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Studies on Children With Developmental Coordination Disorder in the Past 20 Years: A Bibliometric Analysis *via* CiteSpace

Mei-Qin Wu[1]*[†], De-Qing Wu[2†], Chun-Ping Hu[3] and Lai-Sang Iao[4]

[1] Shanghai Key Laboratory of Maternal Fetal Medicine, Department of Women's and Children's Health Care, Shanghai First Maternity and Infant Hospital, School of Medicine, Tongji University, Shanghai, China, [2] Department of Gastroenterology, Shanghai Tenth People's Hospital, Tongji University School of Medicine, Shanghai, China, [3] School of Public Health, Shanghai Jiao Tong University School of Medicine, Shanghai, China, [4] Department of Psychology, Nottingham Trent University, Nottingham, United Kingdom

Children with developmental coordination disorder (DCD) have been commonly observed and drawn an increasing amount of attention over the past decades. The aim of the present study is to evaluate the origin, current hotspots, and research trends on children with DCD using a bibliometric tool. After searching with "children" and "developmental coordination disorder" as the "topic" and "title" words, respectively, 635 original articles with 12,559 references were obtained from the electronic databases, Web of Science Core Collection (WoSCC). CiteSpace V.5.7.R2 was used to perform the analysis. The number of publications in this field was increasing over the past two decades. John Cairney from the Department of Family Medicine, McMaster University, Canada, was found to be the most productive researcher. Meanwhile, McMaster University and Canada were the most productive research institution and country, respectively. Reference and journal co-citation analyses revealed the top landmark articles and clusters in this field. *Clumsiness* was the most strength burst keyword. Moreover, *task*, *meta-analysis*, *difficulty*, *adult*, and *impact* will be the active research hotspots in future. These findings provide the trends and frontiers in the field of children with DCD, and valuable information for clinicians and scientists to identify new perspectives with potential collaborators and cooperative countries.

Keywords: developmental coordination disorder, children, web of science, data visualization, burst detection

INTRODUCTION

Children with developmental coordination disorder (DCD) exhibit severe motor clumsiness that interferes with academic achievement and the activities of daily living (1). Symptoms of DCD occur in the early stage of development, but it is often not identified until school age, leaving missed good opportunities for early intervention (2). These children have previously been described with a variety of terms such as developmental dyspraxia, minimal brain dysfunction, perceptual-motor dysfunction, physical awkwardness, or, most commonly, the clumsy child syndrome (3, 4). In 1994, these children were collectively referred to as DCD at an international consensus meeting which held in London, Ontario (5).

In recent years, there has been growing recognition of the consequences, outcomes, and burden for children with DCD. However, after the London consensus meeting, DCD, as a unified terminology, lacks systematic research on global research trends and hotspots in this field. Evaluative bibliometrics is a field of quantitative science that has emerged as a powerful tool to evaluate research performance, which can serve to identify influential articles that have shaped medical practice and fostered new research ideas (6).

CiteSpace, one of the bibliometric analysis tools, which was invented by Dr. Chaomei Chen (School of Information Science and Technology, Drexel University, Philadelphia, PA, USA), has been widely used in other research fields (7–9). Professor Chen Chaomei, as the inventor of CiteSpace, published a visual analysis of the emerging research trends in the field of regenerative medicine, on the Expert Opinion on Biological Therapy in May 2012 (10). This study accurately predicted the winner of the 2012 Nobel Prize in physiology/medicine, the Japanese scholar Shinya Yamanaka (11, 12). This empirical study shows that CiteSpace software plays an important role in literature mining.

However, to the best of our knowledge, CiteSpace analysis has not been reported in the field of children with DCD. In this study, the literatures related to children with DCD were collected and screened to form a specific database. Then, CiteSpace was used to perform statistical calculations and further generate visualization results for different node types. The purpose of this article is to clearly visualize and explain the origin and major milestones of the research in children with DCD, after DCD was used as a unified terminology.

METHODS

Data Source

The retrieval data for measurements and statistical analysis were screened from the Web of Science Core Collection (WoSCC), which provides citation search, giving access to multiple databases that reference cross-disciplinary research and allowing for an in-depth exploration of specialized subfields (13).

Search Strategy

All data were obtained from WoSCC on May 10, 2021; the data retrieval strategy was as follows: (i) Topic = children and Title = developmental coordination disorder; (ii) Document type = article; (iii) Language = English; (iv) Timespan (custom year range) = 2000–2019. Full records and cited references were selected as plain text format and downloaded for further analysis.

Analysis Tool

This study utilized CiteSpace V.5.7.R2 to analyze existing studies related to children with DCD, aiming to provide scientific and intuitive support for clinicians and researchers

in this field. CiteSpace, which was created by Dr. Chaomei Chen (School of Information Science and Technology, Drexel University, Philadelphia, PA, USA) and his team in early 2004 (14), was used to perform the bibliometric analysis in this study. CiteSpace is a Java application which combines information visualization methods, bibliometrics, and data mining algorithms in an interactive visualization tool.

Data Analysis

Two separate folders for the DCD project were created. One folder contains data files which were just downloaded. The other folder is the project folder. We did not find duplicate documents that needed to be deleted. The overall selected time span was from January 2000 to December 2019. Then, the time span was sliced into 10 parts corresponding to 10 different colors, each of which was 2 years. The node type was selected according to the type of analysis performed. The size of the circles represents the number of papers published by the country/region, institute or author. The shorter the distance between two circles, the greater the cooperation between the two countries/regions, institutes or authors. Purple rings indicate that these countries/regions, institutes or authors have greater centrality (no <0.1).
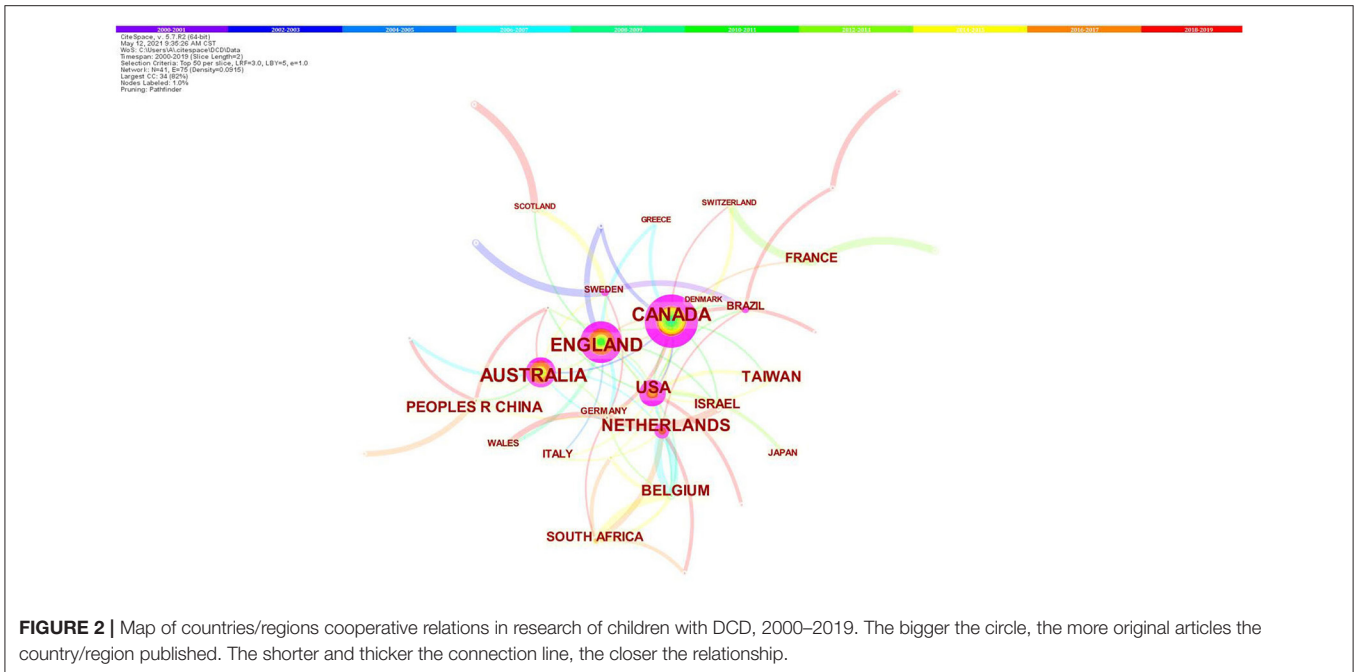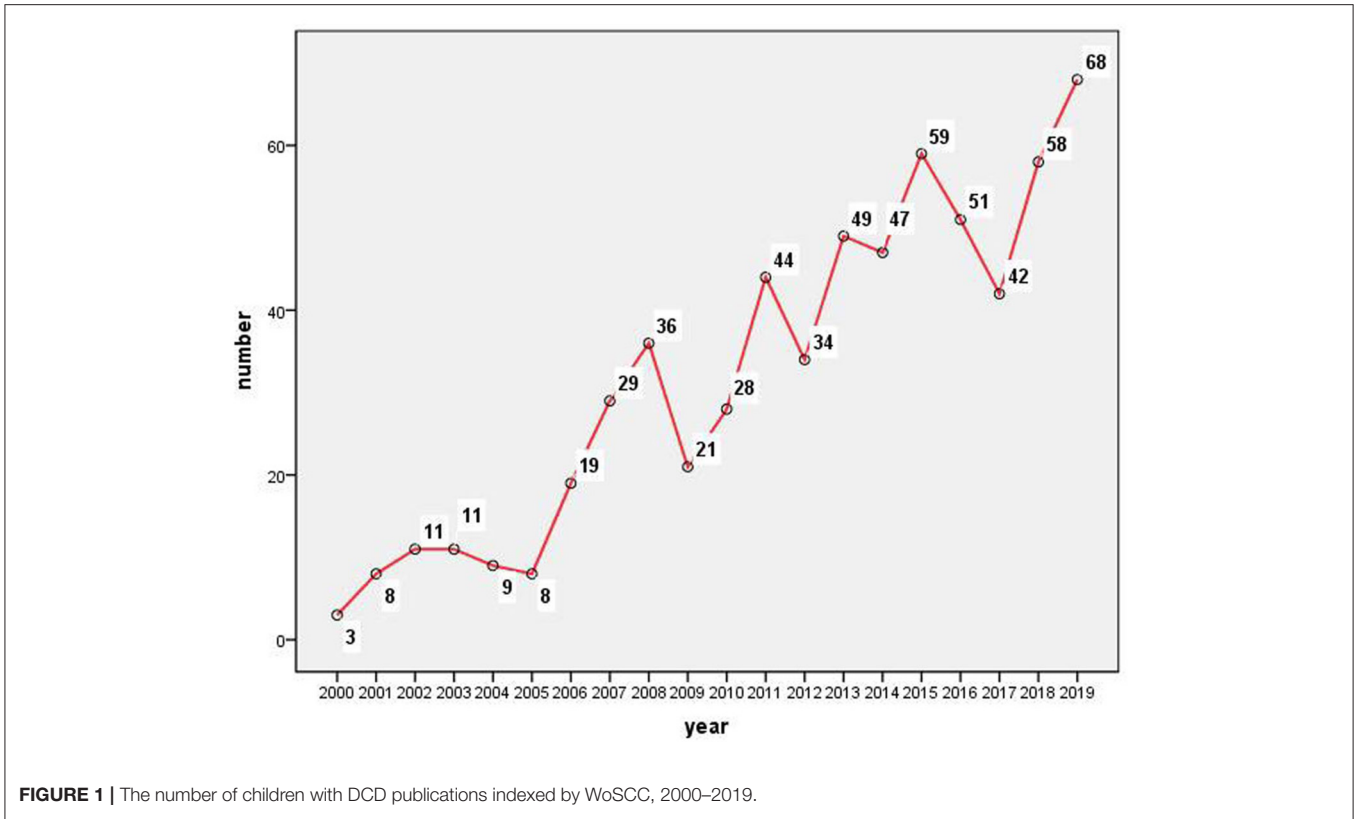
RESULTS

General Data

The initial search for children with DCD resulted in 635 original articles published in English between 2000 and 2019, without duplicate record. According to the publication years, although with some fluctuations, the quantity of published articles on children with DCD increased significantly over the studied period, especially from 2005 to 2008, with an average annual growth rate of 65.10% (**Figure 1**).

Quantitative and Cooperation Analysis

Countries/Regions

Figure 2 displays the cooperation network of the productive countries/regions. The size of circles represents the number of publications of countries/regions, and the shorter distance between two circles suggests the more collaboration between individual countries/regions. The purple rings outside the circle refer to centrality. Canada (137) ranks first in the publication quantity, which is followed by England (114) and Australia (104). The top 10 prolific countries/territories in this research field are shown in **Table 1**, which are sorted out from the network summary table.

Institutes

Figure 3 exhibits the major productive co-institutes in the field of children with DCD. The Canadian McMaster University is the most productive and influential institute in this field, with a total number of 54 published articles, and the centrality of 0.74. Brock University, which ranks second in productivity, also locates in Canada. The top 10 prolific institutes in this research field are shown in **Table 2**.

Abbreviations: BOT-2, Bruininks–Oseretsky Test of Motor Proficiency, Second Edition; DCD, developmental coordination disorder; DSM-V, Diagnostic and Statistical Manual of Mental Disorder, Fifth Edition; EACD, European Academy for Childhood Disability; LLR, log-likelihood ratio; MABC-2, Movement Assessment Battery for Children, Second Edition; SOT, sensory organization test; WoSCC, Web of Science Core Collection.

FIGURE 1 | The number of children with DCD publications indexed by WoSCC, 2000–2019.

FIGURE 2 | Map of countries/regions cooperative relations in research of children with DCD, 2000–2019. The bigger the circle, the more original articles the country/region published. The shorter and thicker the connection line, the closer the relationship.

Authors

Figure 4 is the co-authorship network map generated by CiteSpace. Regarding the authors who were active, John Cairney from the Department of Family Medicine, McMaster University,

Canada, ranks the first (40 publications), followed by Chialiang Tsai from the Institute of Physical Education, Health and Leisure Studies, National Cheng Kung University, Taiwan (22 publications). The top 10 authors are presented in **Table 3**.

TABLE 1 | Top 10 prolific countries/regions in research of children with DCD, 2000–2019.

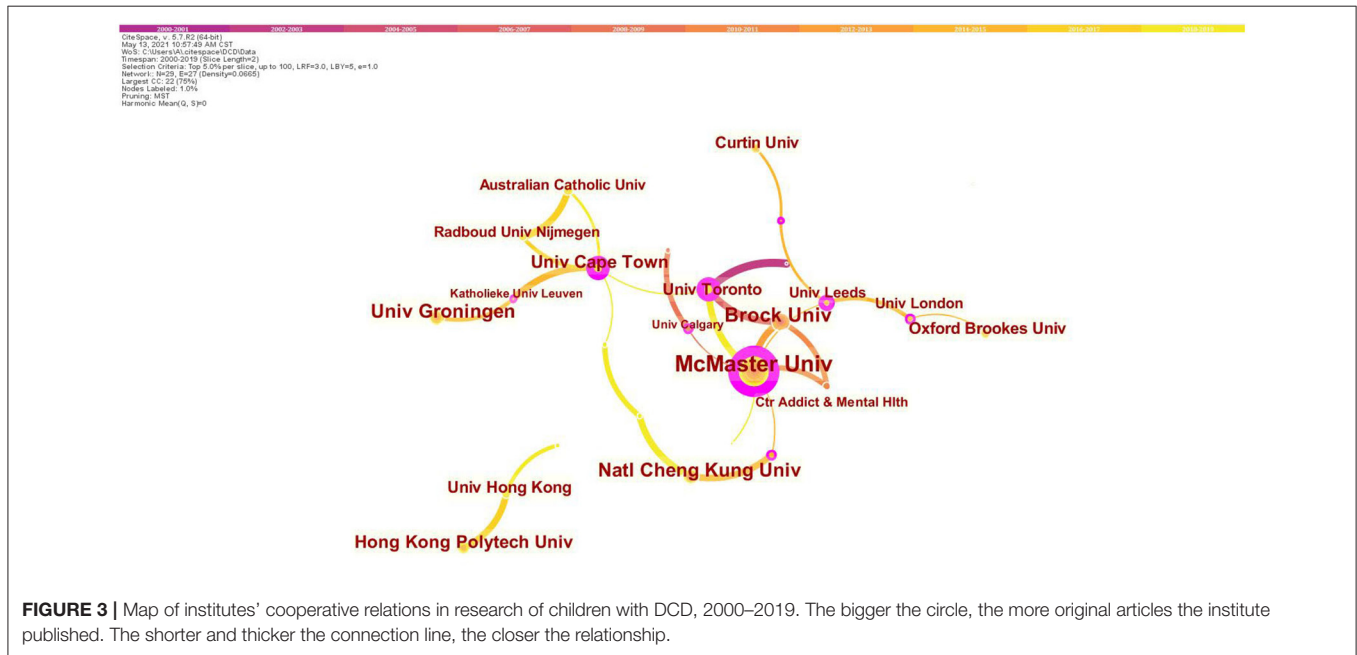| Ranking	Country/region	Frequency	Centrality	Ranking	Country/region	Frequency	Centrality
1	CANADA	137	0.44	6	TAIWAN	51	0.00
2	ENGLAND	114	0.24	7	BELGIUM	36	0.04
3	AUSTRALIA	104	0.15	8	PEOPLES R CHINA	36	0.10
4	USA	73	0.37	9	SOUTH AFRICA	31	0.02
5	NETHERLANDS	72	0.13	10	FRANCE	26	0.08

FIGURE 3 | Map of institutes' cooperative relations in research of children with DCD, 2000–2019. The bigger the circle, the more original articles the institute published. The shorter and thicker the connection line, the closer the relationship.

TABLE 2 | Top 10 prolific institutes in research of children with DCD, 2000–2019.

Ranking	Institute	Frequency	Centrality
1	McMaster University	54	0.74
2	Brock University	27	0.02
3	University of Groningen	24	0.00
4	Natl Cheng Kung University	22	0.07
5	University of Cape Town	20	0.46
6	Hong Kong Polytechnic University	19	0.00
7	University of Toronto	15	0.48
8	Oxford Brookes University	15	0.00
9	University of Hong Kong	14	0.01
10	Curtin University	13	0.00

Research Topic Analysis
Reference Co-citation

After selecting reference as node type for statistical analysis, it shows that 635 original records containing 12,559 references were primary downloaded and entered the database. Colors, moving from purple to yellow, indicate the citation time from 2000 to 2019, respectively. The clusters are named by extracting nominal terms as labels from the titles of the cited articles. The LLR (log-likelihood ratio) algorithm is used as the extraction method. **Figure 5** shows a cluster visualization of the reference co-citation network which is divided into six co-citation clusters including 0# manual dexterity, 1# m shuttle run, 2# sensory organization, 3# suspected DCD, 4# age hypothesis, and 5# physical fitness. The summary of the largest five clusters is shown in **Table 4**.

The top ranked article by citation counts (**Table 5**) is American Psychiatric Association (15) in Cluster #0, with citation counts of 111. The second one is Blank et al. (16) in Cluster #3, with citation counts of 85. The third is Wilson et al. (17) in Cluster #0, with citation counts of 75. The fourth is Zwicker et al. (3) in Cluster #3, with citation counts of 44.

Journal/Instruction Manual Co-citation

A total of 12,559 citation references are from different journals/instruction manuals. **Table 6** lists the top 10 highly cited journals/instruction manuals. The highest cited journal is the Developmental Medicine and Child Neurology, with 548 citations, followed by the Journal of Human Movement Science (547) and Movement Assessment Battery for Children (462).
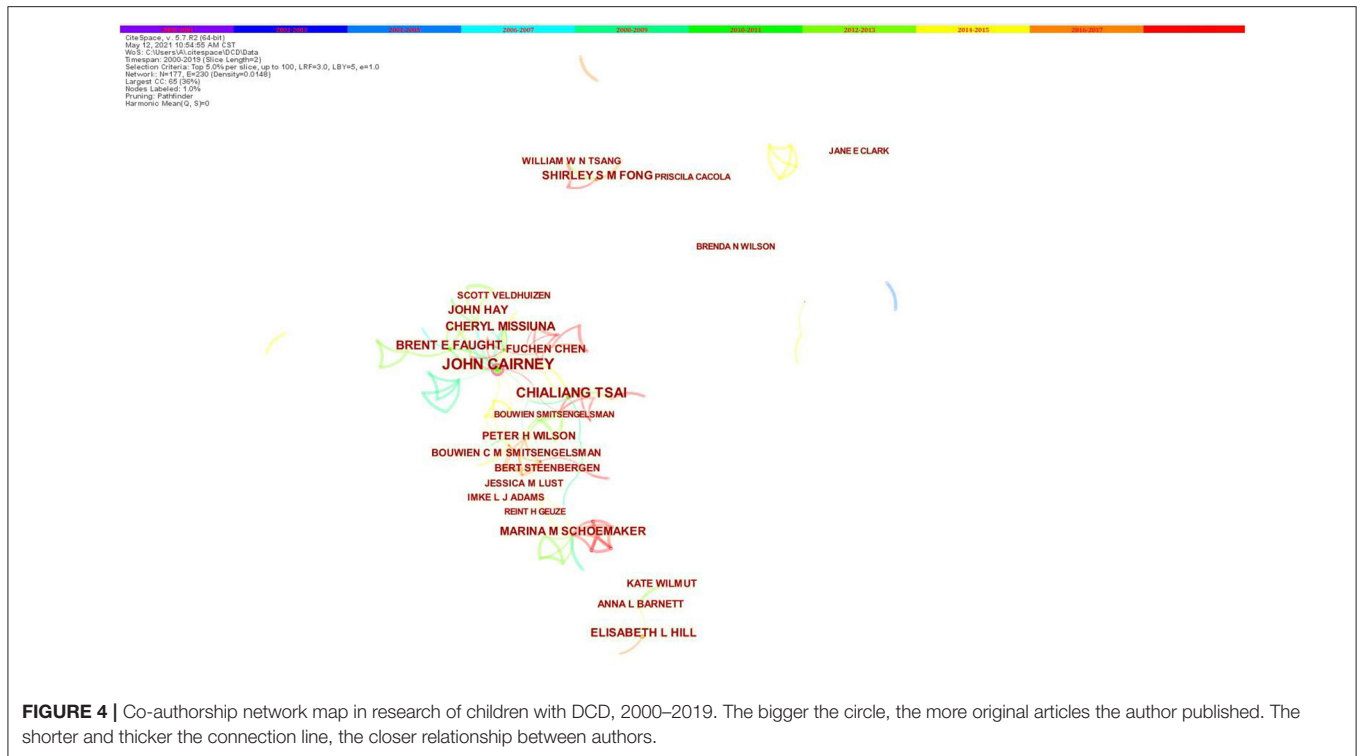
FIGURE 4 | Co-authorship network map in research of children with DCD, 2000–2019. The bigger the circle, the more original articles the author published. The shorter and thicker the connection line, the closer relationship between authors.

TABLE 3 | Top 10 active authors in research of children with DCD, 2000–2019.

Ranking	Author	Publications	Centrality
1	John Cairney	40	0.16
2	Chialiang Tsai	22	0.04
3	Brent E Faught	18	0.03
4	Cheryl Missiuna	17	0.07
5	Elisabeth L. Hill	16	0.00
6	John Hay	14	0.03
7	Shirley S. M. Fong	13	0.00
8	Marina M. Schoemaker	13	0.06
9	Peter H. Wilson	12	0.05
10	Fuchen Chen	11	0.02

Future Research Direction Analysis

The burst detection in CiteSpace is based on Kleinberg's algorithm, which based on modeling the stream using an infinite-state automaton to extract a meaningful structure from document streams that arrive continuously over time (19). These analyses can show the fast-growing topics that last for multiple years as well as a single year. **Figure 6** shows the top 25 keywords with the strongest citation bursts in published articles on children with DCD. The blue line represents the time interval, and the red line refers to the duration of the citation burst. In the keyword's citation burst detection analysis, clumsiness is the strongest burst keyword that appeared in 2000 with the burst strength of 15.15, followed by clumsy children (11.43), motor skill (5.86), and age (5.49). Five frontiers in the field of children with DCD that

have impacts on future research are task, meta-analysis, difficulty, adult, and impact.

DISCUSSION

Quantity and Cooperation Analysis

In this study, we utilized information visualization to analyze original articles on children with DCD published from 2000 through 2019. Before the expert meeting 1994, a wide variation in terminology and diagnostic criteria was used to describe children with DCD, hampering the external validity of the scoping review. In 2001, a survey of 234 professionals from the UK, including doctors, occupational therapists, and speech therapists, found that the term "dyspraxia" is much more widely used in the UK rather than DCD (20). So, in 2012, the European Academy for Childhood Disability (EACD) published the recommendations on the definition, diagnosis, and intervention of DCD (16). Unified nomenclature is very critical and the most basic requirement for the diagnosis and treatment of a clinical disease in the later stage. In this study, we identified an increasing number of scientific research publications over the last 20-year period. However, it can be seen from **Figure 1** that the quantity of papers published before 2005 was still very low.

In this article, Canada's contribution to this field is the most outstanding, accounting for 21.57% (137/635) of the articles in this field in the past 20 years. By analyzing the nodes of authors, cooperative relationship with others could be investigated. Dr. Cairney the Director of the Infant and Child Health Research Laboratory at both the University of Toronto and McMaster University (21) (currently Head of the School of Human
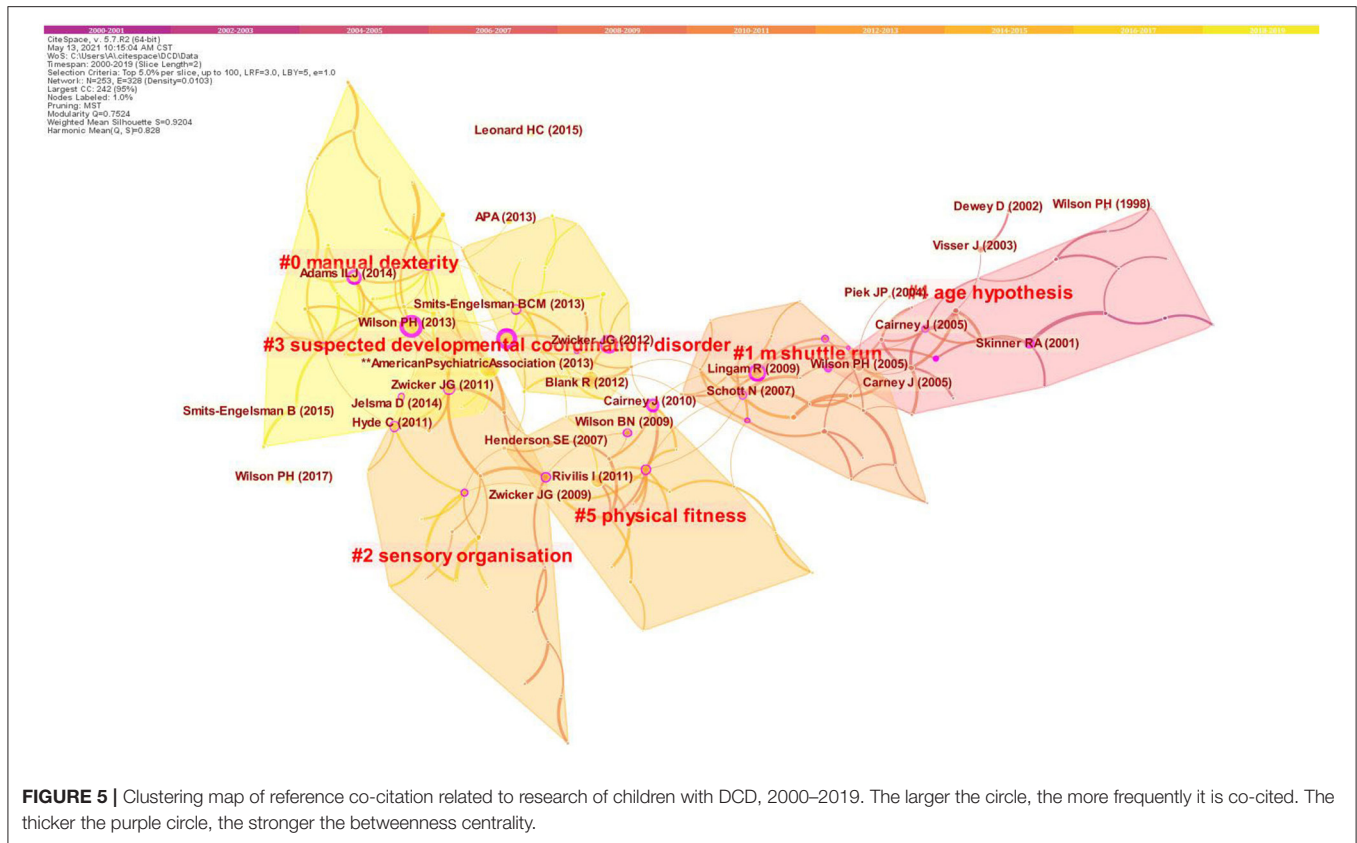
FIGURE 5 | Clustering map of reference co-citation related to research of children with DCD, 2000–2019. The larger the circle, the more frequently it is co-cited. The thicker the purple circle, the stronger the betweenness centrality.

TABLE 4 | Summary of the largest five clusters.

Cluster ID	Size	Silhouette	Label (LLR)	Mean (cite year)	Description
0	32	0.942	Manual dexterity	2013	An important manifestation of developmental coordination disorder
1	24	0.889	M shuttle run	2007	A well-established field measure of maximal oxygen uptake in children
2	24	0.967	Sensory organization	2009	Children with developmental coordination disorder have widespread impairment in their sensory organization
3	21	0.857	Suspected developmental coordination disorder	2011	A group of people exposed to risk factors for developmental coordination disorder
4	21	0.878	Age hypothesis	2002	The activity-deficit between children with and without coordination problems widens with age

Size: the number of references that a cluster contains.
LLR, log-likelihood ratio.

TABLE 5 | Top five co-citation references related to children with DCD, 2000–2019.

Ranking	Frequency	Centrality	Source	Cited reference	References	Cluster
1	111	0.09	DIAGN STAT MAN MENT	American Psychiatric Association (2013). Diagnostic and Statistical Manual of Mental Disorders. 5th Edition, APA, Washington, DC	(15)	#0
2	85	0.08	DEV MED CHILD NEUROL	European Academy for Childhood Disability (EACD): Recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version)	(16)	#3
3	75	0.48	DEV MED CHILD NEUROL	Understanding performance deficits in developmental coordination disorder: a meta-analysis of recent research	(17)	#0
4	44	0.31	EUR J PAEDIATR NEURO	Developmental coordination disorder: A review and update	(3)	#3
5	42	0.06	RES DEV DISABIL	Physical activity and fitness in children with developmental coordination disorder: A systematic review	(18)	#5

TABLE 6 | Top 10 highly cited journals in research of children with DCD, 2000–2019.

Ranking	Journal	Frequency	Centrality	Impact factor (2019)
1	Developmental Medicine and Child Neurology	548	0.16	4.406
2	Human Movement Science	547	0.27	2.096
3	Movement Assessment Battery for Children*	462	0.07	—
4	Diagnostic and Statistical Manual of Mental Disorder*	460	0.07	—
5	Research in Developmental Disabilities	353	0.23	1.836
6	Child: Care, Health & Development	320	0.14	1.918
7	Adapted Physical Activity Quarterly	305	0.24	1.462
8	Journal of Child Psychology and Psychiatry	255	0.04	6.129
9	Pediatrics	216	0.05	5.401
10	American Journal of Occupational Therapy	206	0.14	1.952

These two are manuals.

Movement and Nutrition Sciences at University of Queensland in Australia), is the most productive researcher in this field. His research examined the relationships among motor skill, physical activity, and physical and mental health in children (22). He is internationally known for his work on DCD and its impact on physical and psychological well-being in children (with the strongest centrality of 0.16). McMaster University also becomes the most productive (frequency: 54) and influential (centrality: 0.74) research institution in this field. Besides, it is obvious that the collaboration in investigating children with DCD is relatively close, mostly linked with institutions with high centrality, such as McMaster University, University of Toronto, and University of Cape Town. The top two institutions both come from Canada, indicating the leading role in this field.

Research Topic

In a co-citation network, references cited by a given article provide valuable information regarding intellectual connections between various scientific concepts (12). The literature represented in the co-citation network is organized into six different clusters. Each node represents a cited article, and the clusters represent a distinct specialty or a thematic concentration. The silhouette value of a cluster measures the quality of a clustering configuration, which ranges between −1 and 1. The higher the silhouette score (recommendation value >0.70), the more consistent of the cluster members are, providing the clusters in comparison have similar sizes (23).

During the past two decades, a significant amount of research has been conducted to study children with DCD. Compromised *manual dexterity* is a hallmark of the DCD symptom profile

(24, 25), which has become a focus point of children with DCD research during more recent years. *Manual Dexterity* has also become one of the three components of the Movement Assessment Battery for Children, Second Edition (MABC-2), which is a validated, standardized, and norm-referenced test used to measure motor proficiency in children with DCD (26).

Besides *manual dexterity* problems, children with DCD are also known to have lower levels of physical fitness, including cardiorespiratory fitness, anaerobic capacity, and muscle strength. Sprinting tests are commonly used to assess general anaerobic capacity, but only the *shuttle run* item of the Bruininks–Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), and the 10×5 m sprint were investigated, which are currently the best choices (27, 28).

Actually, balance dysfunction is one of the most common sensorimotor impairments observed among children with DCD. However, until now, a comprehensive understanding of the etiology is still lacking. A majority of studies suggested that the impaired postural control can be ascribed to a deficit in central control and *sensory organization* (29). The *sensory organization test* (SOT), which has demonstrated good reliability and validity, was used to evaluate the *sensory organization* of balance control for children with DCD (30, 31).

Age hypothesis was presented that the activity deficit in children with DCD would grow larger as children's play became more complex and rule-bound (32). In other words, problems and secondary consequences in early childhood can persist through childhood and into adolescence and adulthood in children with DCD (33). To prevent these problems, early recognition of *suspected DCD* seems to be paramount in order to give the child the necessary support.

Therefore, many kinds of questionnaires have been designed to detect the play characteristics of young children who are suspected for DCD. The DCDQ-R (Developmental Coordination Disorder Questionnaire, Revised Version) has been shown to be one of the most utilized screening tools for DCD and a useful adjunct in studies using clinical samples (34–36). Further, the DCDQ-R has been revised for use in younger children that are 3 and 4 years of age: the Little DCD Questionnaire or Little DCDQ (18).

Research Fundamental

The top co-cited articles are often considered fundamental and a basis for a certain research field. Based on co-citation networks, top-cited publications are further analyzed to investigate the knowledge base for the field of children with DCD. Therefore, by combining with **Figure 5** (thick purple ring) and **Table 5** (centrality: 0.48 and 0.31), we find that high-quality meta-analysis published in the *DEV MED CHILD NEUROL* by Wilson et al. (17) and literature review published in the *EUR J PAEDIATR NEURO* by Zwicker et al. (3) are the solid foundation of the research in this field. Meta-analysis was also widely used in systematic reviews in many other disciplines and fields. Especially, it plays an important role in the field of evidence-based medicine and public health (37). Among the listed top five co-cited references in **Table 5**, the first two are both guidelines/manuals in this field
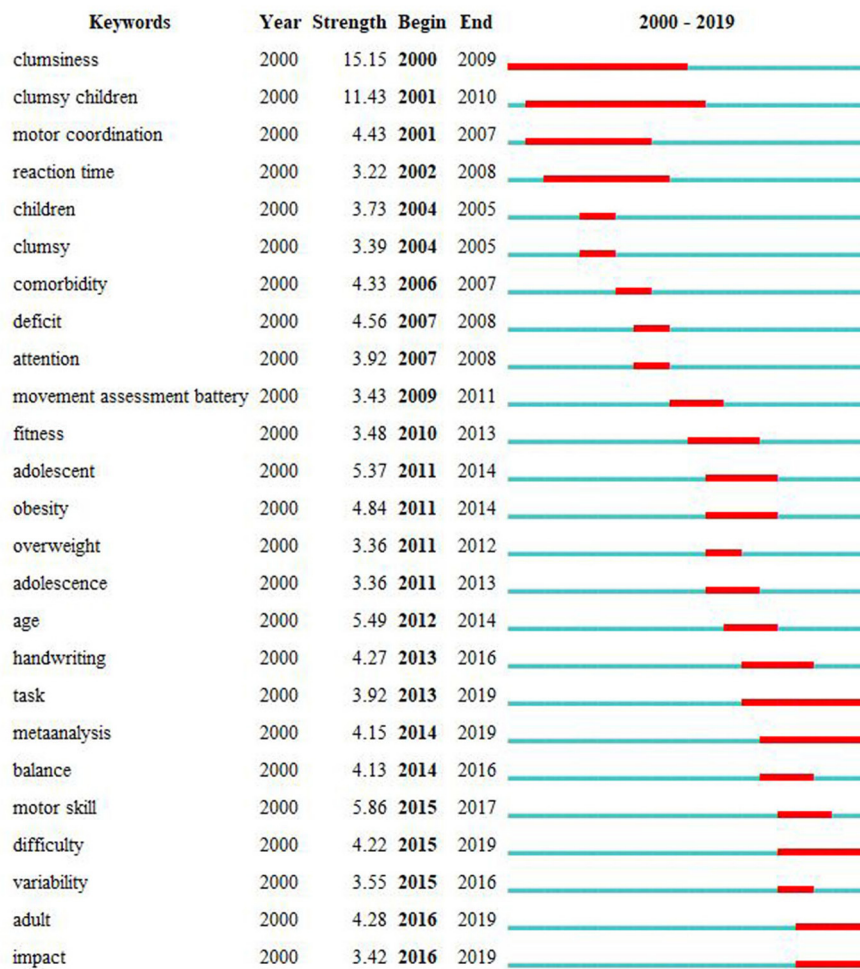
FIGURE 6 | Keywords with the strongest citation bursts in published articles on children with DCD, 2000–2019. The timeline is depicted as a blue line, and the time interval that a subject was found to have a burst is shown as a red segment which indicated the beginning year, the ending year, and the duration of the burst.

(15, 16), which play fundamental and instructive roles in the research of children with DCD. These two articles belong to cluster #0 and #3, respectively, which labeled "manual dexterity" and "suspected developmental coordination disorder."

Research Source

The highly cited journals reflect the best source in the research field of children with DCD to a certain extent. *Developmental Medicine & Child Neurology* has defined the field of pediatric neurology and childhood-onset neurodisability. It is a multidisciplinary journal, one of the world's leading journals in the whole field of pediatrics. As a kind of specific motor skill developmental disorder, the assessment of DCD is very critical. Therefore, main studies should refer to the assessment tool or manual, such as the MABC-1/2, and the Diagnostic and Statistical Manual of Mental Disorder, Fifth Edition (DSM-V).

Future Research Direction

From **Figure 6**, the hot topics switched from *clumsiness*, the burst keyword with the most strength, *clumsy children*, *motor coordination* to *movement assessment battery*, *adolescent*, and finally to *task*, *meta-analysis*, *difficulty*, *adult*, *impact*, and so on. Research foci in children with DCD seems to have shifted from children to adolescent and adult, from research in general symptom to specific assessment. Moreover, research foci mainly focused on clinical research rather than basic science or mechanism. Based on the evolution of keywords bursts and the ending year displayed with red segment, the future research trends in this field could be concluded as follows.

①DCD is a neurodevelopmental abnormality found in healthy children and persisting in "*adulthood*," which may "*impact*" everyday living (38). Therefore, new studies were conducted for "*adolescents/adults*" in the latest recommendations in 2019 to update the recommendations in 2012 (35). In recent years,

many case–control and longitudinal studies have been reported (39, 40), and it will become one of the hot spots in this field in the future.

②Since motor control and executive function deficits are expressed as a function of "*task type*" and difficulty, interventions for DCD can be broadly categorized into two types: process or deficit-oriented and "*task-specific*" (3, 35). "*Task-specific*" training was found to be useful in improving the performance of children with DCD based on the type of task trained (41, 42). Some reviews and meta-analysis also found that approaches from a task-specific perspective yielded stronger effects, whereas this preliminary evidence is currently insufficient (43, 44). Therefore, it will be also one of the research trends in this field.

Strengths and Limitations

To our knowledge, this bibliometric study is the first of its kind to identify and characterize research in children with DCD. Moreover, our findings provide a clear visual analysis, from the quantity, quality, citation analysis, and so on, of the publications of children with DCD. It will be a good example of visualization analysis available to explore research hotspots in other fields.

There are also some weaknesses to the study. Although we used the WoSCC for our bibliometric analysis, there are other public and commercially available bibliometric databases, such as Scopus, Medline, and PubMed. However, there are some reasons for this choice of database. For example, PubMed records do not include information on cited references so it is not possible to perform citation analysis using PubMed (45).

CONCLUSION

From the current bibliometric analysis of children with DCD publications over the previous 20 years, it is found that related publications increased at a rapid rate. Canada has the highest publication rate and centrality, and the institution and researcher that are most prolific in this field are also from Canada. The analysis and interpretation of the research literature will be very helpful to the clinicians and scientists in this field.

AUTHOR CONTRIBUTIONS

M-QW, D-QW, C-PH, and L-SI contributed to study design and acquisition of research data. M-QW conducted the data analysis. M-QW and D-QW drafted the manuscript. All authors contributed to improvements of the manuscript for important intellectual content and approved the final version for publication.

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