a great predictor of nutritional status (beta = 0.899, R-squared = 0.809). Net of confounds in the model, physical fitness (beta = -1.052), nutritional status (beta = 0.603), and the learning environment (beta = -0.299) each had a significant direct effect on motor ability, and all six hypotheses were supported. Learning environment transmission indirect effects were quite small (-0.432 and 0.193), suggesting that biological factors impacted primarily the motor ability through direct rather than mediated pathways. Conclusively, in an educationally homogeneous setting, children's physical fitness and nutritional status are the primary determinants of their motor ability, whilst the learning environment represents more of a facilitating than a mediating factor. Practical implication: Physical-education programmes should focus on fitness development and nutritional monitoring while continuing to offer a positive and supportive instructional atmosphere.

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Introduction

Motor ability, the comprehensive skill of managing the body through harmonious, well-balanced, agile, and speed-sensitive movements, ranks among the most significant developmental breakthroughs in middle childhood. From the time children turn six until they are twelve, they perfect the basic movement skills that will eventually enable them to engage in sports, stay physically active as a habit, and even aid their cognitive and socio-emotional growth (McDonough et al., 2020; Meylia et al., 2022). Since motor skills developed during this period usually carry over into the teenage years, the shortcomings that arise during the primary schooling years are not only rarely corrected without outside intervention but often get worse over time (Bardid et al., 2021; Carballo-Fazanes et al., 2022). Thus, knowing the factors leading to the development of motor skills during this age is more than just describing; it aims to be the basis for creating physical education that will reduce early movement gaps rather than increase them.

In the past ten years, the developmental importance of motor skills has been restated with the idea of a positive feedback cycle. Skilled movers enjoy more physical activity, get fitter and more confident, while less skilled movers gradually withdraw and get less and less competent (Burton et al., 2023; Garcia-Hermoso et al., 2023). Large studies conducted in several countries confirm that there is a positive, two-way relationship between motor skills and health-related fitness, and they also show that children with better motor skills tend to have healthier body composition and better psychosocial functioning (Batez et al., 2021; Katanic et al., 2024). However, the same studies indicate that there is a continuing worldwide decline in children's fundamental movement skills and cardiorespiratory fitness. This negative trend has been further exacerbated by sedentary lifestyles and less unstructured play (Godoy-Cumillaf et al., 2024; Marques et al., 2021). The issue is highlighted by the fact that the need for motor development is at its peak, yet the opportunities for it are decreasing."

Three factors keep appearing throughout all the research cited here. The first one is physical fitness. Components such as endurance, strength, speed, agility, and coordination together make up the physiological basis for performing motor skills, and kids who are fitter generally find it easier to learn new motor skills than their less fit friends (Bustamante-Sanchez et al., 2022; Hohmann et al., 2021). The next determinant is the nutritional status which influences the development of muscles, bones, and the brain that motor performance relies on. Both undernutrition and overweight have been linked to slower or limited motor development (Denova-Gutierrez et al., 2023; Escobedo-Monge et al., 2025). Lastly, the learning environment which involves the physical conditions, methods of instruction, and the social atmosphere of the physical education classes, controls how much and what kind of movement a child gets to experience (Baafi, 2020; King-Dowling et al., 2020). Each factor alone can be strongly backed up by empirical data; together, they are hardly ever considered in the same model.

The evidence base around physical fitness is quite consistent overall. Intervention and cohort researches demonstrate that doing structured and regular physical activities can improve neuromuscular functioning, movement efficiency, and coordination, which lead to motor competence improvements that can also be measured (Cocca et al., 2020; Engel et al., 2022). In the case of Indonesia, studies conducted in the school settings on students with low fitness levels showed that these students not only had poor motor skills but also tired quicker and were less engaged in the lessons (Asnaldi et al., 2021; Gusril & Rasyid, 2021). However, the strength and even the direction of the fitness-motor association change after other factors are taken into account, which indicates that the association is part of a larger system rather than functioning independently (Drenowatz et al., 2021).

Results regarding nutritional status are quite mixed. Proper nutrition is one of the main factors that help the brain and muscles to develop the ability for fast, coordinated movement. However, the sizes of the observed effects are dramatically different not only in terms of locations, but also in terms of ages and types of anthropometric measurements that were used (Barrozo et al., 2025; Papotot et al., 2021). Some articles note that children suffering from insufficient nutrition have delayed motor milestones, while others talk of overweight and obesity as main factors that negatively affect agility and locomotor control; yet others find that the relationships become very weak or non-existent after taking fitness into account (Jones et al., 2020; Masanovic et al., 2020). Such contradictions seem to suggest that nutrition and fitness are interwoven rather than separate, a circumstance that a joint modelling approach can very well help to explore.

One important factor that causes the research on learning environment to be so difficult is that it is not clear that certain features of the environment that are expected to be supportive will turn out to be effective, or that at least the whole treatment will have the desired, overall effect. For example, one could say that the student body as a community is the key, not merely the elements that one can modify. Besides, good facilities, active teaching methods, and close teacher-pupil relationships make happen greater skills development. In addition, our kids learn more when they have strong motor skills that had been developed through physical education. This is one reason why the physical education in our schools is being given a new emphasis (Cheng et al., 2025; Sneck et al., 2023). Nevertheless, the impact of an environment is highly dependent on the individual. Hence, in a scenario where an entire student body attends basically one school, curriculum, and staff, the environmental differences that exist among children become so small that their influence on each child becomes overshadowed by that of the child's own biological characteristics (Gleddie & Morgan, 2021; Lorås, 2020). The question of

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whether the environment has a direct impact or whether it acts as a channel through which the effects of fitness and nutrition are passed is still an open one and is a vital element of the current study.

Overall, the article highlights that physical fitness, nutritional status, and the learning environment are all factors that influence one another. However, there are three major gaps outstanding: firstly, the determinants are mostly analyzed individually or in pairs so we do not know their relative contributions and dependency on each other; secondly, very few researchers have laid down an explicit mediation structure that could show whether biological factors affect motor ability directly or through the environment; and lastly, there are very few studies in South-East-Asian primary schools that have used objectively measured fitness, anthropometric nutrition, and a validated environment instrument combined in a single causal model (Hidayat et al., 2024; Siregar et al., 2023). To fill these gaps, an analytical method that is able to break down direct and indirect effects at the same time is needed.

Although previous studies have independently examined physical fitness, nutritional status, and learning environment, few have simultaneously modeled their direct and indirect effects on children's motor ability using path analysis. Furthermore, evidence from Indonesian primary-school settings remains limited, particularly in educationally homogeneous environments. Addressing this gap may improve understanding of the relative contributions of biological and environmental determinants.

This paper tries to resolve these issues by using path analysis to examine how physical fitness together with nutritional status influence motor ability not only directly but also indirectly through learning environment as a mediator. The three points of originality of this work are that: it chiefly/models integration of biological vs. environmental determinants whereas various works usually treat them separately; it formalizes a mediation hypothesis which is largely missing in the literature; lastly, it does so in an educationally homogeneous laboratory-school setting, which exemplifies a natural experiment in which individual biology or shared environment predominates when environmental variation is minimal. The importance of the research is in showing a decomposed effect structure to be a source of specific physical education directions and school health policy.

Thus, the research set the following targets: determining the direct impacts of physical fitness, nutritional status, and the learning environment on motor ability; determining the direct impact of physical fitness on nutritional status; and determining the indirect impacts of physical fitness and nutritional status on motor ability mediated by the learning environment. The six hypotheses that were put forward are: (H1) physical fitness has a direct influence on motor ability; (H2) nutritional status has a direct influence on motor ability; (H3) the learning environment has a direct influence on motor ability; (H4) physical fitness has a direct influence on nutritional status; (H5) physical fitness has an indirect effect on motor ability through the learning environment; and (H6) nutritional status has an indirect effect on motor ability through the learning environment.

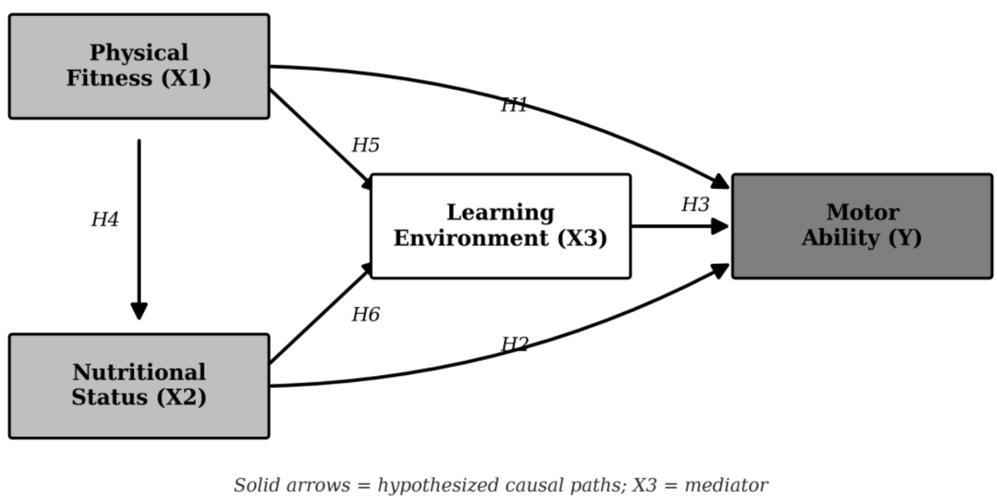

Figure 1. Hypothesized Conceptual Framework Linking Physical Fitness (X1), Nutritional Status (X2), The Learning Environment (X3, Mediator), and Motor Ability (Y)

Method

Research Design

This study chose a quantitative, cross-sectional correlational design analysed through path analysis. The researchers chose this design because their research questions were about the structure and size of causal-directional relationships among observed variables rather than the influence of an experimental manipulation. Path analysis goes beyond multiple regression by enabling a variable to function at the same time as an outcome and a predictor, thus allowing the breakdown of total associations into direct and indirect components (Putra et al., 2024).

Participants, Population, and Sampling

The target population were pupils in the fifth grade at a laboratory primary school located in a public university in Padang, West Sumatra, Indonesia. A total-sampling (census) method was used because the accessible population was of a size that the researchers could measure the whole; hence, the final sample comprised all 38 pupils in the fifth grade (approximately aged 10-11 years). Total sampling eliminates the sampling error within the frame and is suitable when the population is small and clearly defined. Because only one fifth-grade class was available during the study period, the present study should be interpreted as an exploratory path analysis rather than a confirmatory population model. Students who have medical contraindications for vigorous activity will be excluded on the test day, but no such cases were reported.

Sample Size Justification

Because the accessible population consisted of a single fifth-grade cohort, total sampling was employed. A post hoc statistical power analysis using G*Power 3.1 indicated that the final sample ($N = 38$) achieved statistical power above 0.80 for detecting large effect sizes ($f^2 \geq 0.35$) at $\alpha = .05$. Therefore, although the sample was relatively small, it was considered adequate for the exploratory path analysis conducted in this study.

Ethical Considerations

The research was carried out following the ethical principles of the Declaration of Helsinki. The school gave institutional approval, and parents or guardians gave written informed consent while children gave verbal assent. Participation was voluntary, data were anonymised before analysis and children could withdraw at any time without any explanation.

Variables and Instruments

Four variables were operationalised. Physical fitness (X1) and nutritional status (X2) were the two exogenous variables; learning environment (X3) was the mediating variable; and motor ability (Y) was the endogenous variable.

Physical fitness was measured by the medium of the Indonesian Student Fitness and Skill Test (TKSI), Phase C, which was designed by the Ministry of Primary and Secondary Education for students at this developmental stage. The test consisted of a series of five activities: eye-hand coordination (Child Ball Test), manipulative accuracy (Tok-Tok Ball Test), trunk strength and coordination (Move-the-Ball Test), agility and speed (8 x 10 m shuttle-run with ball transfer), and cardiorespiratory endurance (600 m run). The component scores were transformed based on age- and sex-referenced norms and combined into a composite index.

Anthropometry was applied to determine nutritional status. Measurement of body mass (using a digital scale) and stature (with a microtoise) was performed to calculate body-mass index, which was then expressed as BMI-for-age (BMI/A) and categorized according to the Indonesian Ministry of Health child anthropometric standard as undernourished, normal, and obese.

The learning environment was evaluated through a structured questionnaire which was modified from a well-established Indonesian framework. This framework describes the school, family, and community aspects of the learning context. The participants indicated their level of agreement on a five-point Likert scale, and scores were summed up to form a total environment score.

The Nurhasan Motor Ability Test was used to evaluate motor ability. It includes a 4 x 10-meter shuttle run (agility), a throw and catch of a ball against the wall from one meter (eye-hand coordination), the stork stand test for balance (balance), and a 30-meter sprint (speed). Raw scores were transformed into standard scores and then summed up to form a composite motor ability score.

Instrument Validity and Reliability

Psychometric characteristics of the instruments complied with the research standards before the main analysis was done. Nurhasan Motor Ability Test's validity and reliability coefficients were 0.870 and 0.930 respectively. As for the fitness battery, the validity coefficients varied from 0.376 to 0.645 while the reliability coefficients from 0.473 to 0.545, which are the values of moderate reliability that is typically expected from single-trial field tests of different motor components. The learning-environment questionnaire was developed from a previously validated instrument; the items were checked for validity before the testing procedure. Since the model that was estimated was based on composite observed scores through regression-based path analysis rather than latent-variable structural equation modelling, construct-level indices such as composite reliability and average variance extracted were not relevant; the classical validity and reliability coefficients reported here serve as the corresponding evidence for measurement adequacy. The internal consistency of the learning-environment questionnaire was satisfactory, with a Cronbach's alpha coefficient of 0.87, indicating good reliability for research purposes.

Data-Collection Procedures

Data was collected in the physical-education sessions that were scheduled. Field tests were administered by trained examiners according to the official test manuals, with demonstrations and familiarisation trials ahead of scored attempts. Two sets of anthropometric measurements were taken and the average was used. The questionnaire on the learning environment was handed out after the practical tests. Verbal clarification of the questions was done to make sure that the pupils understood them well enough given their reading level.

Data Analysis

IBM SPSS Statistics version 27 was used for analyses. Initially, variables were summarised through descriptive statistics while its regression-based path analysis classical assumptions were tested: normality of residuals using one-sample Kolmogorov-Smirnov test; linearity through ANOVA F tests of linearity and deviation from linearity; multicollinearity via tolerance and variance inflation factor; model significance by ANOVA F test. Accordingly, three structural equations were used in the path analysis estimation: Structure I regressed nutritional status on physical fitness; Structure II regressed learning environment on physical fitness and nutritional status; and Structure III regressed motor ability on physical fitness, nutritional status, and learning environment. Direct effects were measured by Standardised path coefficients (beta), while indirect effects were computed by multiplying the individual path coefficients of the mediator. The significance of indirect effects was further evaluated using bootstrapped confidence intervals with 5,000 resamples. Total effects, on the other hand, were the sum of direct and indirect components. Residual path coefficients were obtained by taking the square root of one minus the coefficient of determination. At alpha = 0.05, statistical significance was checked, and hypotheses were retained when the computed t was greater than the critical t (or p was 0.05 or below).

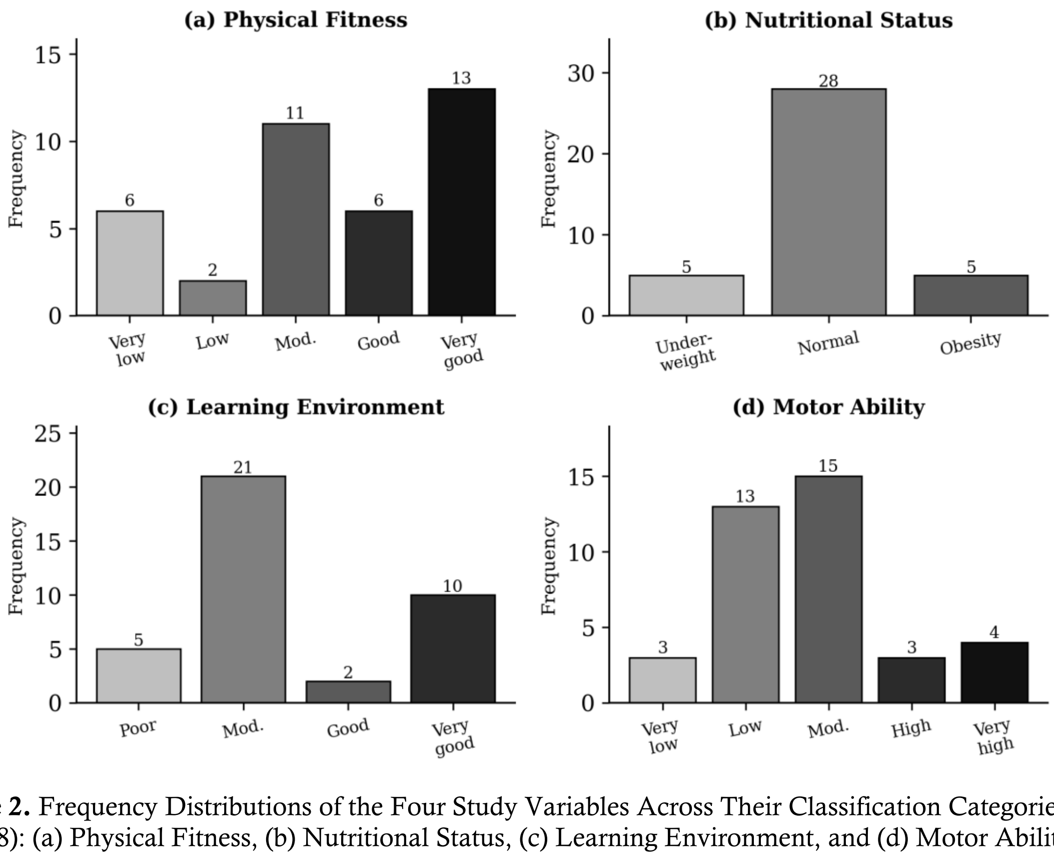

Figure 2. Frequency Distributions of the Four Study Variables Across Their Classification Categories (N = 38): (a) Physical Fitness, (b) Nutritional Status, (c) Learning Environment, and (d) Motor Ability

Results and Discussions

Result

Participant Characteristics and Descriptive Statistics

All of the 38 participants were fifth-grade pupils, recruited as a complete census of the grade cohort. Their distribution across the different classification bands of each variable is summarized in Table 1, while the central-tendency and dispersion statistics for the continuous measures are given in Table 2. The majority of the pupils concentrated around the mean of the motor-ability distribution, whereas their physical-fitness scores were more positively skewed and they were mostly of normal nutritional status.

Table 1. Participant characteristics by classification band (N = 38)

Variable / band	n	%
Physical fitness		
Very good	13	34.21
Good	6	15.79
Moderate	11	28.95
Poor	2	5.26
Very poor	6	15.79
Nutritional status		
Undernourished	5	13.16
Normal	28	73.68
Obese	5	13.16
Learning environment		
Very good	10	26.32
Good	2	5.26
Moderate	21	55.26
Poor	5	13.16
Motor ability		
Very high	4	10.53
High	3	7.89
Moderate	15	39.47
Low	13	34.21
Very low	3	7.89

Table 1 shows that although fitness scores leaned toward the upper bands, motor ability was concentrated in the moderate and low categories, with roughly four in ten pupils performing below the moderate threshold. This divergence between generally adequate fitness and only moderate motor performance foreshadows the more nuanced multivariate pattern reported below.

Table 2. Descriptive statistics for the study variables (N = 38)

Variable	M	SD	Min	Max
Physical fitness (X1)	20.82	2.73	14.00	25.00
Nutritional status (X2, BMI/A)	Normal-dominant	—	—	—
Learning environment (X3)	84.68	7.45	74.00	100.00
Motor ability (Y)	50.82	3.20	44.30	57.30

Note. M = mean; SD = standard deviation. Nutritional status is a categorical BMI-for-age classification (73.68% normal) and is summarised distributionally in Table 1.

As per the data presented in Table 2, the mean score for physical fitness was 20.82 (SD = 2.73) and for the learning environment 84.68 (SD = 7.45) which indicates a moderate level of variability whereas on the other hand, motor ability recorded an average score of 50.82 (SD = 3.20) and came with a relatively smaller range. This limited spread of the scores for the environment and motor ability is quite telling in itself because when a mediator is homogeneous, it limits the scale of any indirect route that it can carry.

Reliability and Validity of Instruments
Table 3 confirms that the composite motor-ability instrument possessed high validity and reliability, while the individual fitness components showed the moderate coefficients characteristic of single-trial field tests. The measurement base was therefore adequate for the subsequent path-analytic modelling.

Table 3. Validity and reliability coefficients of the measurement instruments

Instrument / component	Validity (r)	Reliability	Interpretation
Nurhasan Motor Ability Test	0.870	0.930	High
Child Ball Test (coordination)	0.511	0.494	Moderate
Tok-Tok Ball Test (accuracy)	0.376	0.524	Moderate
Move-the-Ball Test (strength)	0.472	0.508	Moderate
8 x 10 m shuttle-run (agility)	0.645	0.473	Moderate
600 m run (endurance)	0.545	0.490	Moderate

Assumption Testing
Before we move on to fitting structural models, we checked whether the assumptions of regression-based path analysis still hold (Table 4). The residuals were normally distributed (Kolmogorov-Smirnov $p = .200$); the three predictor, outcome relationships were linear (linearity $p < .05$ and deviation-from-linearity $p > .05$ throughout); and there was no multicollinearity as the tolerance values were above 0.10 and variance-inflation factors below 10.

Table 4. Summary of classical assumption tests for the path model

Assumption / relationship	Statistic	Value	Decision
Normality (K-S, residuals)	Asymp. Sig.	.200	Normal
Linearity X1 -> Y	Sig. (lin / dev)	.004 / .765	Linear
Linearity X2 -> Y	Sig. (lin / dev)	.024 / .459	Linear
Linearity X3 -> Y	Sig. (lin / dev)	.019 / .627	Linear
Multicollinearity X1	Tol. / VIF	0.193 / 5.169	None
Multicollinearity X2	Tol. / VIF	0.192 / 5.207	None
Multicollinearity X3	Tol. / VIF	0.983 / 1.018	None

Note. K-S = Kolmogorov-Smirnov; Tol. = tolerance; VIF = variance-inflation factor; lin = linearity; dev = deviation from linearity.

The tolerance values for physical fitness and nutritional status (0.193 and 0.192) were marginally acceptable; however, they were substantially lower compared to the learning environment (0.983), indicating a very high shared variance between the two biological predictors. Even though this overlap is below the multicollinearity threshold, it still matters when deciphering the coefficient signs that come afterward.

Structural Regression Models
Table 5 indicates that every structural model was statistically significant. Structure I explained 80.9% of the variance in nutritional status, Structure II explained 81.9% of the variance in the learning environment, and Structure III explained 43.2% of the variance in motor ability. The models were therefore admissible for estimating direct and indirect effects.

Table 5. Significance of the three structural regression models

Structure (outcome)	F	df	R2	Sig.
I (X2 on X1)	152.124	1, 36	0.809	<.001
II (X3 on X1, X2)	78.990	2, 35	0.819	<.001
III (Y on X1, X2, X3)	8.607	3, 34	0.432	.001

Note. All models were statistically significant at alpha = 0.05 and thus admissible for path decomposition.

Direct, Indirect, and Total Effects
Tables 7 and 8 demonstrate that learning environment related pathways were small in size (-0.432 and 0.193) as compared with direct effects, and for nutritional status the indirect path even supported the direct path in the same positive way. The breakdown clearly shows that biological factors influenced motor ability mainly through direct channels rather than through mediation.

Table 6. Standardized direct effects (path coefficients) across the structural models

Path	beta	t	Sig.	Decision
X1 -> X2	0.899	12.334	<.001	Significant
X1 -> X3	1.446	8.517	<.001	Significant
X2 -> X3	-0.644	-3.794	<.001	Significant
X1 -> Y	-1.052	-3.560	.001	Significant
X2 -> Y	0.603	2.037	.050	Significant
X3 -> Y	-0.299	-2.309	.027	Significant

Note. beta = standardized path coefficient; critical t = 2.032 (df = 34) and 2.028 (df = 36).

Table 7. Indirect effects transmitted through the learning environment (X3)

Indirect path	Computation	Effect	Direction
X1 -> X3 -> Y	1.446 x (-0.299)	-0.432	Negative
X2 -> X3 -> Y	(-0.644) x (-0.299)	0.193	Positive

Note. Indirect effect = product of the constituent standardized path coefficients.

Table 8. Decomposition of direct, indirect, and total effects on motor ability

Predictor	Direct	Indirect	Total
Physical fitness (X1)	-1.052	-0.432	-1.484
Nutritional status (X2)	0.603	0.193	0.796
Learning environment (X3)	-0.299	—	-0.299

Note. Total effect = direct + indirect. The learning environment has no indirect pathway in this model.

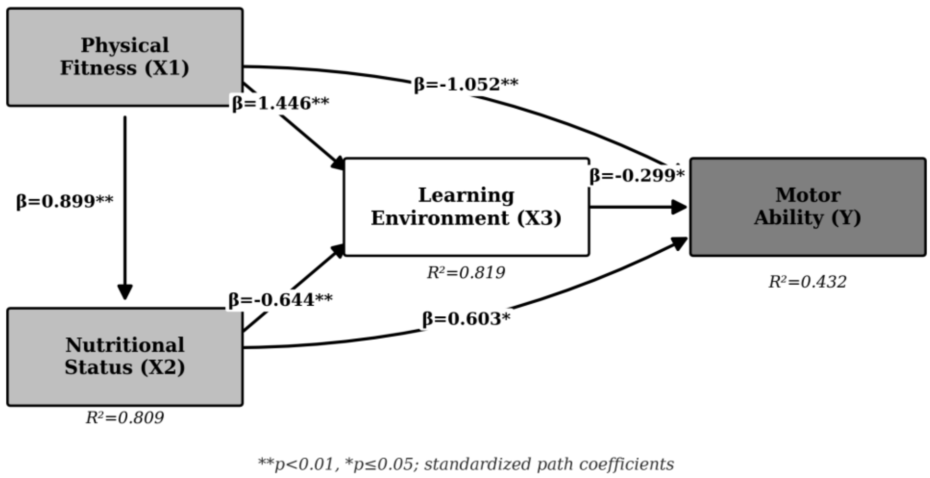

Figure 3. Empirical Path Diagram with Standardized Coefficients for the Three Structural Models. Coefficients of Determination are Shown Beneath Each Endogenous Variable

Model Fit and Explained Variance

Table 9 measures how much of the variance each model can explain. The biological chain was very predictable: fitness by itself explained 80% of the variability in nutritional status, and fitness and nutrition together explained almost the same proportion of variability in the environment score. On the other hand, motor ability had a large residual (e = 0.754) which shows that more than half of its variability cannot be explained by the predictors used in the model.

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Table 9. Coefficients of determination and residual path coefficients

Structural model	R2	Explained (%)	Residual (e)
I (nutritional status)	0.809	80.9	0.437
II (learning environment)	0.819	81.9	0.425
III (motor ability)	0.432	43.2	0.754

Note. Residual coefficient e = sqrt (1 - R2).

Table 10. Summary of hypothesis testing

Hyp.	Path	Effect	Sig.	Decision
H1	X1 -> Y (direct)	-1.052	.001	Supported
H2	X2 -> Y (direct)	0.603	.050	Supported
H3	X3 -> Y (direct)	-0.299	.027	Supported
H4	X1 -> X2 (direct)	0.899	<.001	Supported
H5	X1 -> Y via X3 (indirect)	-0.432	<.05	Supported
H6	X2 -> Y via X3 (indirect)	0.193	<.05	Supported

Note. All six hypotheses were statistically supported at alpha = 0.05.

It is clear from Table 10 that all the six hypotheses have been successfully supported. Direct as well as indirect paths were significant statistically thereby indicating that physical fitness, nutritional status and the learning environment each play a role in motor ability while fitness also affects nutritional status.

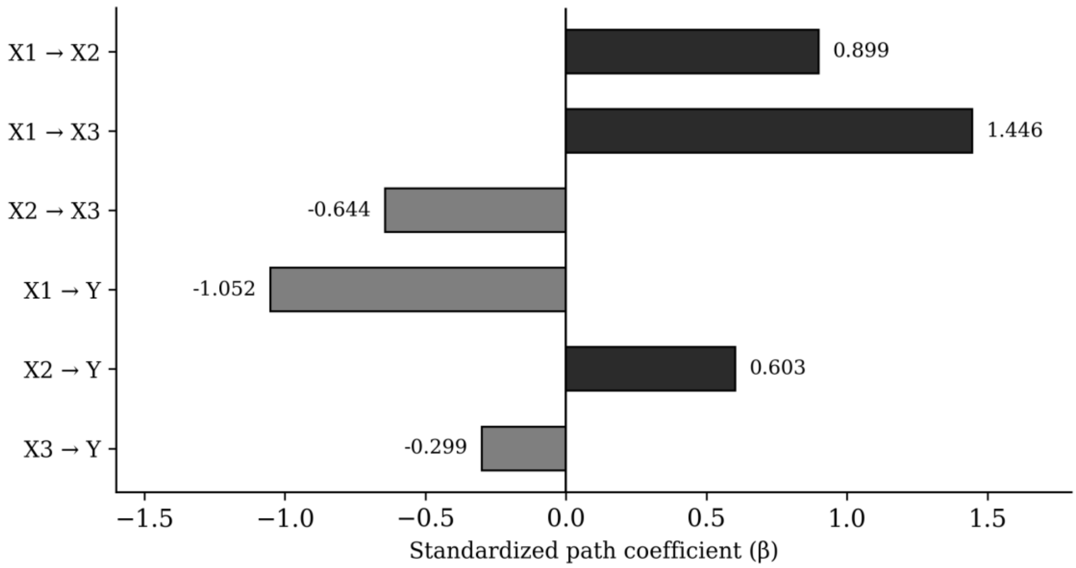

Figure 4. Standardized Direct Path Coefficients for All Six Modelled Relationships. Bars to the Right of Zero Denote Positive Effects; Bars to the Left Denote Negative Partial Effects

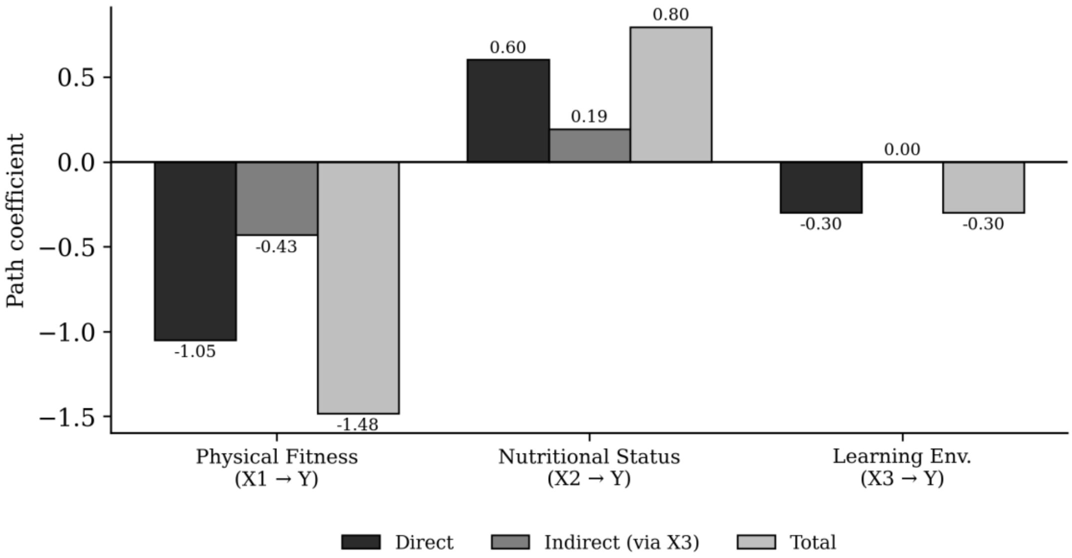

Figure 5. Decomposition of Direct, Indirect, and Total Standardized Effects on Motor Ability for Each Predictor

Discussion

The researchers in this study aimed to model the combined effects of physical fitness, nutritional status, and the learning environment on the motor ability of primary-school children, and to examine whether the learning environment acts as a mediator in the relationship between the two biological determinants. All six hypotheses were confirmed, however, reading the pattern of coefficients tells us much more than simply counting significant paths. The most significant result is that when the three determinants are taken into account at the same time, motor ability is mainly influenced by children's biological readiness, while the learning environment plays a role as a facilitating essentially but not a mediating force. The next paragraph evaluates each pathway one by one, compares it with the international evidence, and extracts its scientific and practical implications.

Physical Fitness and Motor Ability

Physical fitness brought about a substantial direct impact on motor skill, which is in line with H1. From a theoretical standpoint, fitness provides the basic elements of endurance, strength, speed, agility, and coordination that motor functions rely on, so kids with a powerful physiological base tend to learn and carry out movement activities in a highly efficient manner (Bustamante-Sanchez et al., 2022; Hohmann et al., 2021). This is in agreement with a large part of the literature that has showed how especially structured and habitual physical activities lead to increased neuromuscular function and movement economy which, in turn, enhance motor competence (Cocca et al., 2020; Engel et al., 2022). In Indonesian schools, similar relationships have been found and less fit students have been viewed to possess less motor skills and get tired quicker during the class time (Asnaldi et al., 2021; Gusril & Rasyid, 2021).

However, after controlling for nutritional status and the learning environment, the direct coefficient became negative. This figure should not be considered as proof that children in better physical condition become less proficient movers. In a model involving multiple predictors, the coefficient for each one stands for the partial effect that is estimated after eliminating the common variance with the other predictors, and the very strong link between fitness and nutritional status (beta = 0.899) suggests that the greater part of the raw fitness-motor association is given to nutrition when these two are entered in the equation. In fact, the negative partial coefficient is a statistical suppression or control effect rather than a substantive reversal, a fact that is widely recognised in regression with correlated predictors (Drenowatz et al., 2021; Putra et al., 2024). The tolerance figures in Table 4 support this interpretation: fitness and nutrition have a large portion of their variance in common while still being below the multicollinearity threshold. To further verify that this negative standardized coefficient resulted from statistical suppression rather than a true inverse association, future studies should employ larger samples and structural equation modeling (SEM), allowing latent-variable estimation and more robust parameter stability.

One way to understand figure 5 is that it reflects the main conjecture of the reinforcing-spiral model of motor development, fitness and motor competence form a feedback loop; they influence each other. As a result, getting a "clean" partial effect of one on the other is very tricky, if not impossible, in principle (Bardid et al., 2021; Burton et al., 2023). Practical implication however is straightforward and upbeat: fitness being the most upstream

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biological variable in the chain and the driver of both nutritional status and, together with it, the environment score, it follows that raising fitness is the highest leverage target for motor outcomes improvements. The main scientific value of this paragraph is that the fitness-motor relation in young children is an embedded, system-level relationship that can go either way depending on model specification, rather than a simple bivariate law.

Nutritional Status and Motor Ability

We learned that the nutritional condition of the body goes in the same direction as the motor skills development and also it does so positively; thus, H2 goes. This is, in fact, the most straightforward biological rationale among the model pathways: better-nourished children showed more excellent motor functioning after fitness and environmental controls. This is quite a plausible finding physiologically, since the proper supply of energy, protein, and micronutrients is primary for the growth of muscles, the strengthening of bones, and the development of the nervous system that the child movement requires (Denova-Gutierrez et al., 2023; Escobedo-Monge et al., 2025). This finding also fits well with the international data showing children of normal nutritional status on motor tasks outperforming both undernourished and over-nourished peers, since growth and neuromuscular development appear to be most optimal within the normal range (Barrozo et al., 2025; Masanovic et al., 2020).

That the effect has strengthened and remains significantly positive even after statistical control is theoretically very important. This means that nutrition has some independent explanatory power and is not just acting as a proxy for fitness, thus supporting the idea that motor development cannot be solely equated to training, but rather it is built on a biological basis (Bustamante-Sanchez et al., 2022; Papotot et al., 2021). The inconsistency or heterogeneity found in earlier studies, where the nutrition effects get diminished once fitness is included, is explained here by the modelling strategy: estimating fitness and nutrition at the same time, the design is able to differentially allocate their respective contributions and unearth a strong, direction-consistent nutritional effect. The practical implication is that motor-development programmes will have more complete returns when combined with nutritional monitoring, and the scientific input is to recognise nutritional status as an independent, and not a merely auxiliary, determining factor of childhood motor ability.

The Learning Environment and Motor Ability

The learning environment was found to have a significant direct impact on motor ability, confirming H3, however, it was the smallest contributory factor among the three determinants. Conceptually, a supportive environment that includes sufficient facilities, an engaging teaching method, and positive relationships with teachers and peers provides more avenues for movement practice, which is essential for motor learning (Baafi, 2020; Cheng et al., 2025; King-Dowling et al., 2020). The relatively small coefficient is in line with the research that show environmental factor, although present, depends on the learner's physical readiness and becomes less significant when biological factors are considered together with environment (Gleddie & Morgan, 2021; Lorås, 2020).

The negative partial sign once again represents the model's governing structure, not the idea that good environments are harmful. One of the main contextual differences was that all the children went to the same school, did the same curriculum, and were taught by the same teachers. This design drastically reduces the variation in the environment from one child to another, as shown by the high concentration of students in the middle category (Table 1) and the quite limited range of environment scores (Table 2). If a predictor does not vary much between individuals, the estimated partial effect of this predictor will easily be overshadowed by predictors that vary more, such as fitness and nutrition (Sneck et al., 2023). The environment hence seems to be a shared enabling factor whose effect is normal through, and is dependent on, the biological characteristics children bring to it. The scientific contribution here is to show, based on data, that in a setting where the education is quite similar, the teaching environment acts more as a helper than a main motivator of motor skills.

Physical Fitness and Nutritional Status

Physical fitness had a significant positive impact on nutritional status. It not only supported H4 but also explained 80.9% of the changes in nutrition. This is the strongest link in the model, and it illustrates the longstanding mutual influence between physical activity and nutrition. Being physically active regularly aids in maintaining energy balance, metabolism, and body composition. Besides, nutrition acts as the source for the development of fitness (Bustamante-Sanchez et al., 2022; Denova-Gutierrez et al., 2023). Moreover, the level of correlation agrees with a rising acknowledgment that fitness and nutrition should be combined as a pair of interdependent factors rather than being considered individually in child-health studies (Escobedo-Monge et al., 2025; Marques et al., 2021).

This result also sheds light on the suppression pattern found in the motor-ability model. Given the extremely close relationship between fitness and nutrition, they share a large amount of variance, this shared variance is redistributed through the coefficients of their partials when both variables are used to predict motor ability. The fact that fitness is upstream, influencing nutritional status and, along with it, the environment, makes it the strategic point of intervention: changes in fitness will influence the entire biological chain. The scientific value of this part is to reveal the internal structure of the biological determinants by showing that they constitute a coupled system whose structure is important for understanding the downstream effects on motor ability.

Indirect and Mediation Effects

Both mediated pathways were statistically confirmed (H5 and H6) but quite small in magnitude. The indirect effect of fitness on motor ability through the environment was -0.432, and that of nutrition was 0.193, both significantly smaller than the respective direct effects. Essentially, this implies that the learning environment was not a strong mediator: the biological determinants attained motor ability mostly through direct routes rather than by first changing the environment children experienced (Gleddie & Morgan, 2021; Lorås, 2020).

One of the most likely explanations is, once more, the uniformity of the environment. Since a mediator can influence only those variations that it possesses within itself, a largely uniform environment among students in one laboratory school, for instance, structurally limits the mediator's ability to carry on indirect effects (Sneck et al., 2023). In fact, this makes biological readiness the immediate cause of motor ability and the environment a distant, permissive factor, an order compatible with developmental explanations that internal capacity limits how fully external opportunities can be utilized (Bardid et al., 2021; Carballo-Fazanes et al., 2022). In the case of nutrition, the indirect path followed the direct one in the same positive direction, which further establishes the biological pathway as the primary one. The main scientific point of this section is that it gave a rare formal examination of the environmental mediation in the development of children's motor abilities and it found that when there is little environmental variation, the mediation is weak and direct biological effects dominate.

Synthesis and Scientific Contribution

Combining the six ways of beta-gamma really helps us understand better. The brain's motor system in these kids is the result of an intertwined biological mechanism, where fitness influences nutrition and both in turn influence the movement competence, which is supported but not mainly mediated by the learning environment. It was the model that accounted for 43.2% of the differences in motor skills with the rest, 0.754, indicating factors that were not considered such as regular physical activity, sleep, motivation, family support, and socio-economic context (Canale et al., 2025; Katanic et al., 2024). This considerable remainder serves as a reminder that motor skills development is influenced by a variety of factors and that no model of three variables can be sufficient to cover everything. The unique feature of this paper is both in its methods and ideas: by breaking down the effects in one single path model in a setting where the kids have the same level of education, it shows that a person's biology is more powerful than the shared environment when the variation in the environment is very low, a point that has direct implications on how physical-education resources should be allocated.

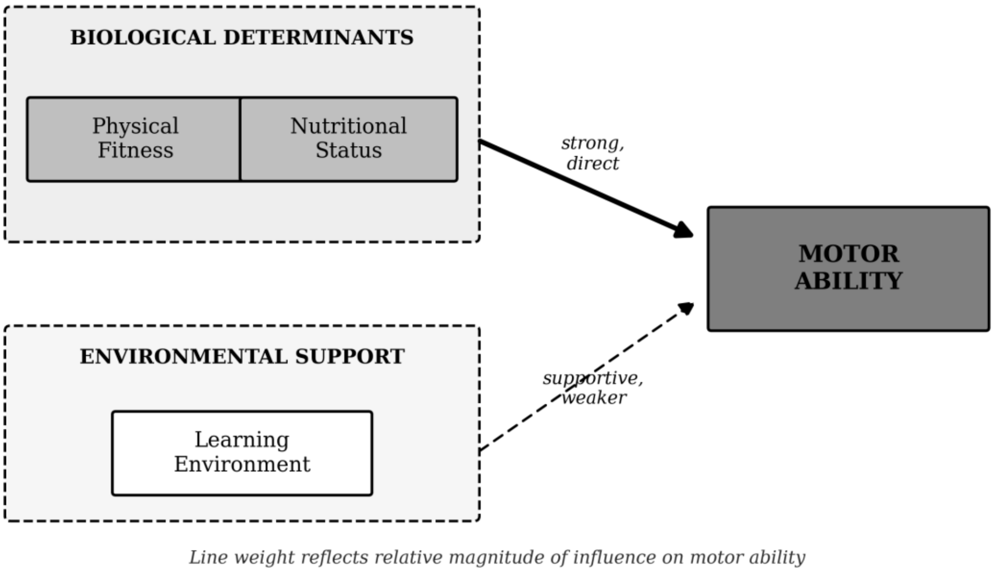

Figure 6. Conceptual Interpretation Model Summarising the Findings: Biological Determinants Exert a Strong, Direct Influence on Motor Ability, While the Learning Environment Provides Weaker, Supportive Influence

Conclusions

This study demonstrates that physical fitness, nutritional status, and the learning environment jointly contribute to motor ability in primary-school children, with the learning environment serving as a significant but relatively weak mediator. Among these factors, physical fitness and nutritional status exhibited stronger associations with motor ability than the learning environment, suggesting that biological determinants play a more prominent role in this sample. The findings support an integrated perspective in which biological and environmental factors complement rather than compete with one another in promoting children's motor development. From a theoretical perspective, this study provides a comprehensive model that simultaneously considers biological and environmental determinants, helping to explain previous inconsistencies in nutrition-related findings by incorporating physical fitness into the analytical framework. The results also suggest that the mediating role of the learning environment may be limited in relatively homogeneous educational settings. Practically, the findings highlight the importance of coordinated efforts among teachers, schools, policymakers, parents, and researchers to promote children's motor development through improved physical fitness, balanced nutrition, and supportive learning environments. Physical fitness development and nutritional monitoring should be prioritized while maintaining learning environments that encourage regular participation in physical activity and healthy behaviors. Nevertheless, the findings should be interpreted with caution because of several limitations, including the relatively small sample size, the single-school homogeneous setting, the cross-sectional design, measurement limitations, and the moderate proportion of explained variance. Consequently, the observed relationships represent statistical associations rather than causal effects, and the findings should not be generalized beyond populations with similar demographic and educational characteristics. Future research should employ longitudinal and experimental designs, include larger and more diverse samples, apply advanced analytical approaches, and incorporate additional determinants such as physical activity, sleep, motivation, family support, and socioeconomic status. The use of emerging technologies, including AI-based movement assessment and wearable sensors, may also provide more objective evidence and contribute to a more comprehensive understanding of children's motor development.

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