Examining the Relationship Between Motor Skills and Academic Achievement in School-Aged Children and Adolescents: A Systematic Review with Implications for Sports Psychology

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Abstract

Purpose: This systematic review explores the relationship between motor skills and academic achievement in primary and secondary school students, with a specific focus on gross and fine motor skills and their impact on performance across different academic subjects. The study provides insights relevant to sports psychology and educational strategies for enhancing cognitive and physical development. Method: Five electronic databases, including Web of Science, PubMed, PsycINFO, SPORT Discus, and Academic Search Premier, were searched in October 2022. Semi-quantitative assessment methods were used to analyze the results of the 78 studies included in this review. Results: The findings indicate that both gross (positive correlation in 65.0–62.5% of studies) and fine motor skills (positive correlation in 83.3–80% of studies) are positively associated with overall academic performance and language achievement. Fine motor skills showed strong positive correlations with math (75.6%), reading (71.1%), writing (66.7%), and spelling (60.0%) scores. In contrast, the relationship between gross motor skills and achievement in math (51.4%), reading (53.8%), and spelling (50.0%) was less certain. Conclusion: These findings emphasize the importance of fostering motor skill development, particularly in primary school students. Tailored motor skill interventions should be designed to target specific academic outcomes based on the unique benefits of gross and fine motor skills. From a sports psychology perspective, the integration of motor skill development into physical education and sports activities can support cognitive and academic growth, highlighting the critical role of physical activity in holistic education.

Keywords: School Children ; Motor Skills ; Academic Achievement ; Review.

1. Introduction

Motor skills refer to the learned sequences of movements that are combined to produce a smooth, efficient action to master a particular task (Van der Fels et al., 2015). Motor skills are not only the movement themselves, but include the cognitive processes giving rise to movement, which may be related to the academic learning of children (Burton & Rodgerson, 2001).

Motor and cognitive skills are intertwined since they share the same brain structures. Functional neuroimaging has found close co-activation of the neocerebellum and dorsolateral prefrontal cortex during several motor and cognitive tasks (Desmond et al., 1995; Diamond, 2000). At the same time, cognitive skills are closely related to academic performance (Alloway & Alloway, 2010; Oberer et al., 2018). On the other hand, the theory of cognitive load provides a new perspective.

The theory assumes a finite processing capacity for a given task (Sweller, 1988). When children with strong motor skills in the classroom, they do not need to devote attention resources and energy to behavioral tasks (Pagani & Messier, 2012). Children with strong attention, self-control, and working memory may engage more readily with new and sophisticated learning tasks (Cameron et al., 2016). These possible explanations highlight a need to explore how motor skills relate to academic achievement and whether the link is specific to certain categories of skills. Motor skills are classified into gross motor skills and fine motor skills.

Gross motor skills pertain to skills involving large muscle movements like independent sitting, crawling, walking, or running. Fine motor skills involve coordinating small muscle movements needed for tasks like grasping, drawing, writing, and playing an instrument. Several studies explored the relationship between gross motor skills, fine motor skills, and academic achievement of children, but achieved different findings. Several studies found that gross (de Bruijn et al., 2019; Schmidt et al., 2017; Syväoja et al., 2021) and fine motor skills were positively associated with academic achievement, whereas other studies showed that they are not significantly related to student's academic achievement (Costa et al., 2021; Cresswell et al., 2021; Macdonald et al., 2018). The

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findings from these studies may be synthesized in order to comprehensively and objectively assess the respective relationships between these two types of motor skills and academic achievement among children.

To date, only McDonald and collaborators reviewed 55 studies from 2000 to 2018 that examined the relationship between motor proficiency and math and reading achievement among children and adolescents aged 22 months to 18 years (Macdonald et al., 2018). Their results indicated that fine motor integration and the total fine motor score were significantly and positively associated with mathematics and reading. Speed and agility, upper limb coordination and the total gross motor score were also significantly and positively associated with mathematics and reading. However, numerous works studying the relationships between motor skills and academic achievement since 2018, and these studies were not summarized and reviewed. Moreover, studies focused on the relationship between motor skills and different subjects, like language, writing, science, spelling and overall academic achievement among children and adolescents were not reviewed.

Thus, to better understand the relationship between motor skills and academic achievement, there is a need to conduct a more extensive review to summarize the achievement of different subjects. Preschool education attaches more importance to the evaluation of the learning quality of preschool children, academic achievements are not emphasized in this stage. This review focused on school students academic (i.e., from primary to high school students) and aimed to (1) systematically summarized the studies on the relationships between school students' motor skills and academic achievement before 2022, and (2) quantify the association between motor skills and achievement on different subjects. This review will help to develop interventions to increase motor skills participation and improve academic achievement for school-aged students.

2. Methods

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Guideline (PRISMA) statement.

2.1. Search Strategy

Five electronic databases, namely, Web of Science, PubMed, PsycINFO, SPORTDiscus, and Academic Search Premier were searched on October 2022. Search terms were based on the combination of three main areas:(1) student* OR youth* OR teenage* OR child* OR juvenile* OR adolescen*; (2) motor skill* OR motor competence OR motor abilit* OR motor development OR motor coordination OR gross motor skill* OR fine motor skill*; (3) academic achievement OR academic performance OR academic grades OR scholastic achievement.

2.2. Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were as follows:

(1) studies examining the associations between motor skills and academic achievement were included; those focusing other topics were excluded;

(2) studies that separately tested gross or fine motor skills were included; studies that used measurement batteries that included fine motor skills as part of a composite score were excluded;

(3) studies targeting primary (i.e. approximately 5-11 years of age; Grades 1-6) to high school students (i.e. approximately 12-17 years of age; Grades 7-12) were included, some longitudinal studies conducted in the preschool that focused on predicting future performance also included; students of the other ages were excluded;

(4) studies published in peer-reviewed journals in English until October 2022 were included; hence, non-English studies, unpublished dissertations, conference proceedings, literature review, and comments were excluded; and

(5) quantitative studies were included; therefore, qualitative studies, case reports, and expert opinions were disregarded.

The identified studies were assessed independently by the first and third authors based on the inclusion and exclusion criteria. The second author was consulted in case of disagreements.

2.3. Quality Assessment

To determine the methodological quality of the included studies, the researchers used the adapted McMaster Critical Review Form-Quantitative Studies (Jinfeng & Bo, 2021). The form was chosen because it demonstrated good inter-rater agreement of 75-86%. The form contains 16 items, which addressed the study purpose (1 item), study background (1 item), study design (1 item), sampling (2 items), measurement (4 items), data analysis (4 items), conclusions (1 item) and implications and limitations (2 item). The researchers scored all items by the degree to which specific criteria were met (yes = 1, no = 0). Two reviewers independently assessed all studies. Calculated the summary score for each study by summing the total score obtained across relevant items and dividing it by the total possible score. Any uncertainty and disagreement were resolved by the third reviewer. Scores of ≤50%, 51−75% and >75% were interpreted as low, good and excellent quality, respectively.

2.4. Data Extraction and Synthesis

Data extraction was conducted by the first author and verified by the second author. The demographic data of these studies were summarized and included type of research, geographical location, participant

characteristics, motor skills measurement methods and methodological quality (Table 1). The geographical location was summarized into the countries where the study was conducted. The participant samples were split into four groups (<100, 100-249, 250-500, and >500). The methodological quality was divided into excellent, good and low categories.

2.5 Coding of Analysis

A semi-quantitative assessment was used in this review to determine the consistency of different types of relationships. This assessment provided additional objective evidence beyond the reporting of narrative results only. For every result in each paper, it is indicated whether the identified association is positive or negative.

The codes "0" indicates a non-significant association between motor skills and different subjects' achievement. The codes "+" or "–" indicate positive or negative direction of the association between motor skills and different subjects' achievement, respectively. When findings reported separately by sex, or age/year, these were noted as "male" or "female" or the age/year group. Next, we further coded these relationships by analyzing the studies supporting the correlates. Relationships that appeared once were not described and discussed in the text and were coded as "No Description (ND)".

For those variables appearing twice or more, we summarized and coded them by following the rules drawn up by Sallis: (Sallis et al., 2000) (1) no association, coded "0" (0–33% of studies supporting a significant association); (2) inconsistent/uncertain association, coded "?" (34–59% of studies supporting a significant association); (3) positive or negative association, coded "+" or "–"(≥60% of studies supporting a significant association).

3. Results

3.1. Search Results

The PRISMA diagram in Figure 1 summarizes the results of the four-step approach taken to identify, screen, and select studies for inclusion in this review. The initial search identified 1564 studies. These studies were exported to software EndNote X2, and duplicates were removed. The remaining 841 articles were then subject to screening on the basis of the title and abstract, resulting in the exclusion of 673 studies. The remaining 168 studies were re-screened by reading the full text, 73 were initially identified. Five relevant studies were added by reading the literature and references. Finally, the number of literatures included in the systematic review was 78 (see Figure 1).

3.2 Methodological Quality

Overall, fifty-five out of the 78 included studies (70.5%) were categorized as excellent-quality, eighteen studies (23.1%) were categorized as good-quality, and the remaining five study were categorized as low-quality. The weakest component among the included studies was related to sampling. Specifically, only nine studies (11.5%) justified the sample size (Table 1).

3.3 Study Characteristics

The included studies were published from 2001 to 2022. Most of them were longitudinal studies (n=35, 44.9%), and the remaining is cross-sectional (n=31, 39.7%) and experimental studies (n=12, 15.4%). Twenty studies (25.6%) were each conducted in the USA, five studies in Australia, Brazil, South Africa (6.4%), four studies in Finland, Switzerland, Denmark (5.1%), three studies in Netherlands, Spain, Germany, France, UK (3.8%), two studies in Sweden, Norway, Japan (2.6%), and one in Portugal, Singapore, Turkey, Israel, Italy, Korea, Malawi, Canada, Serbia, Greece, respectively.

Total samples in each study included in the review ranged from 13 to 34491. Most of the studies (n=55, 70.5%) had <500 samples. The research focused on primary to high school students (aged 4-17) and most of the studies (n=72, 92.3%) focused on primary students. Motor skills were assessed by using a range of instruments such as the Movement Assessment Battery for Children-2 (MABC/MABC-2) (n=12, 15.4%)、Bruininks-Oseretsky Test for Motor Proficiency (BOT-2) (n=7, 9.0%) and the visual motor integration test (VMI) (n=7, 9.0%) , Körperkoordinationtest für Kinder (KTK) (n=5, 6.4%) and Early Screening Inventory(n=4, 5.1%) and other Early Screening Tools (Table 1).

3.4 Relationships Between Gross Motor Skills and Academic Achievement

Table 2 displays the results of the relationship between gross/fine motor skills and academic achievement of student. A total of 42 studies examined the relationship between gross motor skills and academic performance. Among them, the relationships between gross motor skills and overall performance (i.e., composite scores and GPA) and academic achievement on math, reading, writing, spelling and language were studied by two or more times.

Gross motor skills are consistently and positively related to the overall academic performance and language performance, with 65.0% and 62.5% of the studies supporting it. Gross motor skills were positively associated with math, reading and spelling performance only with 51.4, 53.8% and 50% (less than 60%) of the studies supporting it, thus made the association uncertain. No correlation between gross motor skills and students' writing skills was found because only 28.6% of the studies supported the relationship.

3.5 Relationships Between Fine Motor Skills and Academic Achievement

A total of 57 studies examined the relationship between fine motor skills and academic performance. Among them, the relationships between fine motor skills and overall performance and academic achievement on math, reading, writing, spelling and language were studied by two or more times. Fine motor skills are consistently and positively related to the overall academic performance and math, reading, writing, spelling and language performance, with 83.3%, 75.6%, 71.1%, 66.7%, 60.0%, 80.0% of the studies supporting it.

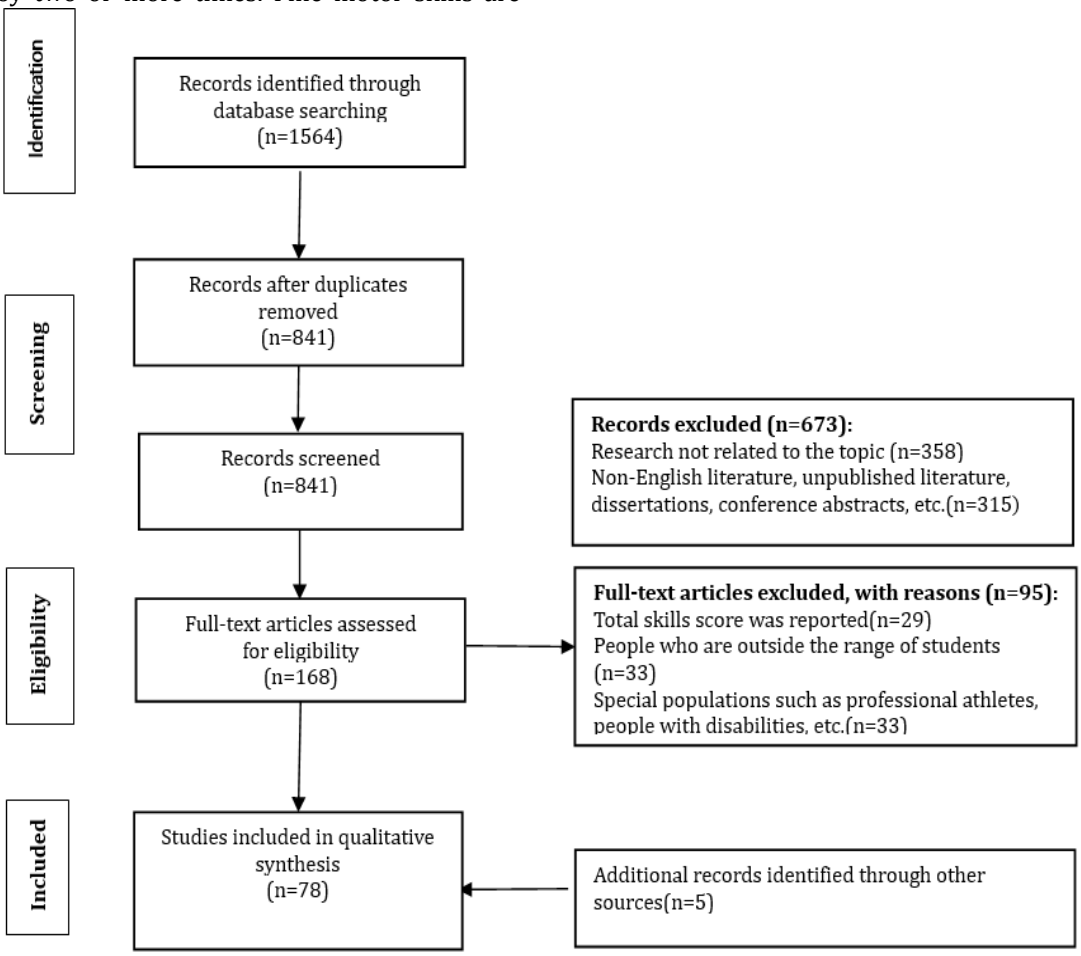

Figure 1: Flow diagram of literature search

Table 1

Descriptive statistics for studies used in the systematic review

Description	N (%)
Type of research	
Longitudinal studies	35(44.9)
Cross-sectional studies	31(39.7)
Experimental studies	12(15.4)
Geographic location	
United States of America (USA)	20 (25.6)
Australia/Brazil/South Africa	5(6.4)
Finland/Switzerland/Denmark	4(5.1)
Netherlands/Spain/Germany/France/United Kingdom (UK)	3(3.8)
Sweden/Norway/Japan	2(2.6)
Other country	10(5.4)
Sample size	
<100	17(21.8)
100-249	22(28.2)
250-500	16(20.5)
>500	23(29.5)
Motor skills measurement	
MABC/MABC-2	12(15.4)
BOT-2	7(9.0)

VMI	7(9.0)
KTK	5(6.4)
Early Screening Inventory	4(5.1)
Methodological quality	
Excellent	55(70.5)
Good	18(23.1)
Low	5(6.4)

Table 2

Summary of studies of relationships between gross/fine motors skills and academic achievement

Summary Coding		Associated		Not Associated	Summary Coding			
Motor Skill	**Subject**	**References No**	**(-/+)**	**References No**	**0**	**n/N**	**(%)**	**coding**
GMS	Math	15、29 F、29 M、30 F、30 M、33、35、36、41、42、44、50、52、(Damsgaard et al., 2020)、(Macdonald et al., 2022)、(Asakawa et al., 2019)、(Taverna et al., 2020)、(Uhrich & Swalm, 2007)	+	29 F、22 F、22 M、32、36、40、43、21、44、45、47、49、53、54、55、56、(Botha & Africa, 2020)	0	18/35	51.4	?
	Reading	15、30 F、35、40、41、42、44、50、51、52、(Ericsson, 2008)、(Asakawa et al., 2019)、(Ericsson & Karlsson, 2014)、(Taverna et al., 2020)	+	30 M、22 M、22 F、42、43、21、44、53、54、55、56、(Uhrich & Swalm, 2007)	0	14/26	53.8	?
	Writing	22 M、40	+	22 F、21、53、54、(Taverna et al., 2020)	0	2/7	28.6	0
	Spelling	(Ericsson & Karlsson, 2014)、(Uhrich & Swalm, 2007)	+	15、44	0	2/4	50.0	?
	Language	29 F、29 M、30 F、35、(Macdonald et al., 2022)	+	32、45	0	5/8	62.5	+
		30 M	–					
	History	29 F、29 M	+	29 F、29 M	0			ND
	Overall Performance	16、29 F、29 M、30 F、31、34、37、38、39、40、46、57 F、(Nobre et al., 2024)	+	30 男、32、37、56、57 男、54	0	13/20	65.0	+
		48	–					
FMS	Math	41、42、43、45、47、49、50、52、53、54、55、56、59、61、62、63、18、63、64、66、68、69、70、71、72、73、74、79、80、81、83、84、(Damsgaard et al., 2020)、(van den Berg et al., 2019)	+	40、42、43、21、44、45、54、64、72、79、82	0	34/45	75.6	+
	Reading	41、42、43、51、52、53、54、55、56、60、61、63、64、20、17、66、67、68、69、73、74、75、76、77、78、81、82、83、85、87、(Ericsson, 2008)、(Avila et al., 2020)	+	40、42、43、21、44、50、51、20、17、66、73、79、(Avila et al., 2020)	0	32/45	71.1	+
	Writing	53、54、64、82、87、(Mullender-Wijnsma et al., 2016)	+	40、21、(Mullender-Wijnsma et al., 2016)	0	6/9	66.7	+
	Spelling	17、76、83		44、17		3/5	60.0	+
	Language	45、62、18、82	+	45		4/5	80.0	+
	Science	18	+					ND
	Overall Performance	46、48、54、56、57 F、58、18、64、65、86	+	40、57 M	0	10/12	83.3	+

Note：1）When the number of documents is 1, the variable is coded as "No Description（ND）"；when the variable appeared twice or more, 60%-100% associations in the same direction were coded as "+" (positive correlation) or "-" (negative correlation)；34%-59% of associations in the same direction are coded as "?"(inconsistent/uncertain association)；0%-33% associations in the same direction are coded as "0" (no association)；2）Three papers (Desmond et al., 1995), (Diamond, 2000), (Alloway & Alloway, 2010), (Syväoja et al., 2021) investigated the correlation between motor skills and academic performance in boys and girls, and the findings were reported separately by gender；3）Bold serial numbers are intervention studies. M: for man; F: for female.

4. Discussion

This review systematically summarized the studies on the relationship between motor skills of school students and academic achievement. Findings showed that both gross and fine motor skills are consistently and positively related to the overall academic performance. According to the 'embodied cognition' model presented by Piaget, body and brain work together in an inextricably linked 'brain–body' system. To be specific, knowledge is constructed through motor behaviors, and furthermore, these behaviors lead to the creation of mental representations and promote the development of complex intellectual reasoning abilities. Neuroscientific and psychological evidence suggested that gross and fine motor skills allow the students to better understand and develop more advanced cognitive abilities such as reasoning, planning and judgement, which promoted their academic performance. It may explain why the gross and fine motor skills are positively associated with overall academic performance. Moreover, results showed that gross and fine motor skills are consistently and positively associated with language performance of students. In recent years, the findings obtained from brain research also echo the view that language processing is an embodied process**.** Many neuroimaging studies have shown that when language is being processed, brain activity occurs in the motor and sensory areas corresponding to the meaning being transmitted. Controlling the motor skills by tensing muscles actually improved participants' self-control and mental focus in unrelated cognitive tasks. Several experimental studies also confirmed that controlling and practice motor skills (both gross and fine) during the language learning process assists in transforming abstract information into concrete and tangible concepts, and displaying the highest learning gains. In reading, spelling, and writing, these different subjects all related to fine motor skills. Reading requires the use of fine motor skills controlling eye movement for word tracking. Speaking and spelling require fine motor skills that control the production of sound and present content. Writing requires fine motor skills with the hands as well as hand-eye coordination. Fine motor writing skills play an important role in creating the conditions for students' learning. In a review of research on embodiment in different cognitive domains, Kiefer and Trumpp show that the writing techniques we use affect reading performance, because of the activation of the motor programs and sensory experiences of writing during reading. As a consequence, people who use handwriting have better letter recognition in a reading test than those who use typewriting. This supports the claim that meaningful sensory-motor experiences result in "stronger sensory-motor memory traces that facilitate learning". Some research also shows that students can learn to spell words more accurately through the process of hand-writing. On the one hand, hand-writing tasks provide children with the opportunity to create internal models for the symbol system necessary to succeed in academic disciplines, which provide the foundation for academic disciplines. On the other hand, research suggests that when students are able to automatically use handwriting to record their thoughts and ideas, they free up cognitive resources and are able to produce more complex compositions. Automatic handwriting allows students to spend all of their energy on writing content instead of having to divide their attention between content and text production. The study also found that fine motor skills can improve mathematics performance, which is consistent with the results summarized by MacDonald. In this review, most of the studies (92%) focus on students in grades 1 to 6, and only one study focuses on secondary school students. The correlation between fine motor skills and mathematics performance is mainly reflected in primary school. Lakoff and Nunez argue that understanding of mathematics is grounded in our physical experiences in the world. According to the "embodiment" view, numerical operations are not merely abstract thinking, but are also based on physical, embodied experiences. Specifically, it seems that fine motor skills support the acquisition of counting skills fundamental to arithmetical abilities. Thus, fine motor training can yield an insight into counting–namely, how the capacity to use one's fingers with precision reduces the number of mistakes and cognitive load of counting. Understanding mathematics concepts also require students to interact with physical objects. Hill contended that the development of motor skills (i.e. the development of good physical muscle control) is closely related to cognitive achievement, and emphasised how the contribution of skill in learning domain. Primary school mathematics classes usually use hands to operated toys, cards, and other methods to help students master the basic concepts of numbers or some symbols (e.g. one-to-one correspondence, counting, sorting), to cultivate and improve their computing ability. According to the "brain" view, the brain areas underlying both finger movement and arithmetical ability are close to each other. Accordingly, the brain areas for both abilities would be activated by training

in fine motor skill, thus improving math performance. Although a preliminary relationship discussion was conducted between gross motor skills and math, reading, and spelling performance, the research results are uncertain. Such a relationship needs to be further explored and clarified, and the scope of follow-up research should be expanded.

5. Limitations and Implications for Future Research

This study also has some limitations. First, only studies published in English were included, and some relevant studies were missed. Secondly, a meta-analysis was not conducted due to the heterogeneity between studies in their design, outcome measures and study quality. In addition, few studies took the influences of other variables, such as demographics, social-economic status, body mass index, and race into account. Therefore, we solely examined the relationship between motor skills and academic achievement. Although there are some limitations, the findings of the present review can shed some light on future research directions and practical implications. First, the research on the relationship between motor skills and academic performance of primary to high school students in China is still absent. Future research should explore the relationship between Chinese students' motor skills and academic performance in the context of Chinese culture. Second, to more accurately compare the results of different studies, researchers should consider using standardized instruments to assess motor skills and academic performance to reduce heterogeneity between studies. Third, we should further focus on the scores of subjects that are not supported by sufficient evidence (such as history and science) and subjects that do not draw definite conclusions due to contradictory evidence (such as reading) and clarify the relationship between the motor skills and these subjects. Fourth, future research should pay more attention to the role of mediating variables, and explore more mediating variables from the perspectives of physiology and cognitive psychology, to understand the internal mechanism of motor skills affecting academic performance. Finally, students with different individual characteristics, it is necessary to clarify which specific motor skills is more effective to improve their academic performance. Therefore, we should further analyze the differences in the relationship between motor skills and academic performance of students of different gender, ages, obesity, and family backgrounds.

6. Conclusions

To sum up, through the semi-quantitative evaluation of the research results, this systematic review revealed a positive association between motor skills and specific domains of academic achievement. The development of fine motor skills can improve math, language, reading, spelling, writing, and overall performance, while gross motor skills can only promote language performance and overall performance. We suggest that future interventions should focus on promoting motor skills, which is the most advantageous avenue to promoting academic achievement.

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