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Thirty Years of Research on Fine Motor Skills in Preschool and School-Aged children: A Scientometric Analysis of Trends

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Abstract

Research on fine motor skills in children has evolved considerably over the last 30 years. However, a scientometric analysis of these changes over time, along with an assessment of researchers' networks and scientific productivity, is currently lacking. We conducted a scientometric analysis of the scientific literature on fine motor skills in preschool and school-aged children to evaluate key themes and trends over the past decades, thereby informing future research directions. We conducted a search in the Web of Science Core Collection from 1994 to 2024 utilizing pertinent keywords. The evolution of co-reference clusters and the performance of research networks across countries, institutions, and authors were analyzed using the Bibliometrix R package (v4.3.0) and CiteSpace (v6.4.R3). There has been an exponential growth in publications, showing a 7.5% annual increase from 2006 to 2021, and a positive correlation (R^2 = 0.89) between the publication year and output, indicating a promising trend in the field. The co-cited reference network analysis revealed 10 clusters in a well-structured network (Q = 0.835) with strong clustering reliability (S = 0.94). The primary research trends identifiedare: 1) the link between fine motor skills and academic achievement; and 2) the traits of fine motor impairment in children with neurodevelopmental disorders. The latest research trends in fine motor skills for children include developing assessment tools and interventions for both typically developing children and those with neurodevelopmental disorders.These findings can inform future directions for funding agencies and research groups.
Keywords: Fine motor skill, Children, Preschool, School-Aged, Scientometric, Citespace

1. Introduction

Fine motor skills can be defined as small muscle movements to hold or manipulate small objects with the use of hands or fingers, requiring precise eye-hand coordination（Luo et al., 2007）. These skills are specifically categorized as grapho-motor（Suggate et al., 2018）, also known as visual-motor/spatial integration (e.g., copying geometric shapes), or as manual dexterity（Backman et al., 1992）(e.g., threading beads onto a string). Recent studies indicate a link between fine motor skills and several important developmental areas in early childhood, such as children's daily living activities（Black et al., 2017 ; Grissmer et al., 2010b）, school readiness（Cameron

et al., 2015 ; Grissmer et al., 2010b), and academic achievement（Becker et al., 2014 ; Dinehart et al., 2013b）. Numerous early childhood programs also recognize fine motor skills as essential for children's development. For instance, Children in the Head Start Early Learning Outcomes Framework spend about 37% of their day engaged in fine motor activities（Marr et al., 2003）. Furthermore, neuroimaging research has revealed that the neural functional networks involved in fine motor skills development overlap with those underlying higher-order cognitive processes, such as executive function（Floyer-Lea et al., 2004）. As children acquire new fine motor or cognitive skills, interactions between these networks intensify, generating extensive patterns of connectivity throughout development（Johnson, 2001）. However, relevant studies indicate that 10% to 24% of children experience fine motor skill challenges that cause them to fall behind their expected development rate（Strooband et al., 2020）. These difficulties have also been extensively documented in children with conditions, such as Developmental Coordination Disorder (DCD), Cerebral Palsy (CP), Attention Deficit Hyperactivity Disorder (ADHD), and Autism Spectrum Disorder (ASD).

In light of the above facts, the amount of research literature in the fine motor skills domain has rapidly increased over recent decades. Trends and hotspots within the relevant knowledge domains have evolved constantly, necessitating new approaches to review and analyze them. Scientometrics is a quantitative branch of informatics that has emerged as a powerful tool, capable of analyzing extensive bibliometric data to reveal the current knowledge landscape and emerging research trends within a particular field. Recently, Wang and colleagues pioneered the use of scientometric analysis to explore the hotspots and trends in motor development among preschoolers. They identified research trends in preschool children's motor development from 2012 to 2022, highlighting a focus on interventions for fundamental movement skills, cognitive function, neurodevelopmental disorders, and emerging topics such as school readiness, socioeconomic status, motor proficiency, and screen time. However, the previous study primarily focused on gross motor skills, giving little attention to fine motor skills (e.g., grapho-motor and manual dexterity) and was limited to the last decade. There is a need for more in-depth scientometric analysis of fine motor skills research that has been the focus in recent decades.

Therefore, the present study aims to conduct a systematic scientometric review to evaluate how research on fine motor skills of preschool and school-aged children has evolved over the past decades. Additionally, our study also aims to assess potential future topics of interest in the field based on emerging trends.

2. Introduction

2.1 Search strategy and data collection

The scientometric analysis data were obtained sourced from the Web of Science Core Collection (WOSCC), recognized as a comprehensive databases for such studies, offering complete references and citations（Singh et al., 2021）. We conducted a search for relevant terms in the titles, abstracts, and keywords on 2nd July 2024 using the following search terms: (“fine motor skill*” OR “fine motor” OR “visual motor” OR “visual-spatial integration” OR “visual-motor coordination” OR graphomotor OR “finger dexterity”) AND (preschool* OR pre-school* OR toddler* OR kinder* OR student* OR child* OR “school aged” OR “elementary school”) NOT (“new born” OR infan*). The database search was restricted to English-language articles and reviews. The full records with cited references from 1994 to 2024 were extracted into plain text files, and duplicate records were moved.

2.2 Data analysis

We used the Bibliometrix R packages (4.3.0) and CiteSpace (6.4.R3) to conduct the analyses. The Bibliometrix R package (4.3.0) is an open-source tool to offer a comprehensive overview of total publications. The Bibliometrix R package was utilized to analyze publication outputs, growth trends, and the annual average citation frequency articles. CiteSpace is a Java-based application designed for scientometrics analysis and data visualization. The approach integrates scientific knowledge mapping and bibliometric analysis to identify hotspots within a research field and predict development trends. All data were imported into CiteSpace (6.4.R3) to perform collaboration analysis (across countries and institutions), co-citation analysis (including co-citation references, author co-citations, and co-citation journal networks), author co-occurrence keyword analysis, and burst detection.

3. Results

3.1 Research Performance

3.1.1 Analysis of publication outputs and major journal

A total of 2,144 studies, comprising 2,011 articles and 133 reviews, were published from 1994 to 2024, averaging 5 authors per publication across 810 distinct sources (e.g., journals or books). As shown in Figure 1, the analysis of publications within this field identified two time periods. The first time period spanning from 1994 to 2005 represents the slow development stage, during which the annual publication did not show growth, while the average citations per year of each article rose from 1.2 in 1994-4.9 in 1999-2.4 in 2005. The second time period represents a phase of rapid development, showing an exponential increase in publications, starting from 33 in 2006 to a peak of 205 in 2021 followed by 122 annually until 2024, reflecting an average annual growth rate of 7.5%. As for literature citations, the average citations per year of each article declined from 3.3 in 2006 to 0.4 in 2024. Moreover, a polynomial curve fit of publications demonstrated a positive correlation (R2 = 0.89) between the publication year and the number of publications, suggesting promising future growth in the field.

The journal with the highest number of relevant papers is the American Journal of Occupational Therapy with 65 (16.5%) publications, followed by Research in Developmental Disabilities with 55 (14.0%), and Perceptual and Motor Skills with 52 (13.2%) (Table 1). Nearly half of the articles within this field have been published in these three journals. The journal Developmental Medicine and Child Neurology received the highest co-citation count of 885; following was Pediatrics with 605. These journals are considered “core journals” due to their high publication and co-citation volumes（Yardibi et al., 2023）.

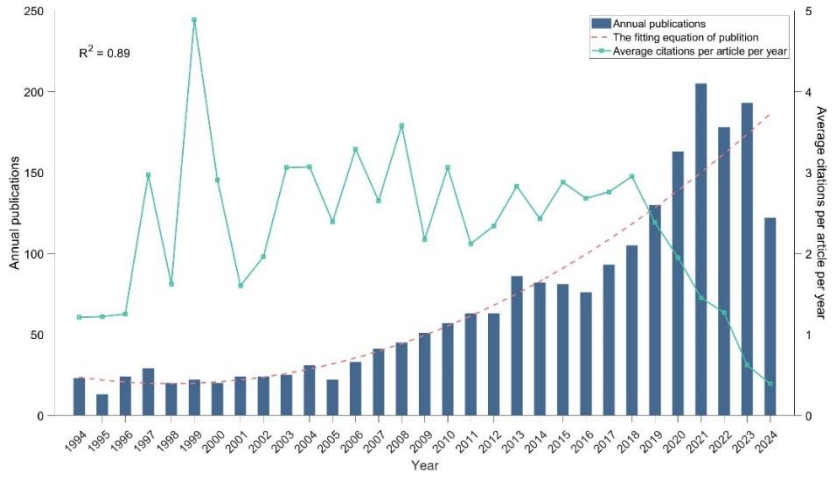


Figure 1. Annual publications and average citations per article on fine motor skills in preschool and school-aged children, 1994–2024.

Table 1. Journals with most articles and citations (Top 10).

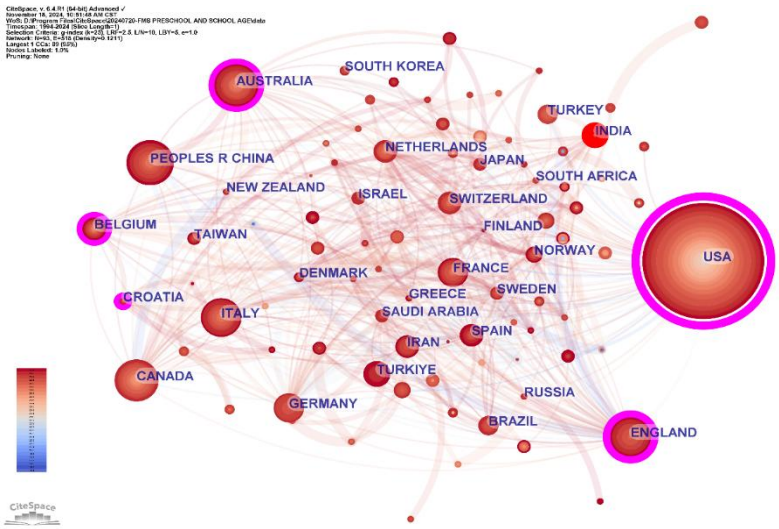
Journals with most articles (1994-2024)	Initial year	Impact factor (2023-2024)	Total articles (%)	Total articles	Journals with most co-citations (1994-2024)	Total co-citations
American Journal of Occupational Therapy	1980	2.9	16.5	65	Developmental Medicine and Child Neurology	885
Research in Developmental Disabilities	1987	2.9	14.0	55	Pediatrics	605
Perceptual and Motor Skills	1949	1.4	13.2	52	American Journal of Occupational Therapy	515
Developmental Medicine and Child Neurology	1958	3.8	11.5	45	Perceptual and Motor Skills	488
Frontiers in Psychology	2010	2.6	9.7	38	Research in Developmental Disabilities	473
Human Movement Science	1982	1.6	8.7	34	Human Movement Science	465
PLOS ONE	2006	2.9	7.6	30	Child Development	457
International Journal of Environmental Research and Public Health	2004	/	6.9	27	PLOS ONE	430
Child Neuropsychology	1995	1.6	6.1	24	Journal of Child Psychology and Psychiatry	384
Journal of Occupational Therapy Schools and Early Intervention	2008	0.7	5.9	23	Frontiers in Psychology	337

3.1.2 Analysis of cooperation networks across countries and institutions

A total of 92 countries were identified. Network analysis of co-authors' countries revealed that the USA (0.64), England (0.31), Belgium (0.12), Croatia (0.12), and Australia (0.11) had the highest centrality degrees. The burstness analysis identified the USA (24.03, 1994-2005), Netherlands (7.83, 2001-2012), and India (7.23, 2022-2024) as the countries with the highest citation burst strength.

For institutions, 567 different institutions were identified. The top three institutions with the greatest centrality scores were University of California System (0.16), University of London (0.16), and Harvard University (0.15). Burstness analysis identified the University of Toronto (5.68, 2011-2017), the University of Haifa (4.98, 2022-2024), and the University of Queensland (4.66, 2014-2018) as the top three institutions with the highest burst strength.

A



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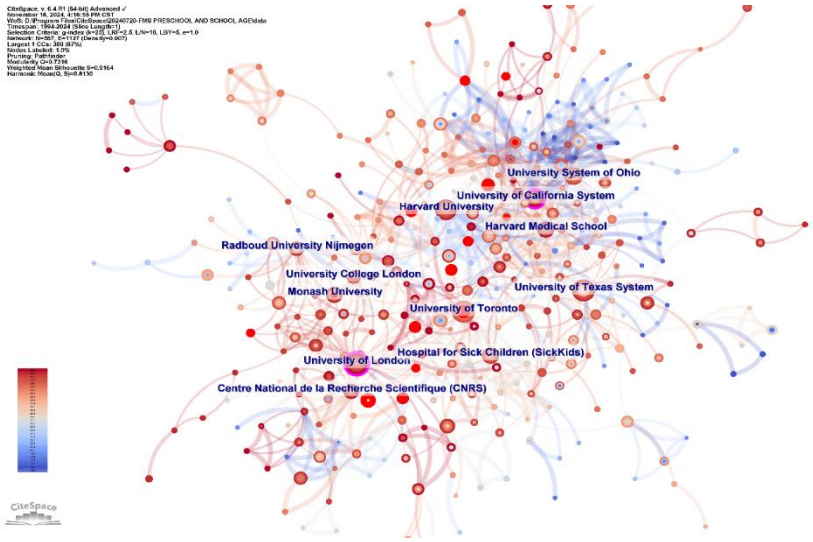

Figure 2. Network of the co-authors' countries (A) and the network of co-authors institutions (B) for fine motor skills in preschool and school-aged children, 1994–2024.

3.1.3 Analysis of co-authorship network

As shown in Figure 3, the co-authorship network identifies cluster #0, labeled 'handwriting', as the most important cluster, based on a likelihood ratio algorithm for keywords. Beery Ke (0.21), Wechsler D (0.12), and Barkley Ra (0.1) were the top three authors in betweenness centrality, linking clusters #3 (Neuropsychology) and #4 (ADHD). Additionally, the burstness analysis confirmed that Cameron CE (11.14, 2016-2022), who linked cluster #1 (Academic Achievement), presented the latest citation bursts.

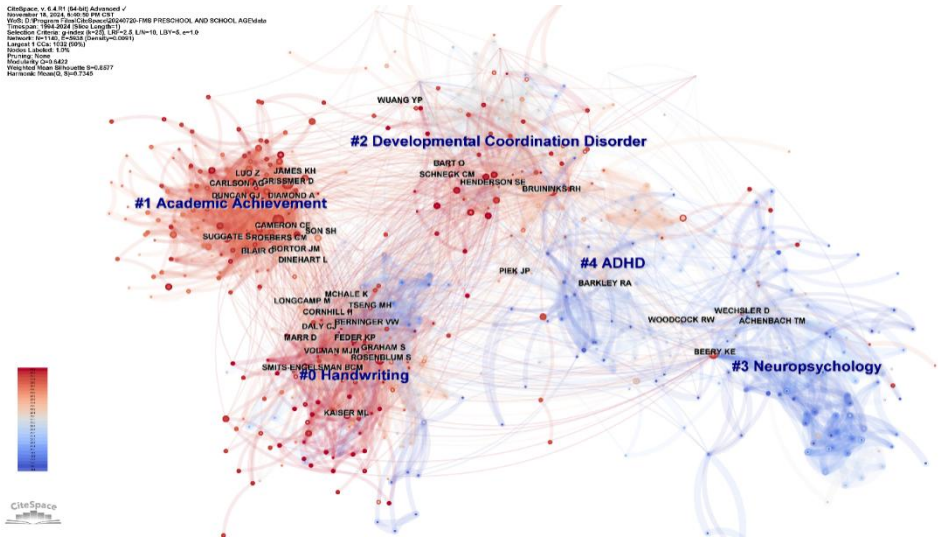

Figure 3. Network of the co- authorship for fine motor skills in preschool and school-aged children, 1994–2024.

3.2 Analysis of co-cited reference: clusters of research and most cited papers

3.2.1 Clusters of research

Fig. 4 illustrates the co-cited reference network for the period 1994–2024, based on CiteSpace slicing.. This network represents the knowledge base, integrating research trend evolution, frontiers, and highly cited papers. We identified 10 distinct clusters within the co-citation reference network, characterized by high modularity and silhouette scores, confirming their reliability (Q=0.835; S=0.94).

Based on the largest connected component of the network, two primary research trends have been identified. The first and largest trend focused on academic achievement. We present the temporal progression of research topic clusters, including theirlabel, size, silhouette score, average year of publication of the cluster members, and most representative reference. The cluster #9 (‘Visual Motor Integration’; 27; S=0.931; 2005) (Barnhardt et al., 2005)（Barnhardt et al., 2005b）, #10 (‘School Readiness’; 26; S=0.938; 2007) (Duncan et al., 2007)（Duncan et al., 2007） and # 4 (‘Handwriting’; 65; S=0.961; 2008) (Feder et al., 2007)（Feder et al., 2007b） contributed to the foundation of research on the connection between fine motor skills and academic achievement. These cluster evolved into #0 (‘Academic Achievement’; 85; S=0.957; 2013) (Carlson et al., 2013)（Carlson et al., 2013b） followed by #1 (‘Child Development’; 81; S=0.882; 2016) (Gaul et al., 2016)（Gaul et al., 2016） and #3 (‘Finger Counting’; 67; S=0.891; 2019) (Fischer et al., 2018)（Fischer et al., 2018）.

The second major research trend focuses on neurodevelopmental disorders, such as ADHD, DCD, and ASD. This research trend began in 1997 with the research cluster #8 (‘Neuropsychological Tests’; 28; S=0.978; 1997) (Stehbens et al., 1991)（Stehbens et al., 1991）, it further evolved with cluster #5 (‘ADHD’; 59; S=0.982; 2000) (Pitcher et al., 2003)（Pitcher et al., 2003b）, then into the largest of this trend #2 (‘Neurodevelopmental Disorder’; 74; S=0.889; 2010) (Blank et al., 2012)（Blank et al., 2012b）, that developed the last cluster #7 (‘ASD’; 42; S=0.983; 2019) (Bhat et al., 2020)（Bhat, 2020）.

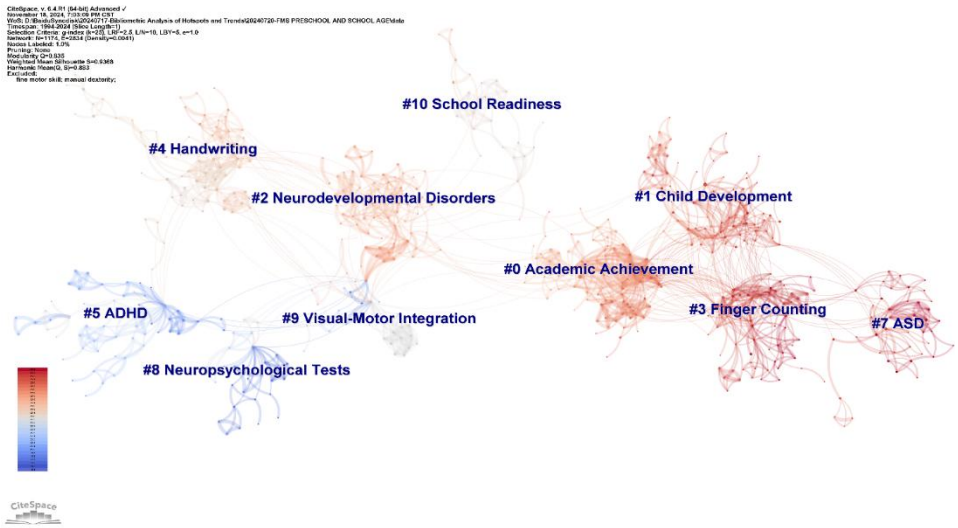

Figure 4. Co-citation references network (1994-2021) and correspondent clustering analysis obtained with CiteSpace.

Table 2. Top 10 co-cited references of our reference co-cited network

Number of citations in the network	Number of citations in the literature	Year	Source	Vol	Pages	Title	Related cluster in Fig.4
38	138	2016	CHILD DEV PERSPECT	10	93-98	How are motor skills linked to children's school performance and academic achievement?	0
27	106	2016	FRONT PSYCHOL	7	-	Fine motor skills predict maths ability better than they predict reading ability in the early primary school years	0
23	51	2018	J RES READ	41	1-19	Do fine motor skills contribute to early reading development?	3
22	303	2012	CHILD DEV	83	1229-1244	Fine motor skills and executive function both contribute to kindergarten achievement	0
21	167	2014	EARLY CHILD RES Q	29	411-424	Behavioral self-regulation and executive function both predict visuomotor skills and early academic achievement	0
20	136	2013	J GENET PSYCHOL	174	514-533	Disentangling fine motor skills' relations to academic achievement: The relative contributions of visual-spatial integration and visual-motor coordination	0
18	1874	2017	LANCET	389	77-90	Early childhood development coming of age: science through the life course	1
18	452	2019	DEV MED CHILD NEUROL	61	242-285	International clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder	7
16	154	2014	HUM MOVEMENT SCI	33	284-297	The relation between cognitive and motor performance and their relevance for children's transition to school: A latent variable approach.	0
15	62	2018	CHILD DEV	89	476-494	Developmental relations among motor and cognitive processes and mathematics skills	3

3.2.2 Most co-cited papers

Most co-cited papers We present the top 10 most co-cited references in Table 2. Cameron's literature review（Cameron et al., 2016） on the link between fine motor skills and academic achievement, published in Child Development Perspectives, is the most co-cited article, with 38 citations in our network and 138 citations in the literature. The second- and third-most co-cited papers are cross-sectional studies by Pitchford（Pitchford et al., 2016） and Suggate（Suggate et al., 2018）, both investigating the role of fine motor skills in the development of early reading and math skills. In our network, these studies were cited 27 and 23 times, respectively, compared with 106 and 51 citations in the literature.

Moreover, we produced the analysis of burstness for the top references of the 1994-2024 time periods. The three papers that presented the most important burst strength were Cameron and colleagues 2016 review（Cameron et al., 2016） links fine motor skills with early academic achievements in literacy and numeracy, Cameron and colleagues 2012 longitudinal study（Cameron et al., 2012） on the predictive roles of fine motor skills and executive function in kindergarten achievement, and Becker and colleagues 2014 longitudinal study（Becker et al., 2014） on behavioral self-regulation and executive function predicting fine motor skills and academic achievement in early education.

3.3 Analysis of author keywords burst

The analysis of the most-cited keywords revealed emerging research trend. The latest keywords with the strongest citation burst were 'Physical Activity' (5.86), 'Autism Spectrum Disorder' (3.20), 'Virtual Reality' (3.28), and 'Neurodevelopmental Disorders' (3.51)."

Table 3. Top 20 keywords with strongest burst during the period 1994-2024

Keyword	Year	Strength	Begin	End	1994–2024
Activities of daily living	2008	3.27	2008	2015	
Psychomotor performance	1996	3.61	2009	2015	
School readiness	2010	2.48	2010	2014	
Fine motor	2009	2.59	2011	2017	
Visual perception	2012	6.29	2011	2016	
Cerebral palsy	1996	3.39	2013	2015	
Language development	2013	2.63	2013	2018	
Binocular vision	2013	2.43	2013	2017	
Gross motor skills	2013	2.37	2013	2021	
Working memory	1994	2.96	2014	2016	
Preschool children	1998	2.44	2015	2021	
Visual motor integration	2016	2.85	2016	2018	
Executive function	2004	2.73	2018	2019	
Developmental delay	1998	2.68	2018	2019	
Occupational therapy	1994	2.35	2019	2019	
Physical activity	2019	5.86	2019	2024	
Autism spectrum disorder	2013	3.20	2020	2024	
Child development	2020	2.96	2020	2024	
Virtual reality	2019	3.28	2021	2024	
Neurodevelopmental disorders	2017	3.51	2022	2024	

4 Discussion

4.1 Summary of the main findings

This study offers an extensive overview of fine motor skill research in children over the last 30 years (1994–2024), including key countries, institutions, authors, journals, papers and trends. We identified a rapid growth of publications on fine motor skills in children since 2006, with an average annual growth rate of 7.5% as of 2024. The most cited journals were the American Journal of Occupational Therapy, Research in Developmental Disabilities, and Perceptual and Motor Skills. The USA has held the leading position in research for decades; however, since 2022, India has been very active with a significant burst of citations. The University of California System, University of London, and Harvard University were the most influential institutions in terms of citation count. Notably, the most cited authors in this field were Beery Ke, Wechsler D, and Barkley Ra.

4.2 Identification of research trends

Analysis of our co-citation reference network indicates that early literature on fine motor skills primarily focused on clinical populations with concurrent impairments in cognitive functions and motor processes. In fact, our initial cluster, arranged chronologically, compiled citations on neuropsychological tests assessing fine motor skills assessments, including the Wechsler Intelligence Scale for Children's the performance scale, used to identify the presence or absence of brain dysfunction. Early evidence from studies of patients with brain lesions or neurodevelopmental disorders indicate a fundamental link between motor and cognitive development（Diamond, 2000）. For example, neuroimaging studies have demonstrated simultaneous activation of the neocerebellum and dorsolateral prefrontal cortex during cognitive tasks. The relationship between fine motor skills and higher-order cognitive skills provides a more specific explanation of the association between motor and cognitive domains. Subsequently, there has been a growing focus on children with ADHD. Studies have shown that children with ADHD are both slower and less accurate in tasks involving fine motor skills（Carte et al., 1996 ; Denckla et al., 1985）. Research indicates that children with ADHD may exhibit poorer fine motor skills because these skills are resource-intensive and compete for limited attentional and perceptual resources（Pitcher et al., 2003a）. Prospective population study（Kalff et al., 2002）also provide indications that deficits in fine motor skills can be predictors of children at risk for later ADHD and could consequently be integrated into the identification process.

Following these initial lines of research, studies on fine motor skills subsequently focused on its subdimension, particularly visual-motor integration (VMI). VMI refers to the ability to coordinate small muscle movements in the hands and fingers with the processing of visual information from the environment（Sortor et al., 2003）. These skills result from the combined effects of various cognitive and neuromotor processes（Smits-Engelsman et al., 2001）, such as visual-spatial perception, visual size discrimination, visual retrieval, and orientation discrimination（Dinehart et al., 2013a）. VMI skills are typically evaluated using tasks that involve writing and copying, such as the Beery Developmental Test of Visual Motor Integration (Beery VMI)（Carlson et al., 2013a）. The development of VMI skills has been reported as one of the most significant predictors of handwriting performance, strongly correlated with writing legibility（Weil et al., 1994 ; Maeland, 1992）. Specifically, forming letters, maintaining appropriate spacing, aligning numbers on a line, and writing words all involve VMI skills（Barnhardt et al., 2005a）. Meanwhile, VMI skills, particularly the ability to copy an oblique cross, are considered indicators of writing readiness in young children（Feder et al., 2007a）. Research has shown that children who successfully copied the initial nine Beery VMI forms, including the oblique cross, were able to copy significantly more letters than those who could not（Weil and Cunningham Amundson, 1994）.

Furthermore, VMI skills have been suggested as key elements of school readiness, given that an estimated 30% to 60% of the school day's required academic activities, such as writing, cutting, and coloring, depend on efficient VMI skills.（Kurdek et al., 2000 ; Carlton et al., 1999 ; McHale et al., 1992） It develops dramatically during early childhood and integrates with executive functions and other skills to form the foundation for successful behaviours in preschool and early elementary learning environments（Pagani et al., 2012）. At the classroom level, children with better VMI skills are more likely to easily translate letters and numbers onto paper, allowing cognitive energy to be allocated to connecting figures and sounds, decoding words, and understanding mathematical concepts（Becker et al., 2014）. In contrast, children with deficits in VMI skills are often more distracted during classroom instruction and homework by the manual tasks involved in copying information from the board, taking notes, completing homework, and underlining（Stoeger et al., 2013）.

More recently, a considerable portion of longitudinal studies has focused on the nature of the relationships between fine motor skills and academic achievement. Research shows that VMI skills, compared with fine motor skills that do not require integration with visual-spatial abilities, are strong predictors of reading and mathematics achievement, as well as academic growth from kindergarten through middle school.（Suggate et al., 2019 ; Brock et al., 2018b ; Cameron et al., 2012 ; Grissmer et al., 2010a） Learners possessing exceptional VMI skills often go on to excel in STEM disciplines such as science, technology, engineering, and mathematics.（Uttal et al., 2012） Several potential mechanisms may underlie the link between fine motor skills and academic achievement, which remains unclear and is an active area of investigation. For example, one hypothesis suggests that fine motor skills enable children to practice linking visual representations with emerging literacy and mathematical skills. Another proposes that children with low fine motor skills might face cognitive overload when trying to keep up with the pace of the learning environment（Brock et al., 2018a ; Pitchford et al., 2016）. More recent investigations have focused on the associations between fine motor skills and emerging numerical abilities, particularly regarding the potential mediating role of finger-counting skills（Asakawa et al., 2022）. Finger counting is considered a prime example of embodied cognition, with findings indicating the involvement of hand motor circuits in the counting process（Suggate et al., 2017）.

Complementing research on children with fine motor skill impairments, more recent investigations have addressed other neurodevelopmental disorders, particularly Developmental Coordination Disorder (DCD) and Autism Spectrum Disorder (ASD). As difficulties in fine motor skills are a core deficit in DCD, the International Guidelines for these populations provide a list of standardized motor tests for diagnosis, all of which require the completion of fine motor tasks（Blank et al., 2019 ; Blank et al., 2012a）. Studies have found that children with DCD exhibit different cortical activation patterns, with decreased activation in regions associated with visuomotor control（Caçola et al., 2018 ; Licari et al., 2015）. Impairments in fine motor skills in children with ASD also have been consistently reported, with deficits in VMI skills being more pronounced than those in fine motor coordination（Carey et al., 2023）. VMI impairment commonly contributes to difficulties in motor imitation, which subsequently leads to the social and communicative deficits central to ASD（Bhat et al., 2022）.

The burst of keywords can help identify emerging research trends in fine motor skills among preschool and school-aged children. Over the past five years, keywords with the strongest citation burst strength have pertained to the following areas: (1) Development and refinement of assessment instruments for fine motor skills to screen children at risk of neurodevelopmental disorders. (2) Effects of physical activity and virtual reality interventions on fine motor skills among typically developing children and those with neurodevelopmental disorders.

5 Conclusion

This scientometric study provides historical perspectives on fine motor skills research involving preschool and school-aged children. Over the past decades, research trends have primarily focused on exploring the association between fine motor skills and academic achievement, as well as the characteristics of fine motor impairment in children with neurodevelopmental disorders. Recent research trends have primarily focused on developing assessment tools and interventions for fine motor skills in both typically developing children and those with neurodevelopmental disorders. Our study provides valuable information for researchers to understand the evolution of research on fine motor skills on children. It also identifies the most influential countries, institutions, and authors, providing valuable insights for researchers and grant applicants.

6 Author’s contributions

B-FZ designed the study and wrote the manuscript; Z-CL, J-BC and C-L searched for literature and analysed the data.

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8 Acknowledgments

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9 Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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