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Determinants of gross motor development in children: A systematic review

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Abstract

Background: Gross motor development is an essential component of childhood development and is influenced by multiple interacting individual, family, environmental, educational, nutritional, and technological factors. Identifying these determinants is important for developing effective strategies to promote children's motor competence. **Objectives:** This systematic review aimed to identify and synthesize the factors associated with gross motor development in children and to examine the evidence regarding interventions and environmental conditions that may influence motor competence. **Methods:** A systematic literature search was conducted using relevant electronic databases following the PRISMA framework. A total of 944 records were identified. After removal of 44 duplicate records, 900 records were screened. Following the screening and eligibility assessment process, 13 studies met the predefined inclusion criteria and were included in the systematic review. The included studies involved children from infancy to early adolescence and employed randomized controlled trials, comparative studies, cross-sectional studies, and feasibility designs. The studies examined gross motor development using standardized and field-based instruments, including the Test of Gross Motor Development (TGMD), Ages and Stages Questionnaire (ASQ), and other measures of motor competence. **Results:** The findings demonstrated that gross motor development is multidimensional and is influenced by several interconnected determinants. Regular physical activity, structured movement experiences, outdoor play, and opportunities to practice fundamental motor skills were generally associated with better motor competence. Family and parental involvement also contributed to children's motor skill acquisition, particularly through parent-mediated activities and supportive home environments. Environmental interventions, such as modified playgrounds, improved locomotor and ball skills, although effects on overall physical activity were inconsistent. Technology-based approaches, including active video games and digital sports dance, showed potential to improve motor competence, locomotor skills, and object-control skills when technology was used to promote active movement. Nutritional factors, including adequate vitamin D intake, were also relevant, although standard supplementation appeared sufficient for most children. Conversely, several interventions demonstrated limited or no significant effects, indicating that intervention effectiveness may depend on duration, intensity, implementation, developmental characteristics, and contextual factors. **Conclusion:** Gross motor development in children is shaped by a complex interaction of physical activity opportunities, environmental stimulation, family support, educational practices, nutritional conditions, and technology use. Interventions that provide frequent, structured, enjoyable, and developmentally appropriate movement experiences appear particularly promising. Future research should adopt standardized assessment procedures and longitudinal designs to clarify the relative contribution and interaction of these determinants across different stages of childhood.

Keywords: Gross Motor Development; Motor Competence; Fundamental Motor Skills; Children; Physical Activity; Determinants; Systematic Review; Motor Development.

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INTRODUCTION

Gross motor development is a fundamental component of child growth and plays a critical role in the development of movement competence, balance, coordination, and overall physical functioning. These skills enable children to perform essential locomotor and object-control movements such as running, jumping, throwing, and maintaining postural stability, which are closely associated with cognitive development, social interaction, and school readiness (Robinson et al., 2015; Stodden et al., 2008). Globally, concerns regarding motor development delays in children have increased due to declining physical activity levels, sedentary lifestyles, and excessive screen exposure during early childhood (World Health Organization [WHO], 2019). Studies have shown that inadequate motor competence during childhood may negatively affect lifelong physical activity participation, health outcomes, and physical literacy development (Cairney et al., 2019; Lubans et al., 2010).

Physical literacy has emerged as an important concept in child development because it emphasizes children's motivation, confidence, physical competence, and knowledge to engage in lifelong physical activity (Edwards et al., 2017). Consequently, schools, families, and communities play important roles in providing movement-rich environments that support children's motor skill acquisition and healthy physical development. Previous studies have demonstrated that structured physical activity programs, outdoor play opportunities, and movement-oriented learning environments positively contribute to children's gross motor competence and physical fitness (Barnett et al., 2016; Webster et al., 2023). In addition, technology-based interventions, including active video games and digital movement programs, have recently gained attention as innovative approaches to improving children's motor skills and physical engagement (Comeras-Chueca et al., 2022; He et al., 2025).

Despite growing research interest in gross motor development, existing evidence remains fragmented across multiple domains, including technology-based interventions, environmental stimulation, nutritional factors, and family involvement (Moss & Gu, 2022; Rodríguez-González et al., 2022). Previous systematic reviews have primarily focused on single interventions or

specific populations, such as exergaming interventions or children with developmental disorders, limiting comprehensive understanding of multidimensional determinants affecting gross motor development (Li et al., 2022; Oppici et al., 2022). Furthermore, rapid advances in digital learning environments and movement-based technologies have introduced both opportunities and challenges for children's physical development, particularly regarding the balance between screen exposure and active movement participation (Bakht et al., 2025; Torres et al., 2021). Therefore, an updated systematic review integrating recent evidence across multiple determinants of gross motor development is necessary to provide a broader understanding that may inform educators, healthcare professionals, therapists, and policymakers in designing effective strategies to support children's physical development and physical literacy.

This review therefore aims to systematically synthesize recent evidence regarding the multidimensional determinants of gross motor development in children, with particular attention to technology-based interventions, environmental influences, nutritional factors, family support, and assessment approaches.

METHOD

Research Design

This study employed a systematic review design to identify, critically appraise, and synthesize empirical evidence concerning the determinants of gross motor development in children. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, methodological rigor, and reproducibility throughout the study selection and evidence synthesis processes. The review protocol was developed prior to the literature search and comprised predefined search strategies, eligibility criteria, study selection procedures, and methodological quality assessment.

Data Sources and Search Strategy

A comprehensive literature search was conducted in five electronic databases: PubMed, Scopus, Web of Science, ERIC, and SPORTDiscus. These databases were selected because they provide broad coverage of biomedical,

health, developmental, educational, physical activity, sport science, and rehabilitation research relevant to children's motor development.

The literature search was conducted between January and March 2026, and studies published from January 2020 to December 2025 were considered eligible. The search strategy was developed using keywords related to the population, outcome, and potential determinants of gross motor development. The primary search terms included “gross motor development,” “gross motor skills,” “motor competence,” “children,” “early childhood,” “preschool children,” “physical activity,” “technology,” “nutrition,” “family support,” “environment,” and “intervention.”

The terms were combined using Boolean operators AND and OR. An example of the search strategy was: ("gross motor development" OR "gross motor skills" OR "motor competence") AND ("children" OR "early childhood" OR "preschool children") AND (technology OR nutrition OR family OR environment OR physical activity OR intervention).

The search strategy was adapted to the indexing requirements and syntax of each database. In addition to database searching, the reference lists of relevant articles were manually screened to identify potentially eligible studies that might not have been retrieved through the electronic database searches.

Eligibility Criteria

Eligibility criteria were established a priori based on the objectives of the review. Studies were considered eligible if they met all predefined criteria. The population consisted of children aged 2–12 years. Eligible studies were published between 2020 and 2025 as full-text, peer-reviewed research articles in scientific journals and were written in English. The review included randomized controlled trials, quasi-experimental studies, experimental studies, observational studies, comparative studies, and feasibility studies that provided empirical data. In addition, studies were required to examine gross motor development, gross motor skills, fundamental motor skills, or motor competence and investigate at least one potential determinant or influencing factor relevant to motor development, including physical activity, environmental stimulation, family or parental involvement, nutritional status,

technology-based activities, educational practices, or other relevant developmental factors.

Studies were excluded if they were systematic reviews, meta-analyses, narrative reviews, editorials, conference abstracts, letters, protocols, case reports, or non-peer-reviewed publications. Studies were also excluded when the population did not fall within the specified age range, gross motor development was not a relevant outcome, the full text was unavailable, or the study did not provide sufficient empirical information to address the review question. Duplicate records retrieved from different databases were removed before the screening process.

Study Selection Process

All records retrieved from the electronic databases were exported to reference management software for organization and duplicate removal. Following deduplication, the remaining records underwent title and abstract screening based on the predefined eligibility criteria.

Two reviewers independently screened the titles and abstracts. Records considered potentially relevant were retrieved for full-text assessment. The full-text articles were independently evaluated by the same reviewers against all inclusion and exclusion criteria. Disagreements between reviewers were resolved through discussion and consensus. When consensus could not be reached, a third reviewer was consulted.

The study selection process was reported using a PRISMA 2020 flow diagram. A total of 944 records were identified through the database and additional searching. After removal of 44 duplicate records, 900 records remained for title and abstract screening. Following screening, 80 records proceeded to the subsequent eligibility stage. Of these, 65 records were excluded, leaving 15 full-text reports for detailed eligibility assessment. After full-text assessment, 2 reports were excluded because they did not meet the predefined eligibility criteria. Consequently, 13 studies were included in the final systematic review.

Data Extraction and Synthesis

Data were extracted systematically from each included study using a standardized data extraction form. The extracted information included author and publication year, country, sample characteristics, participant age, study design, assessment instruments, determinant or exposure examined, gross motor development outcomes, principal findings, and study conclusions.

The extracted findings were synthesized using a narrative synthesis approach because of the heterogeneity among the included studies in terms of study designs, populations, interventions or determinants, outcome measures, and assessment instruments. The determinants identified across the studies were subsequently organized into thematic categories, including physical activity and movement opportunities, environmental factors, family and parental support, educational and pedagogical practices, nutritional factors, technology-related factors, and motor assessment approaches.

Quality Appraisal

The methodological quality of the included studies was independently assessed by two reviewers using the appropriate Joanna Briggs Institute (JBI) Critical Appraisal Tools according to the design of each study. Different JBI appraisal checklists were applied where appropriate, including tools for randomized controlled trials, quasi-experimental studies, cross-sectional studies, and other relevant designs.

The appraisal considered methodological domains such as appropriateness of participant selection, allocation and randomization procedures, identification and measurement of exposures and outcomes, validity and reliability of measurement instruments, completeness of follow-up, control of confounding factors, appropriateness of statistical analyses, and clarity of reporting.

Each appraisal item was rated according to the JBI response categories, including “Yes,” “No,” “Unclear,” or “Not Applicable.” The overall methodological quality of each study was then considered in the interpretation of the evidence. Disagreements between reviewers were resolved through discussion and consensus, with consultation of a third reviewer when necessary.

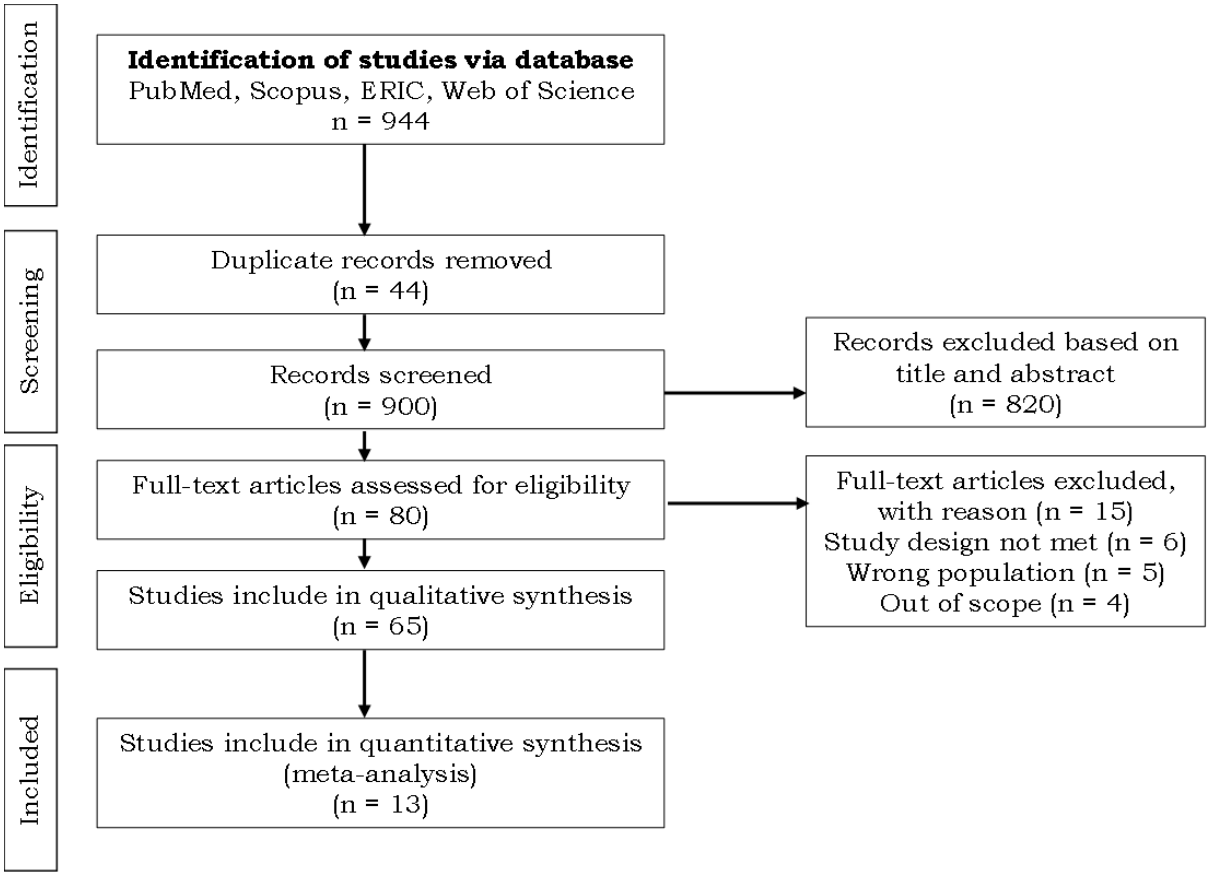


Diagram 1. PRISMA Diagram

Data Extraction and Synthesis

Relevant data from the included studies were extracted systematically using a standardized extraction form. Extracted information included author names, publication year, country, study design, participant characteristics, intervention types, outcome measures, and key findings related to gross motor development.

Due to substantial heterogeneity across studies in terms of participant characteristics, intervention approaches, outcome measures, and research designs, a meta-analysis was not considered appropriate. Therefore, a narrative synthesis approach was employed to summarize and integrate the findings. The included studies were categorized into several thematic areas, including technology-based interventions, environmental stimulation, nutritional factors, family and therapeutic support, and gross motor assessment tools. Findings within each category were synthesized narratively to identify common patterns, differences, and the most influential determinants of gross motor development in children.

RESULT

This systematic review identified 944 records from selected electronic databases and other sources. After removing 44 duplicate records, 900 unique records remained for screening based on titles and abstracts. During the screening process, 80 records were excluded because they did not address gross motor development, involved an inappropriate population, or did not meet the pre-defined eligibility criteria. Subsequently, 65 full-text articles were assessed for eligibility.

A total of 52 full-text articles were excluded for reasons including inappropriate study design, insufficient information regarding gross motor development, irrelevant outcome measures, and failure to meet population or intervention criteria. Finally, 13 studies met all eligibility criteria and were included in the systematic review.

Table 1. Summary of Included Studies on Determinants of Gross Motor Development in Children

Title and Authors	Sample	Design	Research Objective	Conclusion
Effect of Delayed Cord Clamping on Neurodevelopment at 3 Years: A Randomized Controlled Trial (Berg et al., 2021)	In 2014, 540 healthy full-term Nepalese infants were randomized 1:1 to delayed or early cord clamping. At age 3 years, 350 children were followed up.	Randomized controlled trial comparing delayed cord clamping (≥180 seconds) and early cord clamping (≤60 seconds). Neurodevelopment was assessed at age 3 using the Ages and Stages Questionnaire (ASQ) through parent telephone interviews.	To assess the effects of delayed cord clamping compared with early cord clamping on neurodevelopment at age 3 years.	No significant differences were found in overall ASQ scores. However, fewer girls in the delayed cord clamping group were at risk of gross motor developmental delay.
Comparative Analysis of Three Process-Oriented Assessment Tools for Identifying Fundamental Motor Skills	120 children aged 6–12 years.	Comparative study evaluating six skills (running, jumping, kicking, overhand throw, catching, striking) using	To examine differences among three assessment tools for evaluating the same fundamental motor skills in	Instruments with fewer performance criteria may be less rigorous than more detailed tools such

Title and Authors	Sample	Design	Research Objective	Conclusion
Proficiency in Children (Lorenzo-Martínez et al., 2025)		TGMD-2/3, GSGA, and FMSA.	elementary school children.	as GSGA and FMSA, highlighting the need for standardized procedures.
Effects of a School-Based Physical Activity Intervention on Children with Intellectual Disability: A Cluster Randomized Trial (Noetel et al., 2025)	20 government-funded primary schools involving 238 students aged 8–11 years.	Cluster randomized trial with intervention and waitlist control groups.	To evaluate the impact of a blended teacher-professional learning program on fundamental motor skills and physical activity in children with intellectual disabilities.	The school-based intervention did not significantly improve motor competence or physical activity levels.
Active Video Games Improve Muscular Fitness and Motor Skills in Children with Overweight or Obesity (Comeras-Chueca et al., 2022)	29 children (13 girls, 16 boys) with overweight or obesity.	Randomized controlled trial with intervention and control groups over 5 months.	To examine the effects of active video games combined with multicomponent exercise on muscular fitness, physical activity, and motor skills.	The intervention positively affected muscular fitness, motor competence, and physical activity.
Painted Playgrounds for Preschoolers' Physical Activity and Fundamental Motor Skill Improvement: A Randomized Controlled Pilot Trial of Effectiveness (Webster et al., 2023)	51 preschool children (mean age 4.3 ± 0.6 years).	Randomized controlled pilot trial involving playground stencil intervention and teacher materials.	To investigate the effects of environmental intervention on motor skills, physical activity, and sedentary behavior in early childhood centers.	No significant changes in physical activity or sedentary behavior were found, but locomotor and ball skills significantly improved.
Unveiling Developmental Delays in Early Childhood: Insights from a Comparative	707 Iranian children aged 1–42 months with suspected	Cross-sectional comparative study using BSID-III and ASQ-3.	To evaluate developmental delays and examine relationships	The study emphasized culturally sensitive assessment tools and the

Title and Authors	Sample	Design	Research Objective	Conclusion
Study of the Bayley Scales (BSID-III) and the ASQ-3 in Iran (Karimi et al., 2025)	developmental delays.		with parental education.	influence of parental education on child development outcomes.
Associations among Motor Competence, Health-Related Fitness, and Physical Activity in Children (Watanabe et al., 2024)	248 first-grade children aged 6–7 years.	Comparative study using gold-standard and field-based measures.	To compare relationships between motor competence, health-related fitness, and physical activity using different measurement methods.	Gold-standard measures showed stronger associations than field-based measures.
Vitamin D Supplementation and Gross Motor Development: A 3-Year Follow-Up of a Randomized Trial (Weiler et al., 2022)	116 healthy infants.	Three-year follow-up randomized trial of vitamin D supplementation (400, 800, 1200 IU/day).	To test whether vitamin D intake in infancy affects gross motor development in early childhood.	Standard 400 IU/day was sufficient to support gross motor development. Higher doses may benefit children born in winter/spring.
A Randomized Feasibility Trial of a Fundamental Motor Skill Parent-Mediated Intervention for Children with Autism Spectrum Disorders (Columna et al., 2021)	15 families with children aged 4–11 years with ASD.	Randomized feasibility trial comparing workshop and home-based interventions over 10 weeks.	To examine feasibility of parent-mediated interventions for improving motor skills in children with ASD.	Parents were able to facilitate children's motor skill acquisition, though further studies are needed.
Sustainable Effects of a Motor Skill Programme on Physical Activity Levels in 7–8 Years Old	70 school children aged 7–8 years.	Randomized controlled trial with intervention and control groups.	To determine immediate and sustained effects of a 9-week movement program on	The intervention had little or no effect on moderate-to-vigorous physical

Title and Authors	Sample	Design	Research Objective	Conclusion
Children (Idamokoro et al., 2024)			physical activity.	activity levels.
Using 2 Versions of the Test of Gross Motor Development to Classify and Screen Young Children's Motor Skills (Palmer et al., 2025)	226 children (mean age 53.4 months).	Comparative study using TGMD-2 and TGMD-3.	To examine comparability of two TGMD editions in classifying motor skill levels and developmental delay risk.	Both tools similarly identified below-average skills but differed in specific classificatio ns.
Motor Training for Young Children with Cerebral Palsy: A Single-Blind Randomized Controlled Trial (Prosser et al., 2024)	42 children aged 12–36 months with cerebral palsy.	Single-blind randomized controlled trial comparing iMOVE and conventional therapy.	To compare effects of intensive mobility training and conventional therapy on gross motor development.	No between-group differences were found, although many children exceeded predicted improvemen t levels after treatment.
Exploring the Effects of Acute Digital Sports Dance Intervention on Children's Gross Motor Development (He et al., 2025)	38 children aged 7–12 years.	Randomized repeated-measures study using TGMD-3, BRIEF, Stroop, and sEMG.	To examine effects of rhythm-enhanced digital dance on motor ability, cognition, and neuromuscular coordination.	The intervention significantly improved locomotor skills, ball skills, executive function, and muscle coordination .

The first theme concerns the influence of physical activity, environment, and technology on children's gross motor development. Various forms of physical activity and technology were found to have positive effects on gross motor skills. Active video games were shown to improve muscular fitness, motor competence, and physical activity levels among children with obesity through a combination of interactive digital exercise and multicomponent training (Comeras-Chueca et al., 2022). Environmental modifications, such as painted playgrounds, were also found to enhance children's locomotor

skills and overall motor competence in early childhood (Webster et al., 2023). In addition, rhythmic digital dance interventions were effective in improving gross motor skills, locomotor and ball skills, as well as neuromuscular coordination in children (He et al., 2025).

The second theme focuses on family-based influences and interventions for children with special needs. Parental involvement was found to improve the acquisition of fundamental motor skills in children with special needs when families were actively engaged in the intervention process (Columna et al., 2021). Conventional therapy for children with cerebral palsy also demonstrated improvements in gross motor function, although the differences were not statistically significant. However, many children exceeded the predicted level of functional improvement (Prosser et al., 2024). In contrast, school-based interventions for children with intellectual disabilities did not show significant improvements in gross motor skills (Noetel et al., 2025).

The third theme highlights the influence of nutrition and biological factors on gross motor development. Vitamin D supplementation at a dose of 400 IU/day was considered sufficient to support children's gross motor development, although higher doses showed moderate benefits under certain conditions (Weiler et al., 2022). In addition, delayed cord clamping was found to reduce the risk of gross motor developmental delay, particularly in children at the age of three years (Berg et al., 2021).

The fourth theme examines the relationship between gross motor competence, physical activity, and physical fitness. These variables were shown to have a strong association when measured using gold-standard methods (Watanabe et al., 2024). However, a nine-week motor skill development program did not always increase children's physical activity levels in the long term, indicating the need for more personalized and context-based approaches (Idamokoro et al., 2024).

DISCUSSION

Gross motor development in children is influenced by multiple interconnected factors, including physical activity opportunities, environmental stimulation, family involvement, educational support, and the appropriate use of technology. The findings of this review indicate that

movement-oriented interventions and supportive environments play important roles in enhancing children's motor competence, coordination, balance, and physical activity participation. These findings are consistent with previous evidence showing that children who engage in regular movement-based activities tend to demonstrate better physical literacy and healthier developmental trajectories (Robinson et al., 2015; Cairney et al., 2019).

Technology-based interventions demonstrated generally positive effects on children's gross motor development when implemented in structured and active forms. Studies involving active video games and digital sports dance programs showed improvements in locomotor skills, muscular fitness, coordination, and physical activity participation among children (Comeras-Chueca et al., 2022; He et al., 2025). These findings suggest that interactive technologies may enhance children's engagement and motivation by combining visual feedback, rhythmic movement, and enjoyable learning experiences. Exergaming and movement-based digital activities may also stimulate neuromuscular coordination and motor planning through repetitive whole-body movement tasks (Oppici et al., 2022). However, the benefits of technology appear to depend largely on the type, duration, and supervision of its use. Excessive screen exposure without sufficient physical activity has been associated with sedentary behavior and increased risk of delayed motor development in children (Bakht et al., 2025).

Environmental stimulation was also identified as an important determinant of gross motor competence. The reviewed studies demonstrated that outdoor play opportunities and modified physical environments, such as painted playgrounds, positively contributed to children's locomotor and object-control skills (Webster et al., 2023). Open play environments encourage children to engage in running, jumping, climbing, balancing, and exploratory movements that naturally stimulate motor skill acquisition and physical fitness development. Previous research has similarly highlighted the importance of movement-rich environments for supporting children's physical literacy and long-term participation in physical activity (Barnett et al., 2016).

Family involvement and therapeutic support also emerged as influential factors, particularly among children with developmental conditions. Parent-mediated interventions were shown to support the acquisition of fundamental motor skills in children with autism spectrum disorder through active family participation and guided home-based activities (Columna et al., 2021). Family support may enhance children's motor development by increasing practice opportunities, motivation, and consistency of movement experiences in daily life. In addition, therapeutic play interventions that replace passive screen time with active movement activities may help improve motor functioning among children with excessive gadget use (Nurhaini & Herawati, 2023). These findings emphasize the importance of collaborative involvement between families, educators, and healthcare professionals in supporting children's motor development.

Nutritional and biological factors were also associated with gross motor outcomes in early childhood. Vitamin D supplementation was found to support gross motor development, particularly among children with potential deficiencies or seasonal limitations in sunlight exposure (Weiler et al., 2022). Similarly, delayed cord clamping demonstrated potential benefits in reducing the risk of gross motor developmental delay among young children (Berg et al., 2021). These findings suggest that early biological and nutritional conditions may contribute to neuromuscular maturation and motor performance during critical developmental periods.

Despite several positive findings, some interventions demonstrated limited effectiveness. School-based physical activity interventions for children with intellectual disabilities did not consistently improve motor competence or physical activity levels (Noetel et al., 2025). Similarly, some motor skill intervention programs produced only modest long-term effects on children's physical activity participation (Idamokoro et al., 2024). These inconsistent findings may be explained by differences in intervention duration, implementation quality, participant characteristics, and the lack of individualized approaches tailored to children's developmental needs.

Overall, this review suggests that children's gross motor development requires a supportive environment, regular physical activity, family

involvement, proper nutrition, and appropriate use of technology. Combining movement-based learning with support from families and schools can help improve children's motor competence, physical literacy, and long-term health.

CONCLUSIONS

Children's gross motor development is influenced by various factors, including physical activity, environment, family support, education, nutrition, and technology use. Movement-based activities such as outdoor play, structured physical activities, traditional games, and technology-based programs can improve children's motor competence. However, technology should be used in a limited, balanced, and guided manner to prevent increased sedentary behavior.

Overall, optimizing gross motor development requires a holistic and collaborative approach involving parents, educators, health professionals, and the community. Given the heterogeneity of the available evidence, future research should employ longitudinal studies, larger samples, and standardized assessment instruments to identify the most effective strategies for improving children's gross motor development.

AUTHOR CONTRIBUTIONS

Conceptualization: E.L. & D.M.; Methodology: E.L. & D.M.; Investigation: E.L. & D.M.; Data curation: E.L. & D.M.; Formal analysis: E.L. & D.M.; Project administration: E.L. & D.M.; Supervision: E.L. & D.M.; Visualization: E.L. & D.M.; Writing – original draft: E.L. & D.M.; Writing – review & editing: E.L. & D.M. All authors have read and approved the final version of the manuscript and agree to be accountable for the integrity and accuracy of the work.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely to improve language, grammar, and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the accuracy, integrity, and content of the publication.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest with any party in the implementation of this research.

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