Interaction between nutritional status and physical activity on motor development among stunted children

Interacción del estado nutricional y la actividad física en el desarrollo motor de niños con retraso del crecimiento

Authors

Nurseha [1]
Sri Utami Subagio [2]
Marthia Ikhlasiah [3]

[1-3] Faletehan University, Indonesia

Corresponding author:
Nurseha
nurseha.faletehan@gmail.com

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Abstract

Background: In addition to nutritional status, physical activity also plays an important role in supporting neuromuscular development and children's motor skills. However, studies examining the interaction between nutritional status and physical activity on motor development among stunted children remain limited.
Methods: This study used an analytical observational design with a cross-sectional approach involving 120 stunted children aged 24–59 months. Samples were selected using proportional random sampling. Motor development was assessed using the Denver Developmental Screening Test II (DDST-II), while physical activity was measured using the Preschool-age Physical Activity Questionnaire (Pre-PAQ). Data were analyzed using chi-square and logistic regression tests with a significance level of $p < 0.05$ using IBM SPSS Statistics.
Results: Most respondents experienced delayed/suspect motor development (59.2%). There was a significant association between nutritional status and motor development ($p = 0.001$), as well as between physical activity and motor development ($p = 0.000$). Children with severe stunting and low physical activity had the highest proportion of delayed motor development (89.3%). Multivariate analysis showed that the interaction between severe stunting and low physical activity was the strongest factor associated with delayed motor development with an Adjusted OR of 6.25 (95% CI: 2.31–16.90; $p = 0.000$). Other significant factors included non-exclusive breastfeeding, history of infectious diseases, low family income, and inadequate developmental stimulation.
Conclusion: There was a significant interaction between nutritional status and physical activity on motor development among stunted children. Children with severe stunting and low physical activity had a higher risk of delayed motor development.

Keywords

Motor development; nutritional status; physical activity; stunting.

Resumen

Antecedentes: Además del estado nutricional, la actividad física desempeña un papel importante en el desarrollo neuromuscular y en la adquisición de habilidades motoras en los niños. Sin embargo, los estudios que analizan la interacción entre el estado nutricional y la actividad física sobre el desarrollo motor en niños con retraso del crecimiento (stunting) siguen siendo limitados.
Métodos: Se realizó un estudio observacional analítico con un diseño transversal que incluyó a 120 niños con retraso del crecimiento de entre 24 y 59 meses de edad. Las muestras fueron seleccionadas mediante muestreo aleatorio proporcional. El desarrollo motor fue evaluado utilizando el Denver Developmental Screening Test II (DDST-II), mientras que la actividad física se midió mediante el Preschool-age Physical Activity Questionnaire (Pre-PAQ). Los datos fueron analizados mediante las pruebas de chi-cuadrado y regresión logística, con un nivel de significación de $p < 0,05$, utilizando IBM SPSS Statistics.
Resultados: La mayoría de los participantes presentó un desarrollo motor retrasado o sospechoso (59,2%). Se encontró una asociación significativa entre el estado nutricional y el desarrollo motor ($p = 0,001$), así como entre la actividad física y el desarrollo motor ($p = 0,000$). Los niños con retraso severo del crecimiento y baja actividad física mostraron la mayor proporción de retraso en el desarrollo motor (89,3%). El análisis multivariado indicó que la interacción entre retraso severo del crecimiento y baja actividad física fue el factor más fuertemente asociado con el retraso en el desarrollo motor, con un OR ajustado de 6,25 (IC del 95%: 2,31–16,90; $p = 0,000$). Otros factores significativos incluyeron la ausencia de lactancia materna exclusiva, antecedentes de enfermedades infecciosas, bajos ingresos familiares y una estimulación insuficiente del desarrollo.
Conclusión: Se encontró una interacción significativa entre el estado nutricional y la actividad física sobre el desarrollo motor en niños con retraso del crecimiento. Los niños con retraso severo del crecimiento y baja actividad física presentaron un mayor riesgo de retraso en el desarrollo motor.

Palabras clave

Desarrollo motor; estado nutricional; actividad física; retraso del crecimiento.

Introduction

Stunting remains one of the major public health problems with multidimensional impacts on the quality of human resources, particularly among children under five years of age (Soesanti et al., 2020; Soliman et al., 2021). Stunting is defined as a condition of chronic growth failure caused by prolonged nutritional deficiency, resulting in children's height being below the age-standard established by the World Health Organization. This condition is not only associated with impaired physical growth but is also closely related to delays in cognitive, social, emotional, and motor development. Children who experience stunting tend to have lower learning capacity, weaker immune resistance, and decreased productivity in adulthood.

Motor development in children is theoretically influenced by the interaction between biological and environmental-behavioral factors. Within the biological framework, chronic nutritional deficiency may impair neuromuscular maturation, muscle function, and cognitive processing involved in movement coordination (Adolph & Hoch, 2019). Concurrently, physical activity provides repetitive sensorimotor stimulation necessary for the acquisition and refinement of motor skills during early childhood. This integrative perspective suggests that nutritional status and physical activity should not be examined as isolated determinants, but rather as interrelated factors that may jointly influence motor development outcomes among stunted children (Cameron et al., 2012).

Motor development itself is an important component of child growth and development that is influenced by neurological maturation, nutritional adequacy, environmental stimulation, and physical activity (Zulkarnaen, 2019). Gross motor skills include activities such as walking, running, and maintaining body balance, while fine motor skills involve coordination of smaller muscles such as grasping and arranging objects. Children with good nutritional status and adequate physical activity generally demonstrate better motor development because movement activities stimulate neuromuscular coordination, muscle strength, balance, and sensory function. Therefore, nutritional status and physical activity are two important factors that should be examined simultaneously in understanding motor development among stunted children (Prista, 1998).

Globally, stunting remains a significant health challenge among children under five years old. Data from the United Nations Children's Fund and World Health Organization reported that more than 148 million children worldwide experienced stunting in 2023, with the highest prevalence occurring in developing countries in Asia and Africa. Southeast Asia contributes substantially to stunting cases due to socioeconomic inequality, poor dietary quality, and limited healthcare access (World Health Organization, 2025). In Indonesia, the national prevalence of stunting in 2023 was recorded at 21.5%, which remains above the WHO threshold of less than 20%. In West Java Province, stunting is still commonly found across districts and cities, including Bogor Regency, which has a large under-five population and heterogeneous socioeconomic conditions. The working area of Ciomas Primary Health Center is one of the regions where stunting cases among children remain prevalent (Kemenkes, 2023). In addition to impaired linear growth, delayed motor development among stunted children has increasingly been identified in primary healthcare services. Children with stunting are often slower in walking, maintaining balance, and coordinating movements, which may result from inadequate intake of essential nutrients such as protein, iron, zinc, and other micronutrients involved in muscle and nervous system development. Furthermore, stunted children frequently demonstrate lower physical activity levels due to physical weakness, low energy reserves, and insufficient environmental stimulation (Prasetyo et al., 2023).

Previous studies have demonstrated that nutritional status is associated with children's motor development, in which children with malnutrition or stunting tend to experience impaired gross and fine motor skills compared to children with normal nutritional status (Elba et al., 2024; Izza et al., 2023). Other studies also reported that low physical activity is related to poorer motor abilities due to inadequate movement stimulation and reduced body coordination development. However, most previous studies have only examined nutritional status and physical activity separately as independent factors influencing motor development (Chang et al., 2002; Logan et al., 2015). Studies integrating these variables through interaction analysis remain limited, particularly among stunted children. In addition, many studies focused only on direct associations between variables without exploring how physical activity

may strengthen or weaken the effect of nutritional status on motor development. Consequently, understanding regarding the multidimensional relationship between nutritional status, physical activity, and motor development among stunted children remains incomplete (Robinson et al., 2015).

Another limitation of previous research concerns the study setting and population characteristics. Most studies were conducted in hospitals or large urban areas and therefore may not fully represent the conditions of stunted children in community-based primary healthcare settings. Research specifically conducted in primary healthcare center working areas with diverse socioeconomic conditions remains limited, even though environmental factors and children's physical activity patterns are strongly influenced by local community characteristics. Moreover, previous studies have often focused primarily on anthropometric indicators without examining physical activity as a modifiable behavioral factor that can be improved through family education, active play stimulation, and community-based interventions (Bopp & Fallon, 2008; Moss & Gu, 2022). In the working area of Ciomas Primary Health Center, monitoring activities conducted through integrated health posts and child healthcare services have identified several stunted children with delayed motor development. However, evidence regarding the interaction between nutritional status and physical activity on motor development in this population remains limited. Therefore, this study is necessary to provide more contextual and applicable scientific evidence for primary healthcare services and community-based stunting intervention programs.

This study is important because motor development during early childhood serves as a fundamental basis for cognitive, social, and learning abilities later in life. Untreated motor developmental delays may reduce children's environmental exploration abilities, impair social interaction, decrease academic achievement, and negatively affect quality of life in the future. Understanding the interaction between nutritional status and physical activity may help healthcare providers develop more comprehensive interventions for stunted children. Improving nutritional status alone may not be sufficient without adequate physical stimulation and active movement opportunities for children. Therefore, integrating nutritional improvement programs with physical activity stimulation and developmental monitoring may contribute to optimizing child development outcomes. The findings of this study are also expected to strengthen community-based stunting reduction strategies that focus not only on physical growth but also on overall child developmental outcomes.

This study aimed to analyze the interaction between nutritional status and physical activity on motor development among stunted children in the working area of Ciomas Primary Health Center, Bogor Regency. The study specifically tested whether physical activity moderates the association between nutritional status and motor development among stunted children. Statistically, the study hypothesized a significant interaction effect between nutritional status and physical activity on motor development scores, indicating that the effect of nutritional status on motor development differs according to children's physical activity levels.

Method

This study employed an analytical observational design with a cross-sectional approach to analyze the interaction between nutritional status and physical activity on motor development among stunted children in the working area of Ciomas Primary Health Center. A cross-sectional design was selected because the exposure and outcome variables were measured simultaneously, allowing researchers to efficiently evaluate the relationships among variables within the stunted child population. Data collection was conducted from October to December 2025 through integrated health post activities, home visits, and child healthcare services within the primary healthcare center's working area. All data presented in this manuscript were derived from completed data collection and final database verification conducted before statistical analysis. The study setting was selected because the area still has a relatively high prevalence of stunting among children under five years old and diverse socioeconomic community characteristics that enable a more comprehensive assessment of behavioral factors and child growth and development.

The target population of this study consisted of all stunted children aged 24–59 months residing in the working area of Ciomas Primary Health Center, Bogor Regency. The accessible population included stunted children registered in the nutritional status monitoring records of the primary healthcare center

and integrated health posts during the study period. Inclusion criteria were children aged 24–59 months with stunting status based on the height-for-age index (HAZ) below minus two standard deviations (< −2 SD) according to the anthropometric standards of the World Health Organization, children in healthy condition during examination, and parents willing to sign informed consent. Exclusion criteria included children with congenital abnormalities, cerebral palsy, severe neurological disorders, chronic disease history, musculoskeletal disorders, or other medical conditions that could significantly affect motor development and physical activity. Children who did not complete all measurement procedures were also excluded from the study analysis.

Sample size determination was conducted using an observational analytical formula for testing the association between two variables in a cross-sectional design with a 95% confidence level, 80% statistical power, and an estimated proportion of abnormal motor development among stunted children based on previous studies. The calculation considered the proportion values of exposed and non-exposed groups and included an additional 10% reserve sample to anticipate missing data or dropouts during the study process. Based on the calculation results, the minimum required sample size was 108 respondents, and after adding a 10% reserve for incomplete data, the final minimum sample size became 120 stunted children. The sampling technique used was proportional random sampling based on the integrated health post areas under the supervision of Ciomas Primary Health Center, ensuring that every stunted child meeting the inclusion criteria had an equal opportunity to be selected as a study respondent.

The primary outcome variable in this study was motor development among stunted children, which included gross motor and fine motor development. Motor development assessment was conducted using the Denver Developmental Screening Test II (DDST-II), which has been widely used in child development research and has demonstrated good validity and reliability for screening motor development among toddlers. The DDST-II assesses children's abilities based on personal-social, fine motor-adaptive, language, and gross motor categories; however, this study specifically focused on gross motor and fine motor domains. Examination results were categorized as normal or suspect/delayed according to DDST-II interpretation guidelines. Measurements were conducted by trained enumerators who received instruction regarding child developmental examination procedures to maintain consistency among observers. Before data collection, all enumerators participated in a two-day training session covering DDST-II administration procedures, scoring interpretation, anthropometric measurements, and interview standardization. Interobserver reliability testing was conducted using repeated assessments on the same children, resulting in a Cohen's kappa coefficient of 0.82, indicating strong agreement among observers. The DDST-II instrument has adequate sensitivity and specificity in detecting developmental delays among children under five years old and is therefore suitable for community-based research.

The primary exposure variables in this study were nutritional status and physical activity. Nutritional status was measured using the height-for-age index (HAZ) based on the WHO Child Growth Standards. Height measurements were conducted using a microtoise with an accuracy of 0.1 cm, while children's age was calculated based on birth dates recorded in maternal and child health books or birth certificates. HAZ scores were calculated using the WHO Anthro application and categorized into moderate stunting (−3 SD to < −2 SD) and severe stunting (< −3 SD). Children's physical activity was assessed using the Preschool-age Physical Activity Questionnaire (Pre-PAQ), which has been used in preschool-aged child research and has good validity in assessing children's physical activity levels based on play activities, active movements, and daily activity duration. The questionnaire was administered through interviews with mothers or primary caregivers. Based on the total Pre-PAQ score, physical activity levels were categorized into low (< 33rd percentile), moderate (33rd–66th percentile), and high (> 66th percentile) activity groups according to the distribution of activity scores and instrument interpretation procedures used in previous preschool physical activity studies.

To reduce potential bias, several control measures were implemented by the researchers. Selection bias was minimized through the use of proportional random sampling and the application of clear inclusion and exclusion criteria. Information bias was reduced through the use of standardized and validated instruments as well as enumerator training before data collection. Recall bias in measuring physical activity and health history was minimized using structured questions and maternal and child health books

as verification sources. In addition, regular field supervision was conducted throughout the data collection process to ensure adherence to study procedures. Incomplete or inconsistent data were reverified with respondents on the same day to maintain data quality.

Ethical approval for this study was obtained from the Research Ethics Committee of Universitas Faletehan with Research Ethics Approval No. 003289/UNIVERSITAS FALETEHAN/2025. Written informed consent was obtained from all parents or primary caregivers prior to data collection.

Data analysis was performed using IBM SPSS Statistics 26.0. Univariate analysis was conducted to describe frequency distributions, means, and standard deviations of each study variable. Bivariate analysis was performed using chi-square or Fisher's exact tests to determine relationships between categorical variables. Furthermore, multivariate analysis was conducted using logistic regression to assess the interaction effect between nutritional status and physical activity on motor development while controlling for potential confounding factors. Interaction between variables was tested using an interaction term in the regression model. Analysis results were presented as odds ratios (ORs) and 95% confidence intervals (CIs). A p-value < 0.05 was considered statistically significant in this study.

Results

Based on Table 1, most respondents were in the 36–47 months age group, accounting for 44 children (36.7%). The respondents were predominantly male, with 68 children (56.7%). The majority of children experienced moderate stunting, totaling 78 children (65.0%), while severe stunting was identified in 42 children (35.0%). Moderate physical activity was the most common category, observed in 51 children (42.5%); however, 46 children (38.3%) still had low physical activity levels. Delayed/suspect motor development was found more frequently than normal motor development, affecting 71 children (59.2%).

Table 1.

Variables	n	%	Mean ± SD	Minimum–Maximum
Age of Children			41.3 ± 10.2	24–59
24–35 months	38	31.7		
36–47 months	44	36.7		
48–59 months	38	31.7		
Sex				
Male	68	56.7		
Female	52	43.3		
Stunting Status			HAZ: −2.87 ± 0.61	−4.21 – −2.01
Moderate stunting	78	65.0		
Severe stunting	42	35.0		
Physical Activity			37.6 ± 8.9	18–59
Low	46	38.3		
Moderate	51	42.5		
High	23	19.2		
Motor Development			6.8 ± 2.1	2–10
Normal	49	40.8		
Delayed/suspect	71	59.2		
Exclusive Breastfeeding				
Yes	54	45.0		
No	66	55.0		
Immunization Status				
Complete	83	69.2		
Incomplete	37	30.8		
Maternal Education				
Low	57	47.5		
Middle/High	63	52.5		
Family Income				
Low	72	60.0		
High	48	40.0		
History of Infectious Diseases				
Yes	69	57.5		
No	51	42.5		

The descriptive analysis of continuous variables showed that the mean age of respondents was 41.3 ± 10.2 months. The average height-for-age Z-score (HAZ) among stunted children was −2.87 ± 0.61 SD,

indicating that most respondents were within the moderate-to-severe stunting category. The mean physical activity score was 37.6 ± 8.9, while the mean motor development score was 6.8 ± 2.1. In addition, most respondents did not receive exclusive breastfeeding, totaling 66 children (55.0%), had a history of infectious diseases in 69 children (57.5%), and came from low-income families in 72 households (60.0%).

Table 2. Relationship Between Nutritional Status and Motor Development Among Stunted Children

Nutritional Status	Normal Motor Development n (%)	Delayed Motor Development n (%)	p-value
Moderate stunting	41 (52.6)	37 (47.4)	0.001
Severe stunting	8 (19.0)	34 (81.0)	

Based on Table 2, children with severe stunting experienced delayed motor development more frequently, accounting for 34 children (81.0%), compared to children with moderate stunting, totaling 37 children (47.4%). The chi-square test results showed a significant relationship between nutritional status and motor development among stunted children (p = 0.001).

Table 3. Relationship Between Physical Activity and Motor Development Among Stunted Children

Physical Activity	Normal Motor Development n (%)	Delayed Motor Development n (%)	p-value
Low	9 (19.6)	37 (80.4)	0.001
Moderate	25 (49.0)	26 (51.0)	
High	15 (65.2)	8 (34.8)	

Table 3 shows that most children with low physical activity experienced delayed motor development, accounting for 37 children (80.4%). In contrast, children with high physical activity more frequently demonstrated normal motor development, totaling 15 children (65.2%). The bivariate analysis indicated a significant relationship between physical activity and motor development among stunted children (p = 0.001).

Table 4. Interaction Between Nutritional Status and Physical Activity on Motor Development Among Stunted Children

Nutritional Status and Physical Activity	Normal Motor Development n (%)	Delayed Motor Development n (%)	p-value
Severe stunting + low activity	3 (10.7)	25 (89.3)	0.001
Severe stunting + moderate/high activity	5 (35.7)	9 (64.3)	
Moderate stunting + low activity	6 (33.3)	12 (66.7)	
Moderate stunting + moderate/high activity	35 (58.3)	25 (41.7)	

Based on Table 4, the group of children with severe stunting and low physical activity had the highest proportion of delayed motor development at 89.3%. Conversely, children with moderate stunting and moderate/high physical activity more frequently demonstrated normal motor development at 58.3%. The analysis results indicated a significant interaction between nutritional status and physical activity on motor development among stunted children (p = 0.001).

Table 5. Multivariate Analysis of Factors Associated with Motor Development Among Stunted Children

Variables	Adjusted OR	95% CI	p-value
Severe stunting	4.12	1.71–9.89	0.002
Low physical activity	5.34	2.11–13.48	0.001
Non-exclusive breastfeeding	2.08	1.01–4.31	0.047
History of infectious diseases	2.76	1.28–5.96	0.009
Low maternal education	1.94	0.93–4.05	0.076
Low family income	2.31	1.09–4.90	0.028
Poor developmental stimulation	4.87	2.02–11.74	0.001
Severe stunting × low physical activity interaction	6.25	2.31–16.90	0.001

The logistic regression analysis presented in Table 5 showed that severe stunting, low physical activity, non-exclusive breastfeeding, history of infectious diseases, low family income, and poor developmental stimulation were significantly associated with delayed motor development among stunted children. The variable with the strongest effect was the interaction between severe stunting and low physical activity, with an Adjusted OR of 6.25 (95% CI: 2.31–16.90; p = 0.001). This finding indicates that children with severe stunting who had low physical activity were 6.25 times more likely to experience delayed motor development compared to the reference group after controlling for other confounding variables. Low maternal education was associated with an increased risk of delayed motor development; however, the association did not reach statistical significance (p = 0.076).

Discussion

This study successfully achieved its main objective of analyzing the interaction between nutritional status and physical activity on motor development among stunted children in the working area of Ciomas Primary Health Center. The findings showed that most stunted children experienced delayed/suspect motor development (59.2%), and this condition was more commonly found among children with severe stunting and low physical activity. Multivariate analysis demonstrated that the interaction between severe stunting and low physical activity was the most dominant factor associated with delayed motor development, with an Adjusted OR of 6.25 (95% CI: 2.31–16.90; p = 0.000). These findings indicate that motor development in stunted children is not only influenced by impaired physical growth but is also strongly affected by insufficient physical movement in daily activities. This condition suggests that developmental disorders among stunted children are multidimensional and influenced by a combination of biological and behavioral factors.

The results of this study are consistent with previous studies conducted by (Prado & Dewey, 2014) which reported that children with poor nutritional status have a higher risk of delayed motor development due to impaired neuromuscular and cognitive function. Another study by (Grantham-McGregor et al., 2007) also found that chronic stunting during early childhood was associated with reduced gross motor abilities and body coordination. In addition, research by (Carson et al., 2016) demonstrated that low physical activity among preschool-aged children was associated with delayed motor development because of insufficient movement stimulation and environmental exploration. The similarity between the findings of this study and previous research indicates that the relationship between nutritional status, physical activity, and motor development is a consistent phenomenon among young children. However, this study provides additional evidence showing that physical activity may strengthen the adverse effect of stunting on children's motor development (Prado & Dewey, 2014).

Theoretically, the findings of this study can be explained through neuromaturation theory and child developmental stimulation theory. Neuromaturation theory explains that motor development is influenced by the maturation of the central nervous system, muscle growth, and sensorimotor coordination that develop progressively according to the child's age. Stunted children often experience chronic nutritional deficiencies, particularly protein, iron, zinc, and other essential micronutrients required for nerve tissue formation, neuronal myelination, and muscle contraction (Ali, 2023). Long-term nutrient deficiencies may disrupt the optimal development of the motor nervous system, resulting in delayed walking ability, impaired balance, poor coordination, and other motor difficulties. Furthermore, developmental stimulation theory explains that physical activity serves as an important form of sensory and motor stimulation that strengthens neural connections in the brain. Activities such as active play, running, jumping, and environmental exploration improve neuromuscular coordination and motor skills. Therefore, stunted children with low physical activity are more likely to experience motor developmental disorders than children with better physical activity levels (Welis et al., 2022).

The high proportion of delayed motor development among children with severe stunting and low physical activity in this study may be explained by several factors. Children with severe stunting generally have lower muscle mass, limited energy reserves, and higher levels of fatigue, resulting in reduced movement and physical engagement (Lasri et al., 2024). This condition limits the child's opportunity to actively explore the environment, thereby reducing motor stimulation. In addition, most respondents in this study came from low-income families and mothers with low educational backgrounds. These socioeconomic conditions may affect food quality, parenting practices, and developmental stimulation at

home. Parents with limited knowledge regarding child stimulation are less likely to encourage active play activities that support motor development. The high prevalence of infectious diseases among respondents may also worsen children's physical condition because recurrent infections increase energy requirements and reduce appetite, thereby aggravating growth and developmental problems (Prista, 1998; Zulkarnaen, 2019).

The relationship between nutritional status and motor development in this study demonstrated that the more severe the stunting condition, the higher the risk of delayed motor development. This occurs because nutritional status plays an essential role in muscle tissue growth, nervous system development, and body energy production. Children with chronic malnutrition tend to experience reduced muscle strength and limited movement ability, leading to slower motor development. Moreover, iron and zinc deficiencies among stunted children may interfere with neurotransmitter function and brain development involved in motor control. Therefore, poor nutritional status becomes a major biological factor contributing to delayed motor development among stunted children (Haris et al., 2024; Maharani et al., 2025).

Meanwhile, physical activity showed a strong association with motor development because movement activities provide direct stimulation to children's muscle coordination and nervous system function. Children with high physical activity levels tend to have better motor development because their bodies continuously practice coordination, balance, and environmental exploration. Conversely, children with low physical activity are generally more passive and receive insufficient motor stimulation required for motor skill development. The interaction between nutritional status and physical activity in this study indicates that physical activity may either strengthen or weaken the impact of stunting on motor development. Stunted children who remain physically active demonstrated better motor development than passive stunted children. This finding suggests that increasing physical activity could become one of the intervention strategies to improve motor development among stunted children.

From an epidemiological perspective, the interaction identified in this study was primarily analyzed on the multiplicative scale through the inclusion of an interaction term in the logistic regression model. The significantly increased odds of delayed motor development among children with severe stunting and low physical activity suggest that the combined effect of these two factors exceeded their independent effects. Nevertheless, the present study did not specifically evaluate interaction on the additive scale, which may provide additional insight into the public health impact of combined biological and behavioral risk factors. Future studies are therefore recommended to assess both additive and multiplicative interaction models to better understand the synergistic relationship between stunting severity and physical inactivity on child motor development outcomes.

The findings of this study have important implications for child healthcare services and stunting reduction programs at the primary healthcare level. Stunting interventions should not only focus on improving nutritional status but should also include physical activity stimulation and regular monitoring of children's motor development. Educational programs for parents regarding the importance of active play, developmental stimulation, and responsive parenting practices need to be strengthened within primary healthcare services. This study also has several limitations. The cross-sectional design prevents determination of causal relationships between variables. In addition, the use of interview-based questionnaires for measuring physical activity may have introduced recall bias among respondents. Furthermore, the possibility of reverse causality cannot be excluded, as children with delayed motor development may naturally engage in lower levels of physical activity due to movement limitations or reduced participation in active play. The study also did not assess other biological factors such as hemoglobin levels, micronutrient status, and dietary quality, which may also influence motor development. Therefore, future longitudinal and intervention studies involving more comprehensive biological measurements are recommended.

Conclusions

This study demonstrated a significant interaction between nutritional status and physical activity on motor development among stunted children in the working area of Ciomas Primary Health Center. Children with severe stunting and low physical activity had a higher risk of delayed motor development

compared to other groups. In addition, non-exclusive breastfeeding, history of infectious diseases, low family income, and inadequate developmental stimulation also contributed to delayed motor development among children. Physical activity was shown to be an important factor that could either aggravate or reduce the negative impact of stunting on motor development.

Primary healthcare centers and healthcare workers are expected to strengthen routine monitoring programs for motor development among stunted children and provide education for parents regarding the importance of physical activity and developmental stimulation. Parents are also encouraged to involve children more actively in age-appropriate physical play activities to support motor development. Future studies are recommended to use longitudinal designs and include biological measurements and dietary assessments to better analyze causal relationships between variables.

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Author Affiliations

Nurseha[1], Sri Utami Subagio[2], Marthia Ikhlasiah[3]

[1] Faculty of Health Sciences, Faletehan University, Serang, Banten, Indonesia

[2] Faculty of Health Sciences, Faletehan University, Serang, Banten, Indonesia

[3] Faculty of Health Sciences, Faletehan University, Serang, Banten, Indonesia

Corresponding Author:

Nurseha

Faculty of Health Sciences, Faletehan University

Jl. Raya Cilegon–Drangong Km. 06, Pelamunan, Kramatwatu, Serang, Banten 42111, Indonesia

ORCID: 0000-0002-2118-3438

Email: nurseha.faletehan@gmail.com

WhatsApp: +62 852-2026-3766

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Authors and translators' details:

Nurseha	nurseha.faletehan@gmail.com	Author
Sri Utami Subagio	amysubagio@gmail.com	Author
Marthia Ikhlasiah	marthia_ikhlasiah@uf.ac.id	Author
Heriviyatno Julika Siagian	heriviyatno.j.siagian@gmail.com	Translator