Mathematical capacity of children with Developmental Coordination Disorder: Influencing factors and occupational therapy practices in Canada

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“Look up, get up, and don’t ever give up”

- Michael Irvin, 2007

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ADHD; attention-deficit/hyperactivity disorder

DCD; Developmental Coordination Disorder

N/A; non-applicable

SD; standard deviation

TD; typically developing

VMI; visuo-motor integration

VP; visual-perceptual

Contribution of authors

All three manuscripts presented in this thesis are authored by PhD candidate Eliane Dionne. She spearheaded and coordinated all aspects of the research contributing to this thesis, including formulating the research proposal for ethical and scientific approval, participant recruitment, coordination of the participant's evaluations, scoring assessments, data entry, statistical analysis and manuscript preparation. These efforts were conducted under the supervision of Dr. Marie Brossard-Racine, who provided extensive input for conceptualization of the studies and revision of the manuscripts, as well as operational support throughout the course of the thesis.

The co-authors of the manuscripts, Dr. Beauchamp and Dr. Majnemer, provided invaluable perspectives regarding the feasibility, conceptualization, and realization of the studies, as well as contributing significantly to manuscript revision. For the first manuscript, Marie-Ève Bolduc significantly contributed as second reviewer, assisting in study selection, data extraction and quality appraisal.

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Statement of originality

This thesis contains original material and distinct contributions to knowledge not published elsewhere unless where specified. The studies in this thesis contribute to the field of academic learning in children with Developmental Coordination Disorder (DCD). Specifically, the novel contributions of this thesis are:

(i) Synthesizing the published evidence on the prevalence and extent of academic difficulties in school-aged children with DCD.

(ii) Identifying the prevalence and extent of mathematical difficulties in school-aged children with DCD.

(iii) Identifying the factors associated with mathematical capacity in school-aged children with DCD and the extent of this association.

(iv) Determining current assessment and intervention practices of Occupational Therapists for academic activities in children with DCD across Canada.

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Abstract

Background: Developmental coordination disorder (DCD) is a lifelong condition characterized by difficulties with motor coordination and planning, affecting five to six percent of school-aged children. Although the etiology of DCD is unclear, there is evidence to suggest that some of these difficulties may be due to poor visual-perceptual skills. These skills are necessary to perform many daily living tasks and academic activities, including mathematics. Although the handwriting difficulties of children with DCD are well documented, the full scope of all academic challenges in this population had not been comprehensively reviewed. Difficulties in mathematics can lead to significant problems in everyday life for driving, shopping, and managing time, but Occupational Therapists (OTs) can help individuals overcome these challenges by providing targeted interventions. However, no study to date has comprehensively described the frequency or extent of mathematical difficulties or its factors in this population. Furthermore, the practices of OTs regarding academic activities have not been explored in Canada. A better understanding of these practices would help orient future research and clinical practice to address the academic difficulties faced by children with DCD.

Objective: The objective of this thesis was to ascertain the nature and extent of mathematical difficulties in children with DCD and to explore OT practices in Canada related to academic activities for this population.

Methods: This thesis is composed of three studies; (1) a systematic review of the prevalence and extent of academic difficulties in school-aged children with DCD, (2) a cross-sectional study of mathematical capacity and its factors in school-aged children with DCD and (3) a pan-Canadian survey of the assessment and intervention practices of OTs toward academic activities in children with DCD.

Results: The results of the systematic review (Study 1) included 24 studies that revealed a pooled prevalence of 84% of handwriting difficulties and 89.5% of mathematical difficulties in children with DCD. The findings showed that children with DCD had below-norm performance in handwriting legibility ($g = -1.312$) and speed ($g = -0.931$), non-motor aspects of writing ($g = -0.859$), mathematics ($g = -1.199$) and reading ($g = -1.193$). In Study 2, children with DCD ($n = 55$, 9.1 ± 1.5 years, 45 males) had lower overall mathematical capacity compared to normative data (-0.59 SD) on the KeyMath 3rd edition, with poorer performance in processes involving measurements, geometry and problem-solving. Thirty-eight percent of the sample performed below the 15th percentile in overall mathematical skills. Thirty-seven percent of the variance of overall mathematical capacity was explained by visual-perceptual skills, inattention, visuomotor integration and motor impairments while controlling for household income ($F [6,46] = 7.685$, $p < .0001$), with visual-perceptual skills as the most important factor of mathematics and its domains. In Study 3, 226 out of the 229 OTs who completed the survey reported assessing academic activities, most frequently handwriting (96%), then the non-motor aspects of writing (74%), mathematics (72%), and reading (66%). Regarding intervention services, up to 78% of OTs provided direct intervention, compared to 51% for indirect or consultative services.

Conclusion: Children with DCD experience difficulties in mathematics, especially in measurements, geometry and problem-solving, and these are partially explained by poor visual-perceptual skills, highlighting potential avenues for effective intervention. Given the functional daily importance of mathematics, OTs should systematically screen for impairments in this

activity, regardless of their work setting. OTs should aim to comprehensively address the academic needs of children with DCD, thereby promoting their full participation in all activities of daily living and well-being.

Abrégé

Contexte : Le trouble développemental de la coordination (TDC) se caractérise par des difficultés de coordination et de planification motrices touchant cinq à six pour cent des enfants d'âge scolaire. Son étiologie est incertaine, mais certains défis associés seraient dus à de faibles habiletés visuoperceptuelles. Ces habiletés sont nécessaires pour de nombreuses tâches de la vie quotidienne et d'apprentissage, incluant les mathématiques. Les difficultés d'écriture manuelle des enfants ayant un TDC sont bien documentées, mais l'ensemble de leurs défis académiques n'a pas été colligé. Les difficultés en mathématiques peuvent mener à des défis fonctionnels, notamment pour conduire, faire des achats et gérer le temps, pour lesquels les ergothérapeutes peuvent proposer des interventions ciblées. À ce jour, aucune étude n'a décrit la fréquence ou l'étendue des difficultés mathématiques, ni ses facteurs, chez cette population. De plus, les pratiques des ergothérapeutes concernant les activités académiques demeurent inexplorées au Canada. Une meilleure compréhension de ces pratiques permettrait d'orienter la recherche et les pratiques cliniques tout tenant compte des difficultés académiques des enfants ayant un TDC.

Objectif : L'objectif de cette thèse était de déterminer la nature et l'étendue des difficultés mathématiques des enfants ayant un TDC et d'explorer les pratiques des ergothérapeutes au Canada en lien avec les activités académiques pour cette population.

Méthode : Cette thèse comporte trois études : (1) une revue systématique de la fréquence et de l'étendue des difficultés académiques des enfants d'âge scolaire ayant un TDC, (2) une étude transversale sur la capacité mathématique et les facteurs qui y sont associés et (3) une enquête pancanadienne des pratiques d'évaluation et d'intervention des ergothérapeutes envers les activités académiques des enfants ayant un TDC.

Résultats : La revue systématique des écrits (Étude 1) a inclus 24 études démontrant que 84% des enfants ayant un TDC ont des difficultés d'écriture manuelle et 89,5% des difficultés mathématiques, ainsi qu'une performance sous les normes en lisibilité de l'écriture (g = -1,312), vitesse d'écriture (g = -0,931), dans les aspects non-moteurs de l'écriture (g = -0,859), en mathématiques (g = -1,199) et en lecture (g = -1,193). Dans l'Étude 2, les enfants ayant un TDC (n = 55, 9,1 ± 1,5ans, 45 garçons) avaient une capacité mathématique sous les normes (-0,59 ET) au KeyMath 3e édition, particulièrement en mesures, géométrie et résolution de problèmes, et 38% d'entre eux ont performé sous le 15e percentile en mathématiques. Les habiletés visuoperceptuelles, l'attention, l'intégration visuomotrice et les habiletés motrices, tout en contrôlant pour le revenu familial, expliquaient 37% de la variance de la capacité mathématique (F [6,46] = 7,685, p < ,0001), les habiletés visuoperceptuelles étant le facteur le plus fortement associé aux mathématiques parmi ceux-ci. Dans l'Étude 3, 226 des 229 ergothérapeutes ayant répondu au sondage ont rapporté évaluer les activités académiques, plus fréquemment l'écriture manuelle (96%), les aspects non-moteurs de l'écriture (74%), les mathématiques (72%) et la lecture (66%). Quant aux services d'intervention, jusqu'à 78% des ergothérapeutes sondés offraient des services d'intervention directs, comparativement à 51% pour les services indirects ou de consultation.

Conclusion : Les enfants ayant un TDC rencontrent des difficultés en mathématiques, particulièrement en mesures, géométrie et résolution de problèmes, qui sont partiellement expliquées par des difficultés visuoperceptuelles, mettant ainsi en évidence de potentielles pistes d'interventions. Considérant l'importance quotidienne des mathématiques, les ergothérapeutes devraient systématiquement dépister les défis en mathématiques et aborder tous les besoins

académiques des enfants ayant un TDC, favorisant ainsi leur pleine participation à toutes les activités de la vie quotidienne et leur bien-être.

Chapter 1. Literature review

Developmental Coordination Disorder (DCD) is a lifelong motor condition that has significant impacts on daily life activities such as biking, tying shoes and handwriting (Blank et al., 2019), yet the difficulties encountered in academic activities such as mathematics are not well recognized. Understanding the scope of mathematical difficulties is essential to orient intervention services and to support clinical practices that minimize functional impairments related to academic difficulties.

1.1. Introduction

Developmental Coordination Disorder (DCD) is lifelong and has significant impacts on daily life (Blank et al., 2019). Early identification and intervention are crucial to help children with DCD build essential motor skills, improve their independence and self-confidence, and enhance their participation in activities of daily living (Zwicker et al., 2012). Concurrently with their motor challenges, children with DCD often exhibit illegible and slow handwriting (Magalhaes et al., 2011). Yet, the difficulties they may encounter in other academic activities such as mathematics are not well recognized.

In daily life, mathematics plays an essential role in enabling active participation in activities that require effective time management, measuring, problem-solving and logical thinking. These activities include managing money and time, driving, shopping, working, cooking, taking medications and following instructions (Deloche et al., 1996). The basic understanding of mathematics necessary to participate in these activities is usually acquired during elementary education, and adults who do not grasp these concepts may have difficulties securing employment and fully participating in society as productive adults. In turn, this can substantially impact their socioeconomic status, financial stability, health-related quality of life and socio-emotional stability (Cousins & Smyth, 2003; Patton et al., 1997). Given the functional importance of mathematics, these necessitate appropriate support and intervention, which falls under the scope of OT practice. Indeed, OTs, who are typically very involved with children with DCD, bring a unique perspective that bridges both the medical and educational aspects of the disorder. Preliminary evidence suggests that children with DCD have poorer mathematical capacity than their typically developing peers (Gomez & Huron, 2020; Gomez et al., 2015; Gomez et al., 2017). However, the specific domains of difficulty and their factors have not yet been investigated in children with DCD. Identifying areas of weaknesses in mathematics and its factors is of crucial importance, as it will highlight potential avenues for intervention and support clinicians and educators to provide individualized strategies for these children.

Characterizing the academic difficulties of children with DCD constitutes a knowledge creation step, as per Graham's Knowledge to Action process (Graham et al., 2006). It is essential to inform best practice, but new knowledge does not necessarily directly transfer to clinical practice. In fact, to support knowledge transfer onto clinical practice, it is fundamental to understand the current practices of the clinicians. Doing so allows for comparison between current and best practices to identify gaps in practice and therefore support clinicians where needed. However, the current practices of OTs with regards to academic activities have never been reviewed. Therefore, describing the current practices of OTs in terms of assessments and interventions consists as a necessary first step to support future knowledge transfer and eventually change in practice and service delivery for children with DCD.

1.2. Developmental Coordination Disorder

Developmental coordination disorder (DCD), also known as developmental dyspraxia or motor dyspraxia, is a neurodevelopmental disorder in which motor skills and motor coordination are significantly impacted and interfere with activities of daily living. It is diagnosed based on four criteria from the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) (Table 7.1) (American Psychiatric Association, 2013). It has been estimated to affect males more frequently than females (ratios varying from 2:1 to 7:1) (Kadesjö & Gillberg, 1998; Lingam et al., 2009), and occurs in approximately five to six percent of the school-aged population worldwide, which represents one to two children in every Canadian classroom (Blank et al., 2012; Gaines et al., 2008).

The common signs and symptoms of DCD include difficulties with balance, visuo-motor integration, body awareness, agility, and coordination (Blank et al., 2012). These issues make children seem clumsy or inattentive, as they often trip, drop objects and have difficulties with everyday motor tasks such as handwriting, tying their shoes or using scissors. In addition to these motor impairments, difficulties with executive functioning, language development, socialization and academic activities are often reported (Gaines & Missiuna, 2007; Kadesjö & Gillberg, 1998; Lingam et al., 2010). Children with DCD are more likely to experience low self-esteem, depressive symptoms and high anxiety (Missiuna et al., 2014; Zwicker et al., 2013). Children with DCD typically do not outgrow the disorder; it is thus considered a chronic condition with life-long implications that can, however, benefit from early diagnosis and rehabilitation intervention (Zwicker et al., 2012).

Intervention approaches for the management of DCD are either categorized as process-oriented or task-oriented (Zwicker et al., 2012). These approaches may address any activity limitations that children face because of their DCD, whether they have difficulty organizing their written work or tying their shoes. While process-oriented approaches (focused on reducing impairment and improving body function and structure) were initially more common, it has been shown that task-oriented or activity-oriented approaches yield better and faster functional performance outcomes in children with DCD (Smits-Engelsman et al., 2013). Evidence strongly supports the effectiveness of using cognitive approaches, such as the Cognitive Orientation to Daily Occupational Performance approach (CO-OP, a verbally-based cognitive strategy generation approach) or other activity-oriented approaches to facilitate skill acquisition, especially in children with DCD (Blank et al., 2012; Claire et al., 2005; Sugden, 2007). Other approaches used to intervene in children with DCD include sensorimotor, functional, skills training, perceptual-motor or environmental strategies (Mandich et al., 2001).

While its etiology remains idiopathic, it is presumed that a combination of genetic predisposition and neurological and environmental factors are at the origin of the disorder (Martin et al., 2010; Wilson et al., 2017). Neuroimaging studies have shown that there are differences in neural structure and function between children with DCD and typically developing peers, including reduced cortical thickness, hypoactivation of the functional networks and poorly organized neural networks involving sensorimotor structures (Caeyenberghs et al., 2016; Debrabant et al., 2013; Debrabant et al., 2016; Langevin et al., 2015; Pangelinan et al., 2013).

These neurological impairments align with a broader theory of atypical brain development in children with neurodevelopmental disabilities such as DCD (Dewey & Bernier, 2016). However, the mechanisms by which these neurological impairments contribute to motor difficulties remain unclear. Theories suggesting that difficulties with procedural learning, internal modeling or executive functions underlie motor impairments in children with DCD have been posited (Biotteau et al., 2020). Due to the heavy reliance of motor skills on vision in typically developing children, visual-perceptual difficulties have also been suggested as a potential underlying mechanism for DCD (Cheng et al., 2014; Elena et al., 2022; O'Brien et al., 2002; M. Prunty et al., 2016; Schoemaker et al., 2001; P. H. Wilson et al., 2013).

Visual-perceptual skills are a set of abilities that enable the perception of visual information about objects, events and spatial layout (Kellman & Arterberry, 2006). These comprise seven categories of skills: visual discrimination, visuo-spatial relations, form constancy, visual memory, sequential memory, figure-ground discrimination, and visual closure (Martin, 2017). These skills are crucial for numerous daily activities and collectively contribute to the ability to distinguish between similar letters, recognize patterns, perceive spatial relationships, and remember visual information (Feder & Majnemer, 2007). Visual information is processed through two distinct pathways: the ventral stream, responsible for object identification and memorization, and the dorsal stream, which analyzes movement and location (Alipour et al., 2021; Cheng et al., 2014; O'Brien et al., 2002; M. Prunty et al., 2016; Schoemaker et al., 2001; P. H. Wilson et al., 2013). It has been proposed that children with DCD may have impaired visual processing, and that the affected stream would lead to specific set of impairments in visual-perceptual skills (O'Brien et al., 2002; Van Waelvelde et al., 2004). While other senses, such as proprioception and kinesthesia, contribute to motor development in children with DCD (Schoemaker et al., 2001), visual input and its subsequent processing plays a central role for motor learning (P. H. Wilson et al., 2013).

DCD often co-occurs with other neurobehavioral and neurodevelopmental disorders, including autism spectrum disorder (Blank et al., 2019) and attention deficit hyperactivity disorder (ADHD), with the co-occurrence of the latter estimated at 50% (Kadesjö & Gillberg, 1998; Kaplan et al., 2006; Tseng et al., 2007; Watemberg et al., 2007). DCD also co-exists with language impairments in about 30% of the DCD population (Alloway & Archibald, 2008; Scabar et al., 2006; Wisdom et al., 2007). Moreover, children with DCD have a much higher risk of learning disabilities than typically developing children, with approximately 30% experiencing difficulties with reading (Tseng et al., 2007) and 40% with writing (Tseng et al., 2007). These high rates suggest that potential co-occurring diagnoses must be carefully taken into consideration when investigating academic performance in children with DCD.

1.3. Academic activities

Academic activities include activities of literacy (writing and reading), numeracy (mathematics), and all other activities specific to academics and cognition. Children with DCD experience difficulties performing these activities; however, most studies have focused on difficulties with activities of daily living and motor impairments, hence there is no consensus on the extent to which children with DCD have academic performance issues (Magalhaes et al., 2011).

1.3.1. Literacy

Handwriting difficulties are often reported in children with DCD, which is logical considering the motor requirements of handwriting (Huau et al., 2015; Magalhaes et al., 2011; Rosenblum & Livneh-Zirinski, 2008). Children with DCD have difficulty controlling their fine hand movements to create a fluid motor pattern for handwriting (Huau et al., 2015). They struggle with their handwriting size, speed, and spatial placement (Rosenblum & Livneh-Zirinski, 2008). In addition, children with DCD exhibit difficulties with the non-motor aspects of writing, which includes poor proofreading skills, as well as difficulty using punctuation, capitalization and adequate spelling, as they allocate most of their cognitive resources to the motor demands of handwriting (Dewey et al., 2002; Lingam et al., 2010). Consequently, the combination of demands from the motor (handwriting) and non-motor aspects of writing pose a dual-task challenge to children with DCD, limiting their learning potential in written tasks (Sidney, 1997).

Children with DCD often struggle with reading (Alloway & Archibald, 2008; Lingam et al., 2010), and can have both impaired reading comprehension and fluidity (Dewey et al., 2002). Combined with their handwriting difficulties, reading difficulties negatively impact performance in language-based courses, and in other courses that rely on reading for learning. For example, performance in courses such as history and sciences, where instruction and content are learned by reading and most often evaluated using handwriting, can be affected if the child has difficulties with reading and/or handwriting (Emaikwu Sunday, 2014). Most, if not all, academic activities involve some level of writing and reading; hence, DCD has important implications for academic performance.

1.3.2. Numeracy

Mathematics is an academic domain focused on the science of numbers, quantity and space. The different branches of mathematics are referred to as mathematical domains and include numeracy, algebra, geometry, measurements, data analysis, mental calculation, equations and problem-solving. Mathematical performance is characterized by an individual's ability to use mathematics to complete exercises, assessments, or tasks in everyday settings such as at school or home, while mathematical capacity refers to one's abilities in a controlled and standardized setting such as a research context.

While mathematics is generally viewed merely as a school subject rather than a competency, it has numerous applications and is essential for participating in many activities of daily living. Mathematics is used daily to manage money and time, drive, shop, work, cook, plan directions, organize and plan finances and take medications (Deloche et al., 1996). While most of these tasks do not require complex mathematical concepts, these all require a fundamental understanding of mathematics, usually acquired through academic activities at the elementary school level. Adults who do not grasp these basic concepts may have difficulties finding work and participating in society as productive adults. This can influence their socioeconomic status and many other facets of their lives, such as financial stability, health-related quality of life and socio-emotional stability (Cousins & Smyth, 2003; Patton et al., 1997). As such, competency in mathematics is needed to reach independence in everyday tasks across the lifespan. Additionally, early difficulties in mathematics typically persist over time, extending into adolescence and adulthood (Nelson & Powell, 2018). Therefore, it is evident that any difficulties in mathematics must be addressed early in the developmental course to adequately support children's academic and mathematical performance and minimize negative impacts in later life.

Currently, there are only a few studies that have evaluated mathematical capacity in children with DCD. Preliminary evidence suggests that children with DCD present more mathematical difficulties than their typically developing peers, especially in numeracy, mental computation and operations (Gomez et al., 2015; Stefanie Pieters et al., 2012; S. Pieters, A. Desoete, et al., 2012). Children with DCD are significantly slower and sometimes less accurate than typically developing children for numerical equations (Gomez et al., 2017; Pieters et al., 2015). However, the factors that determine mathematical capacity in children with DCD, and the extent of their role, remain unclear.

1.3.2.1. Factors affecting mathematical performance

Multiple preliminary skills support mathematical capacity. For instance, poor working and short-term memory can make it difficult to follow the steps of an algorithm and learn mathematics or to pay attention to mathematical instructions (Alloway & Temple, 2011; Swanson & Kim, 2007). For example, when adding 178 and 34, one must remember to hold the extra tenth when adding 8 and 4, to then add it to the 7 and 3, which leads to an extra hundredth. Poor sustained attention has been associated with poorer performance on measures of mathematics, especially in the context of problem-solving exercises with multiple steps (Preston et al., 2009). Difficulties with sustained attention, and short-term and working memory are possible indicators of attentional difficulties, sometimes diagnosed as ADHD when significantly impaired and meeting the diagnostic criteria. ADHD has been linked to slower mathematical capacity and overall poorer scores in problem-solving and numeracy (Zentall et al., 1994). Considering the high prevalence of attentional deficits in children with DCD (Blank et al., 2012), these may explain some aspects of the mathematical impairments that are observed in this population.

Another possible factor influencing mathematical capacity may be the severity of motor impairments. Children with poorer mathematical capacity have more difficulty completing tasks requiring fine motor coordination (Stefanie Pieters et al., 2012). In children with DCD, those with poorer motor performance experience more extensive mathematical difficulties (S. Pieters, A. Desoete, et al., 2012). Similarly, visuo-motor integration abilities are associated with mathematical capacity in typically developing children, especially in activities that require the use of a number line (Simms et al., 2016). Considering that visuo-motor integration is generally poorer in children with DCD than typically developing children, the severity of visuo-motor integration deficits may exacerbate difficulties in academic domains such as mathematics.

Good visual-perceptual skills in typically developing children have been positively associated with a variety of mathematical concepts including numeracy, geometry, algebra, and mental calculation (Carlson et al., 2013; Lowrie et al., 2017; Raghubar et al., 2015; Vukovic & Siegel, 2010). On the other hand, problem-solving is typically not affected by visual-perceptual skills (Vukovic & Siegel, 2010). Good visuo-motor integration and visual-perceptual skills have been associated with good performance in numeracy and overall mathematics compared to typically developing children (Al-Hroub, 2010). Specifically, spatial ability was identified as a strong predictor of mathematical capacity, especially in equations and number sense (Carlson et al., 2013; Richardson et al., 2014; Tracy, 1987). Studies testing the impact of visual-perceptual interventions on mathematical capacity in typically developing children have shown that visuospatial training can significantly improve mathematical capacity in geometry and numeracy

(Lowrie et al., 2017), as well as in calculations and missing-term problems (e.g., 4 + _ = 6) (Cheng & Mix, 2014). In these studies, visuospatial training consisted of visualization, mental rotation and spatial orientation exercises for the first study, and solely mental rotation in the second. Similarly, visual-spatial memory was strongly correlated with mathematical capacity (Alloway & Temple, 2011; Raghubar et al., 2015).

Difficulties in reading and writing can have a strong impact on academic and mathematical capacity. Indeed, to complete a mathematical task, it is necessary to read it, understand it, and write answers legibly (Emaikwu Sunday, 2014; Feder & Majnemer, 2007; Phonapichat et al., 2014). Thus, spelling and reading comprehension are highly correlated with mathematical capacity (Korhonen et al., 2012), more specifically problem-solving, even when controlling for basic calculation skills (Björn et al., 2016). As children with DCD often experience learning disabilities related to their reading and writing skills, these difficulties may negatively influence their mathematical capacity as well.

Since knowledge of the extent of mathematical difficulties in children with DCD is still limited, it is expected that there is minimal involvement from OTs for assessing and intervening in mathematics. Therefore, as a first step, it is essential to understand the scope, nature, frequency and contributing factors of mathematical difficulties in children with DCD. Understanding these will inform OT services, enabling effective support to overcome these challenges.

1.4. Role of Occupational Therapists

Occupational therapists (OTs) are health care professionals skilled in the assessment and treatment of children with DCD. Their expertise in activity analysis allows them to conduct standardized and qualitative assessments of motor skills to corroborate the first diagnostic criterion for DCD in the DSM-V, which is the need to determine whether motor skills are below age expectations. Additionally, OTs play a role in evaluating the impact of motor skills difficulties on activities of daily living, academic or school productivity, leisure and play, fulfilling the second diagnostic criterion for DCD. Finally, they can determine the third DCD DSM-V criterion regarding the early onset of the symptoms, enabling the child's diagnostician (usually a pediatrician, or neuropsychologist or psychologist in some jurisdictions) to either confirm the DCD diagnosis or conduct additional investigations. Through these valuable contributions, it is evident that OTs play a pivotal role in the diagnostic process for DCD.

Following the assessment process, OTs are typically involved in the intervention process for children with DCD to alleviate their difficulties and minimize impacts on daily life. Generally, OTs tend to target daily living self-care tasks (90% of OTs in a British Columbia survey), play (75%) and developmental milestones (55%), while only two percent aim at optimizing prewriting/printing development when working with children with DCD (Withers et al., 2017). This suggests a proportionally lesser focus on academic activities than other activities, possibly as academic activities concurrently fall under the mandate of other educational and health professionals, such as speech-language pathologists, special educators or neuropsychologists. However, possible barriers to OT implication in academic activities in children with DCD include systemic, awareness and knowledge or even resource issues. As children with DCD often manifest an array of difficulties with academic activities or activities of daily living, OTs could in some cases address these domains in their interventions to align with their holistic approach, meaning that they would not solely focus on body impairments and motor-based activity limitations, but also on academic challenges.

Mathematical difficulties are typically first noticed by school educators during elementary school. Once potential mathematical difficulties are identified, neuropsychologists are often mandated to assess the mental and cognitive processes affecting learning in these children. However, in the case of academic difficulties associated with a medical diagnosis such as DCD, it is essential to consider the possible impacts of all disorder-related symptoms when trying to alleviate these difficulties. Therefore, the involvement of OTs with children facing a medical diagnosis with learning implications is fundamental to properly understand and address their difficulties comprehensively. In fact, the *Ordre des ergothérapeutes du Québec* (OEQ) has recently highlighted the need to better coordinate the medical and educational systems to facilitate children's learning experiences, especially in cases where a diagnosis such as DCD has health and learning implications (*Mémoire présenté dans le cadre de la consultation publique du ministre de l'Éducation, du Loisir et du Sport sur la réussite éducative*, 2016). The recommendations from the European Academy for Childhood Disability concur, stating that participation in daily activities, independent of their setting (i.e., at home or school) should be addressed as part of the intervention process (Blank et al., 2019). Nevertheless, prior to any intervention approach, a clear understanding of the mechanisms of impairments is critical so that the appropriate performance skill or activity is targeted. As such, it is essential that OTs be knowledgeable about the possibility, nature, extent and factors of academic difficulties faced by children with DCD.

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Chapter 2. Objectives

2.1. Thesis objectives

2.1.1. Overarching objective

The overarching aim of this thesis is to support the recognition of the mathematical difficulties of children with DCD and to explore OT practices related to academic activities for this population within Canada. This work aims to guide future research and clinical practice toward improving performance and participation of children with DCD in academic activities.

2.1.2. Specific objectives

The specific objectives of this doctoral thesis are:

Study 1: (i) to systematically review the current literature to determine the extent to which school-aged children with DCD face challenges in academic activities compared to their typically developing peers.

Study 2: (i) to describe the frequency and nature of mathematical difficulties of school-aged children with DCD and (ii) to evaluate the extent to which body functions and structures involved in the symptomatology of DCD are associated with mathematical capacity in school-aged children with DCD.

Study 3: (i) to determine the nature and extent of Canadian OTs' assessment and intervention practices as related to academic activities in school-aged children with DCD and (ii) to identify associations between participant or service characteristics and OT practices.

2.2. Hypotheses

The specific hypotheses of this doctoral thesis are:

Study 1: (i) children with DCD experience frequent mathematical difficulties compared to their peers, and (ii) mathematical capacity has received less attention in the scientific literature than handwriting outcomes in children with DCD.

Study 2: (i) children with DCD commonly experience challenges in mathematics, most notably with basic concepts such as geometry, algebra and numeration; and that (ii) poor visual-perceptual skills are associated with poorer mathematical capacity.

Study 3: (i) OTs assess and intervene on mathematics to a lesser extent than handwriting in children with DCD, and (ii) these practices vary across Canada.

2.3. Thesis structure

The thesis is manuscript-based and structured as a comprehensive investigation into the mathematical challenges faced by children with Developmental Coordination Disorder (DCD), the factors influencing their performance and practical implications for Occupational Therapists. It consists of three manuscripts, and due to the format of the thesis, there is inevitable redundancy between the manuscripts, and with the introduction and discussion sections of the thesis. Nevertheless, the thesis presents the research cycle undertaken to tackle the topic of academic difficulties in children with DCD. The first study is a systematic review that synthesizes existing academic challenges prevalent among children with DCD. This serves as a foundation for subsequent studies. Secondly, a cross-sectional study was conducted on the mathematical capacity of children with DCD and its factors. In the third study, the practices of Occupational

Therapists regarding academic difficulties in children with DCD were surveyed to identify current approaches and future clinical avenues. Altogether, these three studies contribute to a comprehensive understanding of the academic difficulties faced by children with DCD, specifically with regards to mathematics, while also exploring the role of OTs in assessing and intervening on these challenges.

Table 2.1 List of studies and manuscripts

	Manuscript	Chapter	Reference	Status
Study 1	#1	3	Dionne, E., Bolduc, M.-È., Majnemer, A., Beauchamp, M. H., & Brossard-Racine, M. (2022). Academic Challenges in Developmental Coordination Disorder: A Systematic Review and Meta-Analysis. *Physical & Occupational Therapy in Pediatrics*, 1-24. doi:10.1080/01942638.2022.2073801	Published in 2022
Study 2	#2	4	Dionne, E., Majnemer, A., Beauchamp, M. H., & Brossard-Racine, M. (2024). Factors associated with mathematical capacity in children with Developmental Coordination Disorder. Research in Developmental Disabilities, 147, 104710. doi:https://doi.org/10.1016/j.ridd.2024.104710	Published in 2024
Study 3	#3	5	Dionne, E., Majnemer, A., Beauchamp, M. H., & Brossard-Racine, M. (Submitted 2024). Occupational therapy for children with DCD and academic difficulties: A pan-Canadian survey. Canadian Journal of Occupational Therapy.	Submitted for peer-review in 2024

Chapter 3. Manuscript 1, Academic challenges in Developmental Coordination Disorder: A systematic review and meta-analysis

3.1. Preface

While handwriting difficulties in children with DCD have received significant attention due to their motor-based nature, other academic activities have not received much attention in this population. Prior to this study, no consensus had been established regarding the full spectrum of academic difficulties in children with DCD. This project was developed through a comprehensive review of the literature on all academic activities to gain a more thorough understanding of the academic obstacles encountered by children with DCD. Understanding the academic difficulties faced by children with DCD holds significance for educators, healthcare professionals, the children themselves, their families, and policymakers. This review provides healthcare practitioners with evidence-based insights that can guide intervention approaches to support academic success in children with DCD.

Chapter 3 presents the first manuscript of this thesis, a systematic review of the literature on academic challenges in children with DCD. The findings indicate that children with DCD perform significantly worse than their typically developing peers across academic activities, and that mathematical difficulties are as frequent as handwriting difficulties. This chapter concludes the literature review component of this doctoral thesis.

This is the accepted manuscript (April 2022) published in the Journal of *Physical & Occupational Therapy in Pediatrics.*

Dionne, E., Bolduc, M.-È., Majnemer, A., Beauchamp, M. H., & Brossard-Racine, M. (2022). Academic Challenges in Developmental Coordination Disorder: A Systematic Review and Meta-Analysis. *Physical & Occupational Therapy in Pediatrics*, 1-24. doi:10.1080/01942638.2022.2073801

Journal impact factor: 2.1. This journal has a 24% acceptance rate.

Academic challenges in Developmental Coordination Disorder: A systematic review and meta-analysis

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3.2. Abstract

Introduction. Developmental Coordination Disorder (DCD) is a chronic condition affecting motor coordination in daily life activities such as tying their shoes and riding a bike. While motor difficulties are well documented in this population, it is unclear how frequent and to what extent academic activities are affected. **Objective.** The objective of this review is to comprehensively summarize the knowledge regarding the prevalence and extent of academic difficulties in reading, writing and mathematics in school-aged children with DCD. **Methods.** Two independent reviewers analysed original studies on academic difficulties in school-aged children with DCD. A binary random-effects model was used to calculate the pooled prevalence by academic difficulty. A random-effects model using standardized mean differences (g statistic) was calculated to estimate the extent of the academic difficulties. **Results.** Twenty-four studies were included. A pooled prevalence of 84% of handwriting difficulties and 89.5% of mathematical difficulties was found. Children with DCD present with poorer performance in handwriting legibility (g=-1.312) and speed (g=-0.931), writing (g=-0.859), mathematics (g=-1.199) and reading (g=-1.193). **Conclusion.** This review highlights the high frequency and severity of academic difficulties in children with DCD, specifically in mathematics, which stresses the importance of evaluating academic performance to orient targeted interventions to support optimal functioning at school and home.

Keywords: Developmental Coordination Disorder, academic performance, mathematics, handwriting, school-aged.

3.3. Introduction

Developmental coordination disorder (DCD) is a chronic neurodevelopmental condition that affects children's motor skills and coordination, negatively impacting their performance in activities of daily living. Typically, DCD symptomatology includes difficulties with balance, visual-motor integration (VMI), body awareness, visual perception, agility, and coordination (Blank et al., 2019). Therefore, children with DCD may seem clumsy or inattentive, as they often trip, drop objects and have difficulties with everyday tasks such as handwriting, tying their shoes or using scissors (American Psychiatric Association, 2013).

DCD is evident in five to six percent of the school-aged population worldwide (Blank et al., 2019). It often appears as a co-morbidity with other learning and neurodevelopmental disorders. Co-occurrence of DCD and attention deficit hyperactivity disorder (ADHD) is estimated at 50% (Kadesjö & Gillberg, 1998; Kaplan et al., 2006; Tseng et al., 2007; Visser, 2003; Watemberg et al., 2007). About 30% of children with DCD also present with specific language impairment and other language deficits (Alloway & Archibald, 2008; Scabar et al., 2006; Wisdom et al., 2007) and approximately 30% of children with DCD experience reading difficulties such as dyslexia (Kaplan et al., 2006; Tseng et al., 2007). Together, these studies suggest that learning difficulties are a frequent co-morbid occurrence and implies that children with DCD may present with specific challenges conducting academic activities.

By the age of four or five years, most children spend a significant amount of their time at school performing a range of academic activities. Academic activities refer to the scholarly competencies that children usually acquire in school, including writing, reading, mathematics, and all other activities specific to academics and cognition such as memorizing, paying attention, and organizing. Evidence suggests that children with DCD frequently struggle with handwriting, and present with poorer legibility and/or speed (Rosenblum & Livneh-Zirinski, 2008; Rosenblum et al., 2013). Difficulties in mathematics (Gomez et al., 2015; S. Pieters, A. Desoete, et al., 2012) and reading (Ho et al., 2005) have also been documented in children with DCD. Although there seems to be increasing interest in the academic performance of children with DCD, the frequency and extent of academic difficulties remains unclear. Therefore, the objective of this systematic review is to comprehensively summarize the current state of knowledge regarding the prevalence and extent of academic difficulties in school-aged children with DCD. Providing a better understanding of the academic difficulties in children with DCD will allow clinicians to more specifically target interventions to support children's optimal functioning at school and at home.

3.4. Materials and methods

3.4.1. Study selection

The following databases were searched for relevant articles: CINAHL and ERIC via EBSCOHost, and Embase, MEDLINE and PsychINFO via Ovid. The search was restricted to English and French articles, and to articles between 1980 and July 26th, 2021, from which the DCD condition, then known as "clumsy child syndrome" first appeared in the DSM-III (American Psychiatric Association & Work Group to Revise, 1987). The search strategy was developed with the support of a librarian using medical subject headings (MESH), subject headings and keywords pertaining to academic performance in children with DCD. The full search strategy is available in Supplementary table 7.2

After removing duplicate articles, two independent reviewers independently screened titles and abstracts. All articles selected during the first screen by at least one reviewer were included in the second screening process, which involved a full text review. The two reviewers thereafter independently conducted the data extraction and the quality assessment of each of the selected studies using the Joanna Briggs Institute Checklist for Prevalence Studies (Munn et al., 2015). For each included article, data on its location, design, blinding procedures, recruitment methods, sample size, statistical testing, sample characteristics (age, comorbid diagnoses, sex), assessment tools and outcome results, were extracted. Disagreements between the two reviewers were resolved by discussion until a consensus was reached. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Moher et al., 2010) was used to ensure the quality of the review.

Articles were included if they respected the following criteria: 1) publication had empirical data; 2) majority of study participants were children with DCD; 2) the DCD diagnosis followed the DSM-V criteria and was established using results of a standardized assessment of motor skills; 3) sample mean age (± one standard deviation [SD]) fell within six to 12 years and 11 months of age; and 4) at least one outcome reported included the prevalence or extent of difficulties in an academic domain (e.g., writing, spelling, reading and mathematics). Articles were excluded if: 1) not a peer-reviewed publication, a conference abstract, a thesis or a qualitative or case study; 2) ≥25% of the sample was born preterm (i.e., <37 weeks gestational age), as prematurity is highly correlated with learning difficulties (Cherkes-Julkowski, 1998); 3) participants were recruited based on the presence of academic difficulties, biasing the sample or 4) if outcomes were assessed only using child self-report measures or did not objectively evaluate academic performance. If results from a sample were reported in more than one publication, only the one with the largest sample size using academic outcome measures was included in the analysis. When the outcome data was not directly available in the article, corresponding authors were contacted. If they did not respond after two attempts at communication, the study was excluded. Two thousand and four articles were identified through the literature search. Once the duplicates were removed, 1,303 articles were first screened, at which point 1,003 were excluded because they did not meet inclusion criteria. Three hundred articles underwent full text reading, and 24 studies were kept in this systematic review. The flow chart of the study selection process is presented in Figure 3.1.

3.4.2. Data analysis

To better appreciate the results, we grouped the data by outcome categories. Descriptive statistics were used to characterize the studies. When two or more studies presented frequency of difficulties, a binary random-effects model was used to retrieve the pooled prevalence of difficulties for this specific academic outcome.

To pool the extent of difficulties by academic domain, and if at least two studies provided performance results for both a DCD and a control group by outcome, standardized mean differences between the two groups were calculated using a random-effects model with maximum likelihood, and reported as Hedge's g statistic. In the absence of a control group, and where possible, normative data was used to calculate mean and SD. If the results were presented as a median and interquartile range, Wang's method was used to estimate the mean and standard deviation (Wan et al., 2014). When one study reported multiple assessment results for the same outcome, results were pooled together to provide a single data point per study. When results could not be pooled together, the most comprehensive outcome was used. Hedge's g statistic was characterized as small (0.2-0.5), moderate (0.5-0.8) or large (>0.8), according to Cohen's convention (Cohen, 1992). A negative standardized mean difference estimate indicates that the DCD group scored below the performance of controls. Between-study heterogeneity was assessed using the I^2 statistic. When the I^2 point index was larger than 50%, leave-one-out post-hoc analyses were used to eliminate potential source of heterogeneity, and subgroup analyses were employed to examine potential covariates. Outcomes that could not be included in the meta-analysis were presented descriptively.

3.5. Results

3.5.1. Study characteristics

Twenty-four studies reported at least one academic outcome in children with DCD. Together this summed up to a total sample of 920 children with DCD and 593 controls, with average ages ranging from 7.8 to 10.9 years. Sixteen (67%) studies included a control group, four (17%) used tests with normative data in typically developing (TD) children and four (17%) did not use normative tests and therefore only provided DCD data. Eight studies were from the United Kingdom (33%), four from France (17%), two from Belgium (8%), two from Israel (8%), two from Taiwan (8%), one from each (4%) of the following countries: Australia, Canada, China, Netherlands, Tunisia and the United States of America. Most studies (n=20, 83%) used a cross-sectional design, two (8%) were randomized control trials, one (4%) used a non-experimental between group design (4%), and one (4%) was a non-randomized trial (4%).

3.5.2. Quality Assessment of studies

Quality assessment of the reviewed studies identified potential biases that are presented in Supplementary Table 7.3. Overall, minimal statistical or measurement bias was identified among the studies. However, possible sampling and participant selection biases were identified in at least 63% (n=15/24) of the studies. Indeed, sampling frame was deemed unclear in 38% (n=9/24) of the studies, and 54% (n=13/24) of the studies did not clarify how participants were recruited. Finally, potential selection bias could be present in as many as 71% (n=17/24) of the studies, as these did not describe the participants and setting in detail. Studies with two possible types of bias by category were deemed of average quality (33%, n=8), while those with three or more were identified as poor quality (8%, n=2).

3.5.3. Academic performance

Upon data extraction, outcomes were grouped according to the four following academic categories: handwriting, writing, reading and mathematics. Handwriting outcomes were those related to the legibility of the child's written production or the speed of handwriting movement, while outcomes related to language features or content of writing such as punctuation, vocabulary, sentence structure, grammar, and spelling were grouped under the writing domain. Overall, 12 studies had at least one handwriting outcome, 10 studies a writing outcome, 8 a mathematics outcome and 6 a reading outcome.

3.5.3.1. Handwriting

The 12 studies that analyzed handwriting are summarized in Table 3.1.

Prevalence. Six studies (Dunford et al., 2005; Flapper et al., 2006; Lopez et al., 2018; Missiuna et al., 2008; Prunty et al., 2013; Vaivre-Douret et al., 2011) presented the frequency of handwriting difficulties. Among these, handwriting difficulties ranged from 55 to 95%. Together, these studies grouped a sample of 271 children with DCD for which the estimated pooled prevalence of handwriting difficulties was 84.5% (CI = 72.66 – 91.79%). Three studies quantified the severity of the difficulties and reported that 15-25% of children with DCD had dysgraphic handwriting (Flapper et al., 2006; Lopez et al., 2018; Vaivre-Douret et al., 2011).

Extent of handwriting legibility difficulties. Seven studies (Cacola et al., 2018; Cox et al., 2015; Farhat et al., 2016; Flapper et al., 2006; Prunty & Barnett, 2020; Rosenblum & Livneh-Zirinski, 2008; Rosenblum et al., 2013) described extent of legibility difficulty compared to a control group, which gathered a total sample of 143 children with DCD and 125 TD children. Figure 3.2A represents the studies' individual standardized mean differences between children with DCD and controls, as well as the meta-analytic results which estimated a large difference between controls and children with DCD ($g=-1.312$, $p < .001$), meaning that children with DCD have significantly less legible handwriting than their peers. The heterogeneity point index for this outcome was low ($I^2=45.07\%$, $p = .036$).

Extent of handwriting speed difficulty: Handwriting speed was assessed in 7 studies (Cacola et al., 2018; Cox et al., 2015; Farhat et al., 2016; Flapper et al., 2006; Prunty et al., 2013; Rosenblum & Livneh-Zirinski, 2008; Rosenblum et al., 2013) whether by timing the child when writing at their typical speed or when computing the number of characters written during a determined period. All 7 studies reported lower speed in children with DCD compared to controls, but the difference did not reach significance in three studies (Cacola et al., 2018; Cox et al., 2015; Flapper et al., 2006). These 7 studies were be included in a meta-analysis with a total sample of 143 children with DCD and 125 TD children. Figure 3.2B represents the studies' individual standardized mean differences between children with DCD and controls, as well as the meta-analytic results, which indicate a large difference between both groups ($g=-0.931$, $p < .001$), suggesting that children with DCD are slower than their peers. The heterogeneity point index suggests moderate variability between the studies ($I^2=58.91\%$, $p < .010$). Leave-one-out analysis was performed and removed the study with the highest SDs (Cox et al., 2015). When removing this study, the heterogeneity point index was then minimal and insignificant ($I^2=0\%$, $p=0.217$). The meta-analysis then showed even larger difference between children with DCD and controls, ($g=-1.148$, $p < .001$), suggesting that children with DCD are significantly slower than their peers when writing (Figure 3.2C).

3.5.3.2. Writing performance

The 10 studies that assessed the non-motor writing performance of children with DCD compared to norms, which included vocabulary, grammar, spelling, dictation, sentence structure, text organization and other non-motor features of the written work, excluding handwriting, are summarized in Table 3.1.

Prevalence of writing difficulties: Only one study (Tseng et al., 2007) reported rate of writing difficulties tested with the Basic Reading and Writing Test Battery (Hund et al., 2003). They reported an incidence of 40% writing difficulty in children with DCD compared to 35.9% in TD peers, which was not significantly different.

Extent of writing difficulties: All 10 studies reporting writing outcomes found lower mean scores for children with DCD than a control group and were included in a meta-analysis with a total sample of 436 children with DCD and 359 TD children. Figure 3.3A presents the studies' individual standardized mean differences between children with DCD and controls, and the meta-analytic results. A large difference was found between the two groups ($g=-0.859$, $p < 0.001$), indicating that children with DCD have significant writing difficulties when compared to TD peers. The heterogeneity point index was minimal and insignificant ($I^2=19.46\%$, $p = 0.084$).

Spelling difficulty subgroup analysis: Seven studies from the writing domain presented outcomes specific to spelling and were pooled to quantify the spelling difficulties. Since two studies reported outcome of spelling and writing in the same sample (Prunty et al., 2013; M. M. Prunty et al., 2016), the writing results were used in the meta-analysis of writing difficulties, and the spelling results in the meta-analysis of spelling difficulties. Figure 3.3B shows that a large difference was found between children with DCD and controls in spelling ($g=-0.924$, $p < .001$), suggesting that children with DCD have significant spelling challenges. The heterogeneity point index was moderate and significant ($I^2=41.60\%$, $p=0.032$), suggesting that these results must be interpreted with caution.

3.5.3.3. Mathematical performance

The eight studies that reported mathematics outcomes are summarized in Table 3.1. Mathematics is an academic domain focused on the science of numbers, quantity, and space. The different branches of mathematics are referred to as mathematical concepts and examples include geometry, numeracy, and equations.

Prevalence: Only two studies reported the frequency of difficulties in mathematics and both used the same mathematical outcome measure (i.e., the *Kortrijk Arithmetic Test Revision (Baudonck et al., 2006)*). Together, these studies grouped a sample of 86 children with DCD, for which an estimated pooled prevalence of mathematical difficulties of 89.5% (CI = 81.09 – 94.46) was found (S. Pieters, A. Desoete, et al., 2012; Vaivre-Douret et al., 2011). Additionally, it was found that severity of the motor performance impairments was positively correlated with presence of mathematical difficulties (S. Pieters, A. Desoete, et al., 2012).

Extent of mathematical difficulties: Seven studies described the extent of difficulties in mathematical performance, with two reporting on the same sample (Gomez et al., 2015; Gomez et al., 2017). Therefore, we conducted a meta-analysis with six studies and included a total of 252 children with DCD and 247 TD children. Figure 3.4A represents the studies' individual standardized mean differences between children with DCD and controls, as well as the meta-analytic results which indicate a large difference between the groups ($g=-1.269$, $p<.001$), with children with DCD having more extensive difficulties in mathematics than their peers. The heterogeneity point index was elevated ($I^2=65.96\%$, $p<.001$), which prompted a post-hoc analysis. We identified two subgroups of studies based on the outcome measure, one with studies assessing mathematics comprehensively using the *Wechsler Objective Numerical Dimensions (WOND)* and the *Kortrijk Arithmetic Test Revision*, and the other focused on the assessment of arithmetic and equations. Analysis based on this subgroup division showed that in both groups, mathematical performance of children with DCD was largely below that of controls ($g=-1.317$, $I^2=69.44\%$) for subgroup of mathematics, and $g=-1.235$, $I^2 72.91\%$, for the arithmetic subgroup) (Figure 3.4B).

3.5.3.4. Reading performance

Reading refers to all aspects of reading and understanding of a written text, aloud or to oneself. The six studies that examined reading performance in children with DCD are summarized in Table 3.1.

Prevalence: Only one study formally assessed the presence of reading difficulties and found that 27% of children with DCD had reading problems as compared to 21.8% in TD peers, which did not reach statistical difference ($p=.16$) (Tseng et al., 2007).

Extent of reading difficulties: Six studies described the extent of reading difficulties and were pooled in a meta-analysis with a total of 371 children with DCD and 268 TD children. Figure 3.5A represents the standardized mean differences for each study between children with DCD and controls, and the meta-analytic results which showed a large difference ($g=-1.193$, $p<.001$), as children with DCD had poorer reading results than control children. In response to a high heterogeneity point index ($I^2=94.25\%$, $p<.001$), further analysis revealed that results from Tseng et al. (2007), who found 4 SD difference between groups, were responsible for a portion of the heterogeneity and were therefore deemed unsuitable for the meta-analysis. Excluding Tseng et al. (2007) brought the standardized mean difference to $g=-0.812$ ($p<.001$), although heterogeneity remained high ($I^2=58.83\%$, $p=0.017$) (Figure 3.5B). Additional post-hoc analyses did not minimize heterogeneity.

3.6. Discussion

The results of this systematic review and meta-analysis highlight the high prevalence and wide spectrum of academic difficulties in school-aged children with DCD. Handwriting difficulties were the most studied outcome and were the primary outcome of interest in half of the reviewed articles, suggesting that the impacts of DCD on the motor components of writing are well recognized. A pooled prevalence of 84.5% for handwriting difficulties was calculated in children with DCD, which is not surprising considering that handwriting difficulty is a direct consequence of motor impairments and a listed symptom for DCD in the DSM-V (American Psychiatric Association, 2013). In the reviewed studies, legibility of letters, words and numerals were often affected (Cacola et al., 2018; Cox et al., 2015; Rosenblum et al., 2013), and was a consequence of poor letter formation, stroke and letter reversals and problems with spatial arrangement (Rosenblum & Livneh-Zirinski, 2008; Rosenblum et al., 2013). Handwriting speed was significantly slower for children with DCD compared to controls when timed during an alphabet writing task or while copying letters for one minute (Cacola et al., 2018; Cox et al., 2015; Prunty & Barnett, 2017). Not having enough time to write, erasing frequently, or looking up at the board frequently to copy words were the most commonly reported factors affecting the handwriting speed of children with DCD (Rosenblum et al., 2013). The recognition of these difficulties is already current practice for pediatric rehabilitation specialists and recent studies showed that handwriting is an important area addressed by pediatric occupational therapists (OT) who work with children with DCD (Smits-Engelsman et al., 2013; Withers et al., 2017). In this respect, the OT’s focus should be on both legibility and speed aspects of handwriting.

Ten studies (42%) primarily evaluated writing and six studies (25%) focused on reading. Only one study reported the frequency of difficulties for these two outcomes and found that 40% of children with DCD experience writing difficulties and 27% had reading difficulties (Tseng et al., 2007). Considering that writing and reading difficulties are often associated with speech disorders (Hayiou-Thomas et al., 2017; Lenoble, 2010) and that approximately 30% of children with DCD experience either a language or learning disability (Kaplan et al., 2006; Linda et al., 2001; Scabar et al., 2006; Wisdom et al., 2007), it is possible that the rate of reading and writing difficulties may in part be a reflection of both of these comorbid difficulties.

Among the reviewed studies, spelling mistakes were the most commonly reported error associated with writing difficulties (n=7/10, 70%), though text organization, vocabulary, sentence structure, grammar, as well as capitalisation and punctuation, were also reported as important barriers to writing performance (M. Prunty et al., 2016). With respect to reading, both reading fluency and comprehension were significantly lower in children with DCD than controls. Furthermore, despite fewer children having writing or reading than handwriting or mathematical difficulties, the performance of children with DCD was nonetheless 0.9 SD below the mean of the controls for writing, and 1.2 SD below the mean for reading, meaning that their performance in both domains is slightly lower than that of their peers. However, the high heterogeneity index indicates possible cofounders in the relationship between DCD and performance in writing and reading, suggesting that more studies are needed to explore the relation between language difficulties and these academic difficulties in children with DCD.

Although ten studies specifically evaluated the non-motor aspects of writing, most of these used evaluations that relied on a written task (i.e., handwriting), and could have been confounded by the motor aspects of the task (Seo, 2018). Writing is a complex activity that requires the execution of precise fine motor movements while being attentive to grammar, spelling and punctuation. Such an elaborate task involves significant cognitive resources, and may be particularly difficult for individuals who have fine motor difficulties and less cognitive and attentional reserve to allot to the non-motor aspect of that same task (Tseng & Cermak, 1993). Future studies assessing both writing and handwriting performance together and separately in children with DCD (i.e., using a computer or copying tasks) are needed to disentangle these complex relationships. In contrast, in the reviewed studies evaluating the extent of mathematical difficulties, none relied solely on handwritten answers. Therefore, these mathematical difficulties, cannot be explained by presence of concomitant handwriting difficulties.

Mathematics was evaluated in a third of the studies included in the review (n=8/24), and seven of these reported the extent of the mathematical difficulties. The calculated pooled prevalence of 89.5% for mathematical difficulties suggests that these challenges are at least as prevalent as handwriting difficulties. Such numbers strongly demonstrate that mathematical difficulties should be at least as recognized as handwriting difficulties, and accordingly so acknowledged by being an indispensable part of the assessment and intervention services provided to children with DCD. Nevertheless, this prevalence must be interpreted with caution considering its limited generalizability to the whole population of children with DCD, as it relies only on two studies.

Children with DCD experience difficulties in mathematics as they perform 1.3 SD below their TD peers. However, DCD is not the only neurodevelopmental diagnosis associated with mathematical difficulties. Such difficulties are inherent to dyscalculia, but they are also found in diagnoses of other learning disabilities (i.e., dyslexia and dysorthographia) and speech disorders

(Nathan et al., 2004), for which performance in mathematics has been shown to be problematic when compared to TD peers (Morgan et al., 2011). Studies of children with ADHD have also found a negative association between attentional symptoms and mathematical performance (Greven et al., 2014; Maria Grazia et al., 2015), while children with autism spectrum disorder experience difficulties in specific areas of mathematical performance, such as procedural calculations and time-related competencies (Titeca et al., 2015). Since mathematical difficulties are also present in a myriad of neurodevelopmental conditions (DuPaul et al., 2006; Mohammadi et al., 2009; Xin et al., 2017; Yakubova et al., 2015), it is not surprising that mathematical difficulties are also frequent and severe in children with a DCD diagnosis and should likewise receive specific intervention from rehabilitation and education specialists to overcome these challenges.

Children with DCD frequently experience visuo-spatial difficulties, and these have been proposed to underly their difficulties with motor planning and organization in space (Mon-Williams et al., 1999; Tosto et al., 2014). Visuo-spatial skills have been found to correlate strongly with mathematical performance in TD children (Carlson et al., 2013; Lowrie et al., 2017; Vukovic & Siegel, 2010) due to their shared neural pathways (Hubbard et al., 2005). In fact, mathematical concepts almost always include a spatial aspect, particularly in geometry and arithmetic (Zhang & Lin, 2015). For instance, the position in space (left or right) allows differentiation between tenths and units in a two-digit number. The importance of visuo-spatial concepts in mathematics could in part explain the severe difficulties highlighted by our meta-analysis in this subgroup. Indeed, the DCD subgroup of mathematics, which includes some arithmetic tasks, performed 1.317 SD below the norm, as compared to 1.235 SD below the norm in studies using only an arithmetic assessment.

In addition to mathematical difficulties, visuo-spatial skills are positively associated with reading performance in TD children (Hopkins et al., 2019). Indeed, visuo-spatial skills are used in reading to process the spatial order of letters. For example, *care* and *race* are composed of the same letters in a different order and are not read the same nor do they have the same meaning. Spelling, likely because it relies on the order of letters, is also related to visuo-spatial skill competencies (Liu et al., 2016). Hence, the visuo-spatial difficulties observed in children with DCD may in part explain the presence of mathematical, handwriting legibility, reading and spelling difficulties, while motor impairments may also contribute to the presence of handwriting legibility and speed difficulties.

3.6.1. Clinical Implications

Current evidence suggests that both handwriting and mathematical difficulties are frequent in children with DCD, and therefore should be evaluated systematically when determining children's performance profiles. Considering that academic difficulties are associated with poor self-esteem, school failure, difficulties with socialization, anxiety, and depression (Missiuna et al., 2014; Zwicker et al., 2013), supporting academic success should be a priority with all children. Specialized educators play a key role in supporting and optimizing academic success in all children. However, for children with DCD, their academic difficulties could be closely related to the underlying mechanisms of their coordination difficulties and may benefit best from targeted intervention approaches that take into account their motor impairments. Further understanding of the factors of academic difficulties in children with DCD will enable rehabilitation specialists to work closely with educators to identify complementary therapeutic approaches that promote academic success. Academic difficulties can lead to an array of functional challenges such as cooking, organizing time, driving, and managing medications (Deloche et al., 1996), and OTs could provide targeted strategies and interventions to improve academic performance and functional issues in children with DCD.

3.6.2. Limitations

The results of this review need to be interpreted in the context of its limitations. First, this review focused on studies in children with a DCD diagnosis determined using a standardized assessment of motor performance and according to the DSM-V criteria**.** It is possible that we may have excluded a subset of studies in children likely to have DCD but that did not meet the strict DSM-IV criterion which could have limited the generalisability of our findings to the whole DCD population. However, rigorous methodology and inclusion criteria were deemed necessary to preserve the quality of the review. Further, studies that recruited participants based on their academic difficulties were also excluded from the review as they would have led to an over-representation of difficulties. Consequently, it is possible that the extent of the academic difficulties may have been underestimated. The studies included in this review did not report evaluating nor controlling for comorbid conditions, such as ADHD and learning disabilities, which are frequently observed in children with DCD. It is therefore possible that the academic difficulties reported in this review may have been exacerbated by the presence of these comorbid conditions. Nevertheless, this represents the reality of the heterogeneity of the clinical presentation of children with DCD in schools. Lastly, the results of this review cannot be generalized to older adolescents, as only elementary school-aged children were included.

3.7. Conclusion

Children with DCD have overall more academic difficulties than their TD peers, especially in mathematics and handwriting. Considering the high frequency of handwriting and mathematical difficulties, these two academic activities should be evaluated systematically when evaluating children's functional profile at diagnosis in order to identify children at risk and orient them towards appropriate interventions to optimize their success in academic activities. Our findings stress the need to conduct more research on academic difficulties in children with DCD to identify factors that affect performance and to guide rehabilitation and educational specialists in their interventions.

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3.9. Figures and tables

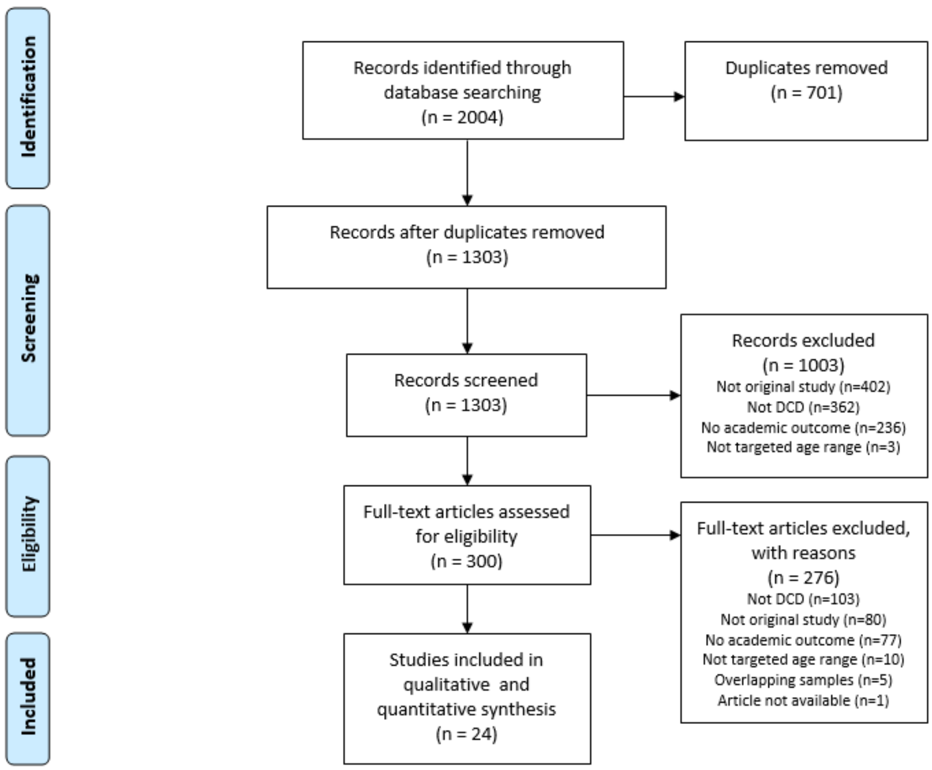

Figure 3.1. Prisma flow chart of the study selection process

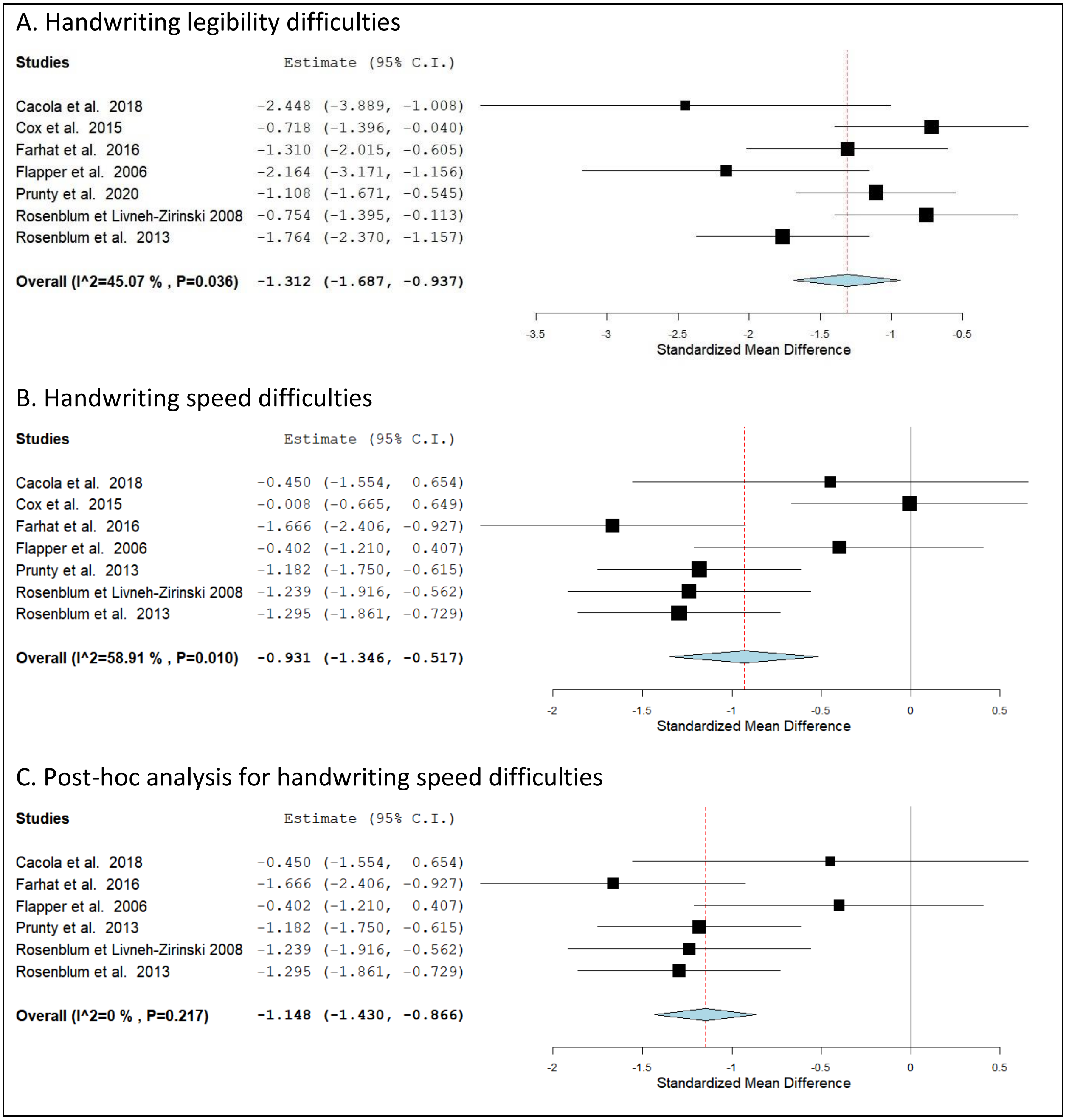

Figure 3.2. Forest plot of the standardized mean difference (estimate) of handwriting difficulties in legibility and speed in children with DCD compared to controls.

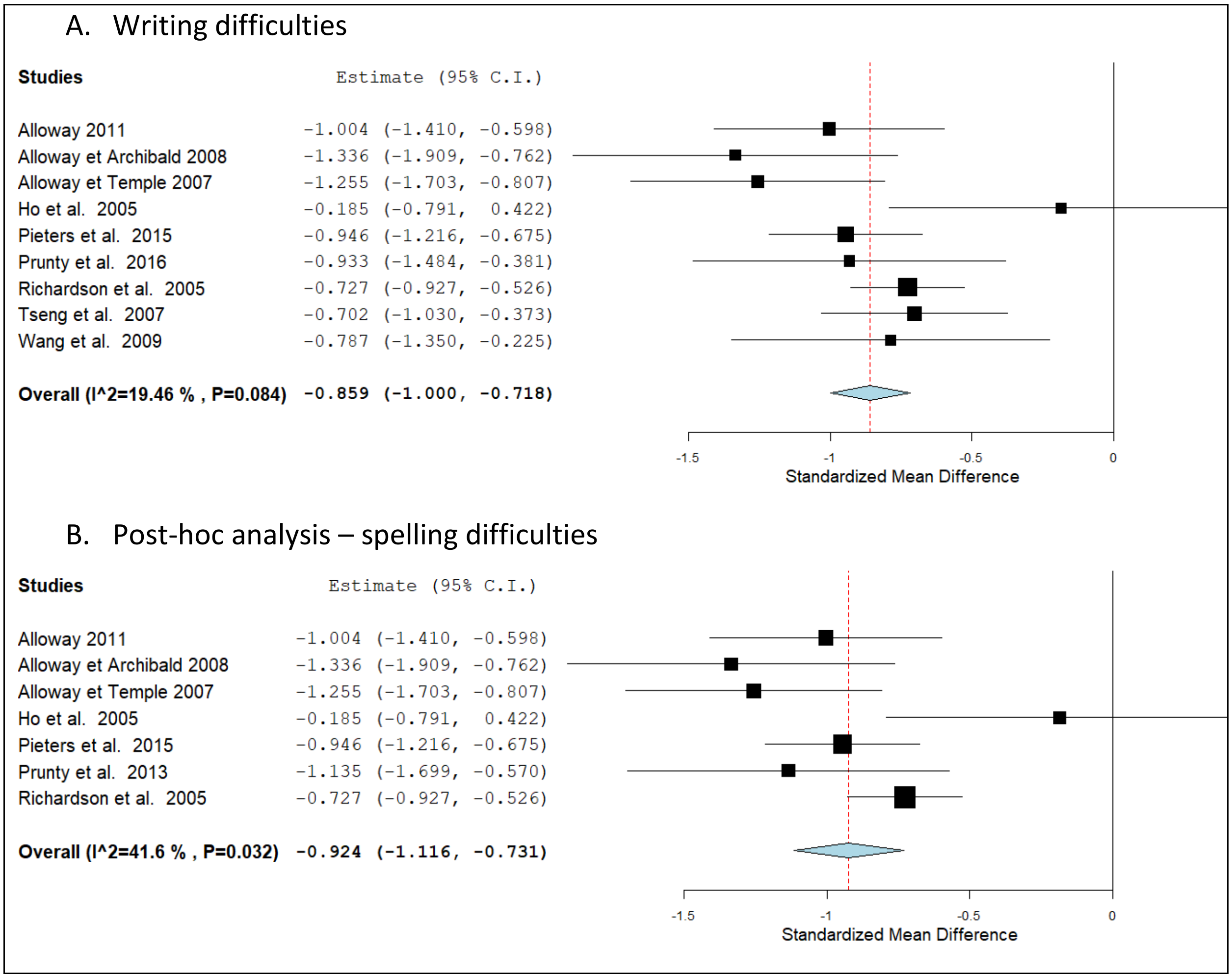

Figure 3.3. Forest plot of the standardized mean difference (estimate) of writing and spelling difficulties in children with DCD compared to controls.

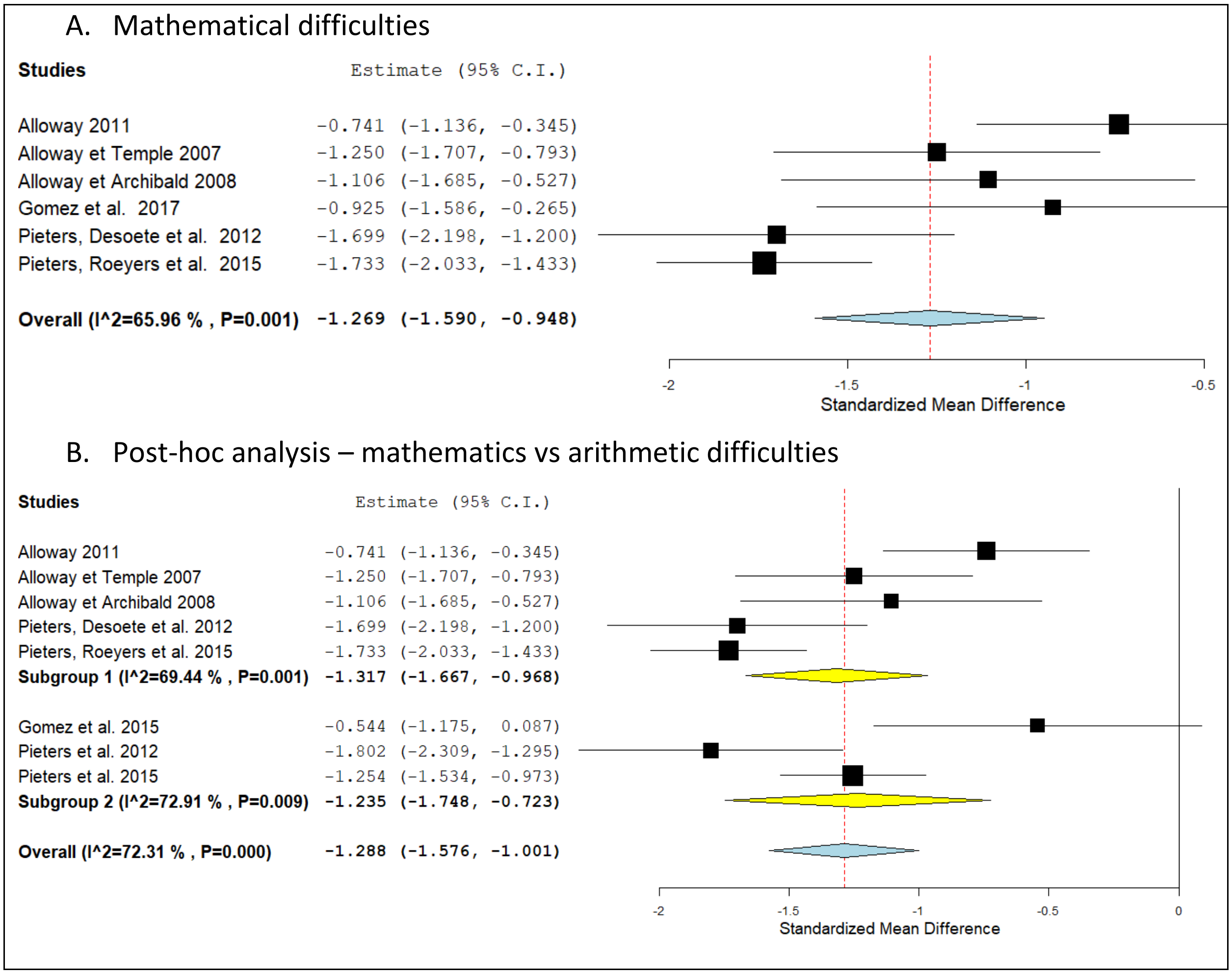

Figure 3.4. Forest plot of the standardized mean difference (estimate) of mathematical difficulties in children with DCD compared to controls.

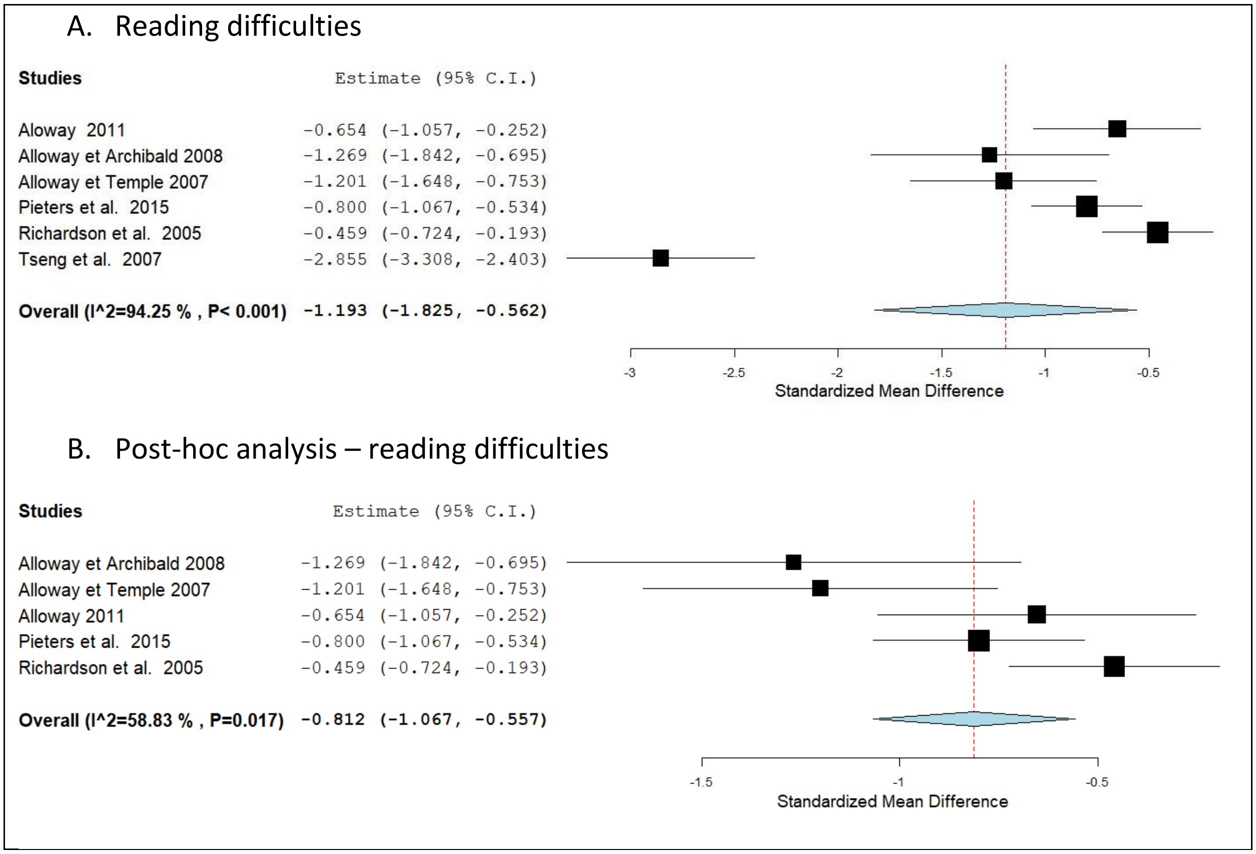

Figure 3.5. Forest plot of the standardized mean difference (estimate) of reading difficulties in children with DCD compared to controls.

Table 3.1. Characteristics and outcomes of studies assessing handwriting, writing, mathematical and reading difficulties in children with DCD

	Principal author	Year	Country	Design	Group: n (mean ± SD)	Comorbid dx	Sex (DCD/TD)	Outcome	Assessment tool	Main results
HANDWRITING	Cacola	2018	USA	C-S	DCD: 7 (8.46y ± 0.97y) TD: 6 (8.46y ± 0.97y)	NM	7B	HL	ETCH (Amundson, 1995)	DCD: 47.76±15.48 TD: 84.11±11.48
								HS		DCD :32.86±8.71 TD: 41.42±24.46
	Cox	2015	Australia	C-S	DCD: 20 (8.35y ± 1.63y) TD: 16 (8.69y ± 2.24y)	NM	15B, 5G 6B, 10G	HL	ETCH (Amundson, 1995)	DCD: 73.8±20.28 TD: 86.2±11.19
								HS		DCD: 36.1±20.81 TD: 36.25±14.48
	Dunford	2005	Britain	C-S	DCD: 35 (7y11m ± 1.68y)	No	29B, 6G	PH	Perceived Efficacy and Goal Setting System (Missiuna et al., 2004)	Trouble with pencil skills according to: child (15/35), parent (11/35), teacher (27/34), parent + child (1/35), child + teacher (3/35), teacher + parent (4/35), and teacher + parent + child (10/35)
	Farhat	2016	Tunisia	NRT	DCD: 27 (8.66y ± 0.85y) TD: 14 (8.6y ± 0.9y)	No	31B, 4G 21B, 7G	HL	Handwriting performance test (Ziviani & Watson-Will, 1998)	DCD: 3±0.7 TD: 4.2±1.2
								HS		DCD: 32.8±6.3 TD: 47.7±12.3
HANDWRITING	Flapper	2006	Netherlands	RCT	DCD: 12 (9y8m ± 1y7m) TD: 12 (9y7m ± 1y2m)	Yes, only ADHD	11B, 1G	PH	Concise Assessment Method for Children's Handwriting (Hamstra-Bletz et al., 1987)	9/12 children with DCD vs 3/12 TD children had dysgraphic handwriting
								HL		DCD: 40±9.17 TD:56.25±4.59
								HS		DCD: 130.75±54.74 TD: 155.5±63.91

	Lopez	2018	France	C-S	DCD: 65 (8.9y ± 2.5y)	Yes, only language disorders	53B + 12G	PH	Échelle d'Ajuriaguerra (de Ajuriaguerra, 1989)	58/65 (89%) children with DCD had poor handwriting 10/65 (15%) had dysgraphic handwriting
	Missiuna	2008	Canada	C-S	DCD: 88 (8y)	Yes, 15/88 with ADHD and 17/88 with learning disability	66B, 22G	PH	Semi-structured parental interviews	76/80 (95%) of children with DCD had handwriting difficulties
	Prunty	2013	UK	C-S	DCD: 28 (10.61y ± 2.23y) TD: 28 (10.95y ± 2.12y)	No	27B, 1G	PH	DASH (Barnett et al., 2007)	11/20 (55%) children with DCD scorer lower than 1SD from the mean in handwriting
								HS		DCD: 84.3±14.3 TD: 100.3±12.31
	Prunty	2020	UK	BTGD	DCD: 28 (10.61y ± 2.23y) TD: 28 (10.95y ± 2.12y)	No	27B, 1G	HL	DASH (Barnett et al., 2007)	DCD: 73.43±22.65 TD: 92.1±6.25
	Rosenblum	2008	Israel	C-S	DCD: 20 (8y) TD: 20 (7.9y)	NM	18B, 2G	HL	Hebrew Handwriting product evaluation (Erez & Parush, 1999)	DCD: 2.55±1.05 TD: 3.75±1.94
								HS		DCD: 28.55±16.66 TD: 50.05±17.35
HANDWRITING	Rosenblum	2013	Israel	C-S	DCD: 29 (10.9y ± 7.46m) TD: 29 (10.11y ± 7.5m)	NM	24B, 5G 24B, 5G	HL	Handwriting Proficiency Screening Questionnaire (Rosenblum, 2008)	DCD:2.66±0.81 TD: 3.87±0.51
								HS		DCD: 42.95±16.35 TD: 67.31±20.53

HANDWRITING	Vaivre-Douret	2011	France	C-S	DCD: 43 (8:3y ±2:4y)	No	35B, 8G	PH	Échelle d'Ajuriaguerra (de Ajuriaguerra, 1989)	38/42 (88%) children with DCD had handwriting difficulties 8/42 (18%) children with DCD had dysgraphic handwriting
WRITING	Alloway	2007	UK	C-S	DCD: 20 (9.75y ± 17m)	NM	14B, 6G	S	WORD – Spelling (Wechsler, 1993)	DCD: 81.25±11.29
	Alloway	2008	UK	C-S	DCD: 12 (8y6m ± 1.64y)	NM	16B + 7G	S	WORD – Spelling (Wechsler, 1993)	DCD: 80±11.82
	Alloway	2011	UK	C-S	DCD: 55 (8.8y ± 19m) TD: 50 (9.91y ± 12m)	No	43B, 7G	S	WORD – Spelling (Wechsler, 1993)	DCD: 86.42±14.5 TD: 100.12±12.41
	Ho	2005	China	C-S	DCD: 21 (104.7m ± 9.9m)	Yes; 9/21 with dyslexia, 1/21 with ADHD	17B, 4G	S	Orthographic subtest from the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (Chung et al., 2007)	DCD: 8.42±3.01
	Pieters	2015	Belgium	C-S	DCD: 102 (106.84m ± 12.13m) TD: 136 (105.85m ± 13.42m)	NM	77B, 25G 66B, 70G	S	PI-Dictation (Geelhoed & Reitsma, 2004)	DCD:14.68±26.54 TD: 45.15±35.73
WRITING	Prunty	2013	UK	C-S	DCD: 28 (10.61y ± 2.23y) TD: 28 (10.95y ± 2.12y)	No	27B, 1G	S	British Ability Scales (Elliott, 1996)	DCD: 95.8±13.7 TD: 111±12.7

	Prunty	2016	UK	C-S	DCD: 28 (10.61y ± 2.23y) TD: 28 (10.95y ± 2.12y)	No	27B, 1G	W	Wechsler Objective Language Dimensions (Rust, 1996)	DCD: 11.35±3.49 TD: 14.85±3.9
	Richardson	2005	UK	RCT	DCD: 112 (105.8m ± 16.3m)	NM	78B,39G	S	WORD – Spelling (Wechsler, 1993)	DCD:93.88±16.98
	Tseng	2007	Taiwan	C-S	DCD: 70 (8.02y ± 0.97y) TD: 82 (7.8y ± 0.71y)	NM	38B + 32G 48B + 34G	PW	Basic Reading and Writing Test Battery – character writing and dictation subtests (Hung et al., 2003)	28/70 (40%) children with DCD had writing difficulties
								W		DCD: 47.19±2.47 TD: 48.55±1.30
WRITING	Wang	2009	Taiwan	C-S	DCD: 16 (8:0y ± 0:9y) TD: 63 (7:10y ± 0:9y)	No	7B, 9G 39B, 24G	W	School Function Assessment (Hwang et al., 2004)	DCD: 81.2±16.4 TD: 91.4±11.8
MATHEMATICS	Alloway	2007	UK	C-S	DCD: 20 (9.75y ± 17m)	NM	14B, 6G	M	WOND (Wechsler, 1996)	DCD:81.05±17.76
								EQ		DCD: 81.15±11.50
	Alloway	2008	UK	C-S	DCD: 12 (8y6m ± 1.64y)	NM	16B + 7G	M	WOND (Wechsler, 1996)	DCD:83.42±13.67
MATHEMA TICS	Alloway	2011	UK	C-S	DCD: 55 (8.8y ± 19m)	No	43B, 7G	M	WOND (Wechsler, 1996)	DCD:86.31±19.31 TD: 97.9±9.82

					TD: 50 (9.91y ± 12m)			EQ		DCD:85.45±14.57 TD: 95.62±8.67
	Gomez	2015	France	C-S	DCD: 20 (8.45y ± 0.27y) TD: 20 (8.5y ± 0.26y)	No	15B, 5G	EQ	Additions	DCD:86.2±16.7 TD:93.9±10.3
	Gomez	2017	France	C-S	DCD: 20 (8.45y ±0.27y) TD: 20 (8.5y ±0.26y)	No	15B, 5G 11B, 9G	NSK	Number line task	DCD:92.7±2.51 TD: 95.1±2.57
	Pieters	2012	Belgium	C-S	DCD: 43 (112.16m ± 5.07m) TD: 41 (113.02m ±7.27m)	NM	29B, 14G 18B, 23G	PM	Arithmetic Number Fact Test (De Vos, 1992)	31/43 DCD scored < 16th percentile on the Arithmetic Number Fact test
									Kortrijk Arithmetic Test Revision (Baudonck et al., 2006)	39/43 DCD scored < 16th percentile on the Kortrijk Arithmetic Test Revision
								NSK	Kortrijk Arithmetic Test Revision (Baudonck et al., 2006)	DCD:10.84±17.69 TD: 52.88±30.05
								EQ	Arithmetic Number Fact Test (De Vos, 1992)	DCD: 29.19±8.48 TD: 43.34±6.97
MATHEMATICS	Pieters	2015	Belgium	C-S	DCD: 102 (106.84m ± 12.13m) TD: 136 (105.85m ± 13.42m)	NM	77B, 25G 66B, 70G	NSK	Kortrijk Arithmetic Test Revision (Baudonck et al., 2006)	DCD:25.62±25.57 TD: 67.12±22.51
								EQ	Arithmetic Number Fact Test (De Vos, 1992)	DCD: 29.09±24.96 TD: 60.18±24.54

	Vaivre-Douret	2011	France	C-S	DCD: 43 (8:3y ±2:4y)	No	35B, 8G	PM	Homemade questionnaire	38/43 DCD have difficulties with mathematics
READING	Alloway	2007	UK	C-S	DCD: 20 (9.75y ± 17m)	NM	14B, 6G	R	WORD (Wechsler, 1993)	DCD: 82.7±14.56
	Alloway	2008	UK	C-S	DCD: 12 (8y6m ± 1.64y)	NM	16B + 7G	R	WORD (Wechsler, 1993)	DCD: 81±11.93
	Alloway	2011	UK	C-S	DCD: 55 (8.8y ± 19m) TD: 50 (9.91y ± 12m)	No	43B, 7G	R	WORD (Wechsler, 1993)	DCD: 87.41±15.90 TD: 97.11±10.84
	Pieters	2015	Belgium	C-S	DCD: 102 (106.84m ± 12.13m) TD: 136 (105.85m ± 13.42m)	No	77B, 25G 66B, 70G	R	One Minute Test (Brus & Voeten, 2007)	DCD: 6.38±3.58 TD: 9.31±3.68
	Richardson	2005	UK	RCT	DCD: 112 (105.8m ± 16.3m)	NM	78B,39G	R	WORD (Wechsler, 1993)	DCD: 96.76±22.5 TD: 105.8±16.3
READING	Tseng	2007	Taiwan	C-S	DCD: 70 (8.02y ± 0.97y) TD: 82 (7.8y ± 0.71y)	NM	38B + 32G 48B + 34G	R	Basic Reading and Writing test battery (Hung et al., 2003)	19/70 (27%) children with DCD had reading difficulties DCD: 47.47±2.19 TD: 52.4±1.18

Legend: dx, diagnosed; UK, United Kingdom; C-S, cross-sectional design; RCT, randomized controlled trial; NRT, non-randomized trial; BTGD, non-experimental between group design; y, years; m, months; NM, not mentioned; B, boys; G, girls; PH, prevalence of handwriting difficulties; HL, handwriting legibility; HS, handwriting speed; W, writing; S, spelling; PW, prevalence of writing difficulties; M, mathematics performance; PM, prevalence of mathematics difficulties; NSK, number system knowledge; EQ, equations; R, reading; ETCH, Evaluation Tool of Children's Handwriting;

DASH, Detailed Assessment of Speed of Handwriting; WORD, Wechsler Objective Reading Dimensions; WOND, Wechsler Objective Numerical Dimensions.

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Chapter 4. Manuscript 2, Factors associated with mathematical capacity in children with Developmental Coordination Disorder

4.1. Preface

In the previous chapter, the systematic review established that academic difficulties in children with DCD were frequent across different academic activities, including mathematics, reading and writing, extending beyond just handwriting. Notably, mathematical difficulties were found to be as frequent as those in the handwriting domain. However, the specific domains of mathematical difficulties and their contributing factors in children with DCD remained unclear. To address this gap, a cross-sectional study was conducted to assess mathematical capacity and its potential associated factors in school-aged children with DCD. This approach allowed the identification of the nature, frequency and extent of mathematical difficulties in this population, as well as an investigation of the potential relationship between mathematical capacity and visual-perceptual, visuo-motor integration, motor and attentional skills. Understanding mathematical capacity in children with DCD is essential for health and education professionals to provide targeted and effective interventions. Given the lifelong impacts that mathematical difficulties can have on daily functioning (Deloche et al., 1996), it is crucial to ensure early identification and provide appropriate interventions to children who experience such difficulties.

Chapter 4 presents the second manuscript of this thesis. Manuscript 2 is a cross-sectional study of mathematical capacity in children with DCD. The findings indicated that some children with DCD exhibit poor mathematical capacity, particularly in measurement, geometry and problem-solving. Visual-perceptual skills were found to explain a larger portion of mathematical capacity than visuo-motor integration, motor or attentional skills. This suggests that children with DCD should be systematically screened for mathematical difficulties to better orient the services provided to them.

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Factors associated with mathematical capacity in children with Developmental Coordination Disorder

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Highlights:

- Children with DCD frequently present with significant mathematical difficulties.
- Visuoperceptual skills are strong factors of overall mathematical capacity in children with DCD.
- Children with DCD should be systematically assessed for mathematical difficulties.

What this paper adds: This is the first study to comprehensively assess the different domains of mathematical capacity and their potential factors in children with DCD. We demonstrated that school-aged children with DCD frequently present with poor mathematical capacity, especially with basic concepts such as measurements and geometry, as well as with problem-solving. Visuoperceptual skills explained the most important portion of the variance of all mathematical domains. These findings emphasize the need to systematically assess mathematical skills in children with DCD to orient appropriate services to optimize school performance and funding in daily life.

Keywords: Developmental Coordination Disorder; mathematical capacity; visuoperceptual skills; visual-motor integration; motor skills

4.2. Abstract

Background. Developmental Coordination Disorder (DCD) is a condition characterized by difficulties in motor planning and coordination and affects 5 to 6 percent of all school-aged children. Children with DCD frequently present with difficulties with academic activities such as handwriting. However, no study to date has comprehensively described mathematical capacity and its potential factors in this high-risk group. **Aims**. We aimed to describe the frequency and nature of mathematical difficulties of school-aged children with DCD and to evaluate potential factors associated with performance. **Methods**. A total of 55 elementary school-aged children with DCD underwent comprehensive standardized assessments of mathematical, visuoperceptual (VP), attentional, visual-motor integration (VMI), and motor skills. The contribution of each factor to mathematical capacity was established using hierarchical multivariate linear regression models. **Results**. Children with DCD (9.1±1.5 years, 44 males) had lower overall mathematical capacity compared to normative data (-0.59 SD) on the KeyMath 3rd edition, with poorer performance in basic concepts and problem-solving. Thirty-eight percent of the sample performed below the 15th percentile in overall mathematical skills. VP skills were the most important factors associated with most mathematical domains. Thirty-four percent of the variance of overall mathematical capacity was explained by VP skills, inattention, VMI and motor impairments while controlling for household income ($F [5,49]=5.029$, $p<.0001$). **Conclusion.** Children with DCD present with mathematical difficulties in basic concepts and problem-solving, which are partially explained by VP skills. Our findings stress the important of systematically assessing mathematical difficulties children with DCD to ensure they receive the necessary support that leads to academic success.

4.3. Introduction

Developmental coordination disorder (DCD) is a chronic condition that affects children's motor skills and coordination, negatively impacting their performance in activities of daily living. DCD occurs in five to six percent of school-aged children worldwide and typically impairs balance, visual-motor integration (VMI), body awareness, visual perception, agility and coordination (Blank et al., 2019).

Despite the well-recognized impacts of DCD on handwriting performance, an important academic activity that highly relies on fine motor control, preliminary evidence suggests that children with DCD also present with academic difficulties that are not primarily motor-based (Dionne et al., 2022). A recent systematic review indicated that up to 90% of children with DCD present with mathematical difficulties compared to typically developing peers, specifically with regards to numeracy, mental computation and operations (Dionne et al., 2022). Since mathematics is essential for many activities of daily living (e.g., driving, shopping, managing money and time), it is crucial to understand the full extent and nature of these difficulties of children with DCD (Deloche et al., 1996). Because the current level of evidence remains preliminary, more studies using comprehensive measurement approaches are needed. Furthermore, identifying the factors associated with mathematical capacity may guide the devise of novel individualized and more effective interventions.

When compared to children with mathematical learning disability, children with DCD perform poorer in numeration, suggesting that some mathematical difficulties are specific to DCD problematic and not only present in children with a dual diagnosis of DCD and mathematical learning disability (Pieters et al., 2015). Furthermore, specific basic numerical skills such as abstract numerosity system and subitizing abilities were found to be poorer in children with DCD than their TD peers (Gomez & Huron, 2020; Gomez et al., 2015). While working memory had previously been identified as a contributor of both numeracy and literacy difficulties, inherent poorer visuospatial skills that are particular to children DCD could underly the specific mathematical difficulties observed in this group (Alloway & Temple, 2007). Visuoperceptual (VP) skills refer to the ability to provide the perceiver with information about the objects, events and spatial layout around them. It encompasses numerous skills such as visuospatial relations, form constancy and visual memory. In typically developing children, good VP skills, especially visuospatial relations, have been positively associated with a variety of mathematical concepts including numeracy, geometry, algebra, and mental calculation (Carlson et al., 2013; Lowrie et al., 2017; Raghubar et al., 2015; Richardson et al., 2014; Tracy, 1987; Vukovic & Siegel, 2010). In contrast, problem-solving is habitually not associated with VP skills (Vukovic & Siegel, 2010). As a first step to understanding the underlying mechanisms of mathematical capacity in children with DCD, we aimed to evaluate the respective contribution of the factors that are also common attributes of the DCD symptomatology. Specifically, we included attentional deficits, which have been linked to slower mathematical capacity and overall poorer scores in problem-solving and numeracy (Zentall et al., 1994) and affect up to 50% of children with DCD (Blank et al., 2019; Blank et al., 2012). Further, since DCD is characterized by motor and VMI impairments, which are both known to be associated with mathematical capacity, we also evaluated these two factors as potential exacerbators of mathematical capacity in children with DCD (S. Pieters, A. Desoete, et al., 2012; Simms et al., 2016). Therefore, the goals of this cross-sectional study was to describe the frequency and nature of mathematical difficulties and to evaluate the extent to which body functions and structures involved in the symptomatology of DCD (motor, attentional, VMI and VP skills) are associated with mathematical capacity in school-aged children with DCD.

4.4. Methods

4.4.1. Participants

School-aged children (Grade 1 through 6) with a diagnosis of DCD were recruited to participate in this study. Children were excluded if (i) they were diagnosed with autism spectrum disorder or a genetic condition, (ii) language difficulties prevented them from understanding instructions during the assessments and (iii) they were not following the conventional educational curriculum in school (i.e., modified curriculum and therefore offered different mathematical education opportunities compared to those in conventional curriculums), as reported by the caregiver.

4.4.2. Measures

4.4.2.1. Mathematical capacity

The KeyMath 3rd Canadian Edition (KeyMath3) is a comprehensive standardized assessment of mathematics for children 5 to 18 years of age (Conolly, 2007). It is an age and sex norm-referenced measure of mathematical capacity with no time-limit that includes 10 subtests divided into 3 domains: basic concepts, operations and problem-solving. The basic concepts domain includes five subtests that evaluate the mathematical concepts of numeration, algebra, geometry, measurement, and data analysis and probability. The operations domain assesses mental computation and estimation, addition and subtraction, and multiplication and division. Finally, the problem-solving domain includes two subtests; foundations of problem-solving and applied problem-solving, which respectively focus on the ability to analyze word problems using strategies and use and apply basic mathematical concepts to solve problems. In each subtest, items focused on both knowledge-based facts and the interpretation of mathematical materials. Overall score and domain scores were used to characterize mathematical capacity. Children can use their fingers to count and must provide their answers verbally, except for the addition, subtraction, multiplication and division subtests where they are provided with writing materials.

4.4.2.2. Visuoperceptual (VP) skills

VP skills were assessed using the Test of Visual Perceptual Skills – 4th edition (TVPS-4) (Martin, 2017). This norm-referenced standardized measure aims to identify VP strengths and weaknesses of individuals aged five to 21 years and uses standard scores (100±15) (Martin, 2017). It contains seven 18-item subtests assessing visual discrimination, visual memory, visuospatial relations, form constancy, sequential memory, visual closure and figure-ground discrimination. Subtest and overall scores were used in the present study. Although few studies have conducted psychometric testing on the TVPS-4, its previous versions such as the TVPS-3 (Martin, 2006) and the TVPS-Revised (Gardner, 1996) have shown excellent psychometric properties, and it was demonstrated that TVPS-R primarily assesses VP skills, and not visual motor integration (Brown & Gaboury, 2006).

4.4.2.3. Attentional skills

Evidence suggests that mathematical difficulties are present in children with attention deficit hyperactivity disorder (ADHD) (Iglesias-Sarmiento et al., 2017; Maria Grazia et al., 2015; Zentall et al., 1994). Considering the high prevalence of attentional difficulties in children with DCD (i.e., approximately 50%), it is possible that these difficulties contribute to poor mathematical capacity (Kadesjö & Gillberg, 1998; Kaplan et al., 2006; Tseng et al., 2007; Visser, 2003; Watemberg et al., 2007). Therefore, we used the parental version of the Conners 3rd edition – short form (Conners), a 20-minute questionnaire, to assess parental perception of potential attentional problems in children aged six to 18 years (Conners, 2008). It consists of six scales: *inattention*, *hyperactivity/impulsivity*, *learning problems*, *executive functioning*, *aggression* and *peer relations*, scored on a total of 45 items graded on a four-point Likert scale. A T-score (50±10) is reported for each scale, and the higher the score, the more problematic the behavior. The Conners' inattention scale correlates highly with other measures of attention, and therefore was used to characterize attentional skills in this study (Kao & Thomas, 2010).

4.4.2.4. Visual-motor integration (VMI)

Visual-motor integration (VMI) was found to be positively associated with mathematical capacity in typically developing children, especially in activities that require the use of a number line (Al-Hroub, 2010; Simms et al., 2016). However, no study has yet reported on this association in the DCD population. To assess VMI in children with DCD, we used the Beery-Buktenica Developmental Test of Visual-motor integration 6th edition (Beery-VMI) (Beery & Beery, 2010), which is a standardized assessment of VMI. It combines both visual perception and motor coordination, and consists of a copying task of a series of 30 geometric shapes. Shapes are organized by level of difficulty, and administration is aborted when three consecutive drawings are failed. Each drawing is scored on a two-point Likert scale (0 if the drawing is inadequate; 1 if the drawing corresponds to the scoring criteria) and yields a total standard score (100±15). The

Beery-VMI is a psychometrically sound assessment of VMI and has been found to be highly predictive of scholastic performance in typically developing children (Harris, 2017).

4.4.2.5. Motor skills

Due to the distinct motor difficulties in DCD, the severity of motor impairments should be considered in terms of their relation to mathematical capacity, especially since in typically developing children, fine motor coordination difficulties are characteristic of poorer mathematical capacity (S. Pieters, A. Desoete, et al., 2012). The Movement Assessment Battery for Children – 2nd edition (MABC-2) was used to assess three motor domains (manual dexterity, ball skills, and balance) with scaled scores (10±3) using eight tasks. Total and domains score were used to characterize motor skills. Test administration depends on age, as three age bands are available for the test. MABC-2 is highly correlated with a number of other well established motor assessments, such as the *Bruininks-Oseretsky Test of Motor Proficiency* and the *Peabody Developmental Motor Scales*, which confirms its content validity as an assessment of motor skills (Barnett et al., 2007). The MABC-2 has strong psychometric properties and has therefore been recognized as a gold standard for validating the presence of the DSM-V's diagnostic criterion A for DCD (Blank et al., 2019; Geuze et al., 2001).

4.4.2.6. Sociodemographic information

Caregivers completed a sociodemographic questionnaire. Questions focused on demographics (age, sex, grade, grade repetition, parental employment and education, mother tongue, household income), child health conditions (co-occurring diagnoses, ADHD medication), rehabilitation interventions (duration and frequency of motor, psychological or mathematical interventions). Socioeconomic status was calculated based on Hollingshead's four factor index (Hollingshead, 1975).

4.4.3. Procedures

Ethical approval was obtained from the Research Institute of the McGill University Hospital Centre and the Integrated Health and Social Services Centre in Outaouais. Potential eligible participants were identified at the occupational therapy Department of the Montreal Children's Hospital (MCH), the rehabilitation center La RessourSe of the Integrated Health and Social Services Centre in Outaouais and private occupational therapy practices in the Gatineau region. When caregivers expressed interest in the study, they were contacted by the study coordinator to obtain further details, confirm eligibility and schedule the assessment. Caregivers provided signed consent and a proof of diagnostic impression of DCD by a health practitioner. If the child had already completed any of the study assessments in the last three months, prior results were accessed with caregiver consent. All assessments were administered by the study coordinator in a single study while caregivers completed the questionnaires.

4.4.4. Statistical analysis

All analyses were performed using SPSS v2.4 (Corp., 2016), and descriptive statistics (e.g., mean, standard deviation, range) were used to characterize the sample and outcomes. Hedge's g was used to determine the standardized mean difference between the group of children with DCD and norms for each outcome measure. The 15^{th} percentile (-1 SD) was used at cut-off values on all assessments to identify difficulties from within-norms performance. Independent t-tests and Pearson and Spearman correlations were used to explore the presence of associations between individual and clinical characteristics (age, sex, grade, grade repetition, mother tongue, parental employment and education, household income, co-occurring diagnoses, medication, rehabilitation intervention) and the main outcomes. Characteristics significantly associated with mathematical capacity, or its domains were considered as confounding variables and included in the subsequent models.

Normality, collinearity and homoscedasticity assumptions were verified prior to multivariate analysis. A hierarchical multivariate linear regression model was performed to estimate the extent to which the factors (i.e., VP, attention, VMI and motor skills) were associated with each mathematical domain and overall mathematical capacity. As no previous model could be used to guide the selection of variables, Pearson and Spearman correlations were run to characterize the relationship between each factor (i.e., VP, attention, VMI, and motor skills) and mathematical capacity and its domains. In each model, the confounding variables significantly associated with the outcome (p-value <.05) were entered in ascending order of contribution, and removed when their presence did not improve the fit of the model. Then, each studied factor was then entered in their own block by order of importance. To maintain a power of 0.80 with a level of significance <.05 in a sample size of 55 participants, a maximum of five explanatory variables were put into each multivariate model. The significance of multicollinearity level was tested by the variance inflation factor (VIF). When the VIF was greater than 10, it indicated multicollinearity between the variables. Missing data was handled by using the group mean.

4.5. Results

4.5.1. Participant characteristics

Fifty-six children were enrolled to the study. Of those, one was excluded at the time of the study visit because the child's language difficulties prevented the participant from understanding the instructions. Therefore, a total of 55 children (44 males, mean age of 9.1±1.5 years) completed the full assessment between July 2019 and October 2021. All children were schooled in French. A total of 11 children repeated a year in school and had significantly lower mathematical capacity than those who did not repeat a grade ($r(52)=.434$, $p<.05$). Most children were right-handed (30/55). Fifty-eight percent of the sample had a co-occurring diagnosis of ADHD (n=32), 26% of learning disability (n=14) and 12.7% of language impairment (n=7). Among those who received intervention services focused on mathematics (n=19, 35%), eight had a co-occurring learning disability and six had repeated a grade. Socioeconomic status was 48.12±10.62 (range of 21-66), but household income was used as an indicator of socioeconomic status, as it was more correlated with mathematical capacity and its domains than maternal education. Only two participants preferred not to disclose the household income. Two children scored at the lower limit of the norm on the MABC-2 (16^{th} percentile), while one child, who had received motor intervention every two weeks for the past 18 months, scored at the 37^{th} percentile. Descriptive statistics are available in Table 4.1.

4.5.2. Mathematical capacity

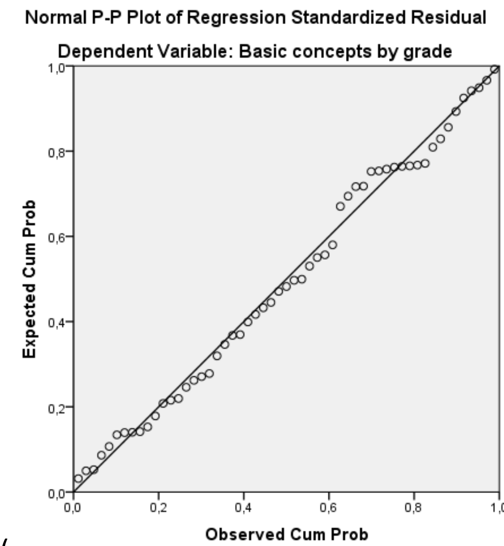
Overall, children with DCD performed 0.59 SD below norms for their age and sex in mathematics, with poorer results in basic concepts domain (-0.64 SD), specifically in its measurement subtest (-0.87 SD). Significant mathematical difficulties were present in 38% of the sample and 55% struggled greatly in the measurement subtest. A total of 42% of children performed below the 15th percentile in at least one mathematical domain. Children with poorer overall mathematical capacity (≤15th percentile) were more likely than their peers to have repeated a grade ($r(54)=.322$, $p<.05$) or have received mathematical intervention ($r(54)=.281$, $p<.05$). Children with DCD and ADHD had slightly poorer mathematical capacity (92.00±13.32) than those with only DCD (93.48±11.41), $t(53)=1.478$, $p=.67$. Detailed scores are reported in Table 4.2.

4.5.3. Factors associated with mathematical capacity

Children with DCD performed significantly poorer than normative data on the Inattention scale from the Conners (-2.16 SD) and the motor assessment of MABC-2 (-2.07 SD). Caregivers reported significant attentional difficulties on the inattention scale of the Conners for 82% of the sample. Children with DCD were found to perform slightly below norms on the TVPS-4 (-0.20 SD), with more important difficulties in the Sequential Memory subtest (-0.33 SD). Detailed scores for each factor are available in Table 4.3.

VMI was significantly correlated with basic concepts, problem-solving and overall mathematical capacity, while total VP skills were correlated with all mathematical outcomes. As for individual VP skills, only visuospatial relations, sequential memory and overall VP skills were significantly correlated to operations, and all but visual memory and form constancy were positively correlated to mathematical capacity, basic concepts and problem-solving. Attentional and motor skills were not found to be correlated with mathematical capacity or any of its domains. Among clinical and individual characteristics, grade repetition, having a co-occurring learning disability and having received mathematical intervention were significantly associated with poor mathematical capacity and its domains (Table 4.4). Paternal and maternal employment were also associated with mathematical capacity and its domains, but to a lesser extent than household income. No other clinical or individual characteristics were significantly associated with mathematical capacity and its domains (Supplementary Table 7.4).

Prior to additional analysis, normality, collinearity and homoscedasticity assumptions were



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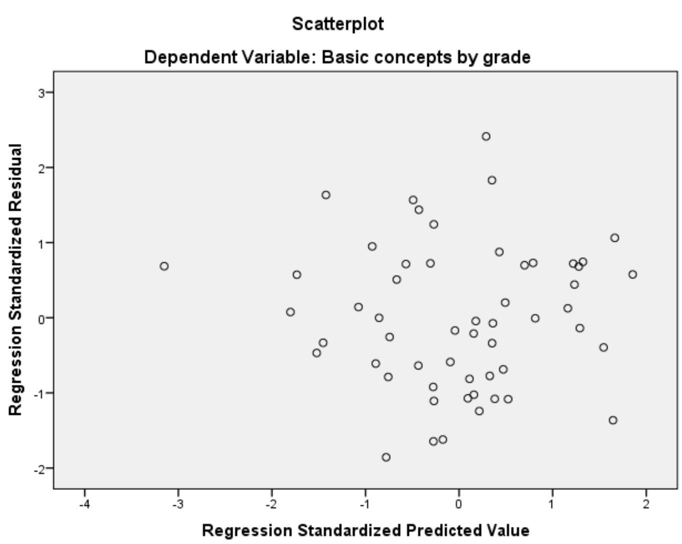

Supplementary Figure 7.1 to 7.4). Then, hierarchical regressions were used to estimate the relative contribution of the severity of motor impairments, VMI, VP skills and attentional skills to mathematical capacity after controlling for household income (Table 4.5). Since mathematical capacity was standardized for grade level, grade repetition was not included in the models. Only household income was included in the models as a confounding variable, as it mitigated the effect of co-occurring learning disabilities and past mathematical interventions in the exploratory analyses. Including all potential factors allowed for comparison of the respective contribution of each factor towards mathematical capacity. A total of four models were computed, one for each mathematical domain and one for overall mathematical capacity. In all models except for operations, VP skills explained a larger proportion of the variance in mathematical capacity than the other factors (15-19%). Inattention, VMI and the severity of motor impairments did not explain a significant proportion of the variance for mathematical capacity, as opposed to VP skills. Exploratory analyses regarding the order of factors in the hierarchical model equation showed significant association between total VP skills and VMI ($r[53]=.458$, $p<.001$), considering the inherent contribution of VP skills in VMI (Leonard et al., 1988). Nevertheless, due to a greater contribution of VP skills in each model compared to VMI, the former was included prior to the latter in each model. Further, since total VP scores was significantly and positively associated with mathematical capacity, it was used in the models instead of using the individual VP skills which may have added a multicollinearity effect to the models. Imputing only the most strongly associated individual VP subtest in each model as representative of VP skills did not lead to a meaningful improvement of the regression coefficients. Overall, 34% of the variance for overall mathematical capacity was explained by VP skills, inattention, VMI and motor impairments, while controlling for household income ($F [5,49]=5.029$, $p<.0001$). The same model applied explained 32% of the variance of basic concepts, 28% of operations and 34% of problem-solving. The respective contribution of each variable for all four models is presented in Table 4.5.

4.6. Discussion

The current study is the first to comprehensively assess an array of mathematical domains using a standardized measure of mathematical capacity in children with DCD. Our results indicated that up to 38% of children with DCD present with poor mathematical capacity in the domains of basic mathematical concepts and problem-solving. Despite performing worse than test normative values, our study showed that the difference in mathematical capacity between children with DCD and norms is modest (overall -.59 SD). Nevertheless, the frequency of their difficulties stresses the importance of systematically evaluating mathematical skills in children with DCD. With regards to the specific mathematical concepts, up to 55% of children with DCD struggled with notions of measurement and geometry, both of which are part of the basic concepts domain and have important daily life applications. For instance, geometry is essential for any type of repair or construction work, while measurements are of utmost importance in cooking and driving.

Previous studies in children with DCD have predominantly used assessments that focused on a single domain of mathematical capacity, and most frequently the domain of operations (Alloway & Archibald, 2008; Alloway & Temple, 2011; Alloway & Temple, 2007; Gomez et al., 2015; Gomez et al., 2017; S. Pieters, A. Desoete, et al., 2012; Pieters et al., 2015). In these studies, up to 80% of children with DCD struggled with operations, while only 25% of the children in our sample presented with such difficulties. This discrepancy could be simply explained by the fact that the evaluation tool used in the current study, the KeyMath3, does not involve handwritten answers and time limits as opposed to most assessment tools used in previous studies (Gomez et al., 2015; Gomez et al., 2017; S. Pieters, A. Desoete, et al., 2012; Pieters et al., 2015). Indeed, time constraint most likely disadvantage children with DCD who typically display longer time of execution than their peers in motor-based activities such as handwriting (Cacola et al., 2018; Farhat et al., 2016; Flapper et al., 2006; Prunty et al., 2013; Rosenblum, 2008; Rosenblum et al., 2013). Moreover, relying primarily on handwritten answers to evaluate mathematical capacity in this population may lead to an overestimation of mathematical difficulties considering that children with DCD frequently display legibility problems (Dionne et al., 2022).

Interestingly, our findings of greater mathematical difficulties in geometry, measurements and problem-solving suggest that children with DCD exhibit a disorder-specific profile of mathematical performance. Indeed, previous studies in children with dyscalculia that used similar comprehensive evaluations of mathematic capacity found marked difficulties with operations and numeration (Mazzocco et al., 2011; Tolar et al., 2016; Watson & Gable, 2013). This could indicate that the mathematical difficulties observed in our sample relate to the symptomatology and neurodevelopment profile of children with DCD and is not a simply explained by the co-occurring of DCD and learning disability such as dyscalculia.

The potential factors associated with mathematical capacity were explored to inform on the underlying mechanisms of the detected difficulties and eventually prompt potential avenues for intervention. We found that VP skills explained the larger proportion of the variance for most mathematical domains compared to any other factor evaluated. Specifically, the VP skills of visual discrimination, visuospatial relations, sequential memory and figure-ground discrimination were recurrent significant factors associated with most mathematical outcomes. In studies in TD children and children with DCD, only the VP skill of visuospatial relations has been investigated in relation to mathematical capacity (Alloway, 2007; Buckley et al., 2019; Cheng & Mix, 2014;

Frick, 2019; Lambert & Spinath, 2018; Mulligan, 2015; Reuhkala, 2001; Sella et al., 2016; Simms et al., 2016). These studies showed that visuospatial relations are important factors associated with basic mathematical concepts such as geometry (Alloway, 2007; Buckley et al., 2019; Frick, 2019; Lambert & Spinath, 2018; Mulligan, 2015) and numeration (Cheng & Mix, 2014; Simms et al., 2016), as well as complex domains such as problem-solving (Buckley et al., 2019; Reuhkala, 2001; Sella et al., 2016), which corroborates with our findings. To our knowledge, no other study of the relation between mathematical capacity and VP skills other than visuospatial skills in children with DCD have been published before today. More studies using comprehensive evaluations of the possible factors contributing to mathematical capacity will help identify factors of performance.

Surprisingly, motor skills were not found to be associated with mathematical capacity. This could be explained by the fact that the KeyMath3 uses verbal answers, and performance is therefore not impacted by the child's motor abilities. In studies in which typically developing children had to provide handwritten answers, fine motor skills explained a significant portion of the variance in mathematical capacity (S. Pieters, A. Desoete, et al., 2012). The lack of association found in the current study may also be explained by the limited range of motor skills throughout our sample since all participants presented with impaired motor skills as per the definition of DCD (Fuchs et al., 2005). Nonetheless, future studies using a more discriminative measure of gross and fine motor skills may provide greater insights into the possible association between motor abilities and mathematical performance.

Approximately 50% of our sample had co-occurring ADHD, which is in line with previous literature on DCD (Kadesjö & Gillberg, 1998; Kaplan et al., 2006; Tseng et al., 2007; Visser, 2003;

Watemberg et al., 2007). Although children with DCD and ADHD in our sample had poorer mathematical capacity than those without ADHD, the difference did not reach statistical significance. ADHD diagnosis and caregiver-reported attentional difficulties were also not found to be significant factors associated with mathematical capacity. Although normative data likely included children with ADHD, which may have led to an underrepresentation of the potential effect of attentional skills on mathematical capacity, the lack of significant association between mathematical capacity and attentional skills suggests that mathematical difficulties cannot solely be explained by co-existing attentional difficulties. Therefore, mathematical difficulties should be considered as a frail area of performance in all children with DCD. Considering the important applications of mathematics in our daily lives, it is imperative to intervene on mathematical capacity in children with DCD early on. Recent studies have identified flexible teaching, technological tools and specialized spatial, kinesthetic and virtual reality strategies to be promising interventions to improve the visualization of mathematical concepts which may help mitigate mathematical difficulties associated with poor VP skills (Bülbül & Güler, 2021; Lowrie et al., 2021; Moleko & Mosimege, 2021; Wuang et al., 2021). Their effectiveness should be evaluated in children with DCD and mathematical difficulties specifically.

4.7. Limitations

There are several limitations to consider in this study. First, almost 80% of our sample reported a high household income (≥100K yearly), which indicates a possible high socioeconomic status and may have introduced selection bias. Previous studies in school-aged typically developing children have identified higher family socioeconomic status as positively associated with mathematical performance (Berger & Archer, 2016; Guzmán et al., 2020; Kaeley, 1990). Further, previous studies in children with DCD reporting higher frequencies of mathematical difficulties had overall lower socioeconomic status than those in this study (Dionne et al., 2022; S. Pieters, A. Desoete, et al., 2012; Vaivre-Douret et al., 2011). Nevertheless, we controlled for this potential confounder in our analyses and still found prevailing mathematical difficulties in children with high socioeconomic status. Another limitation to consider is that only 30% of our participants did not present with co-occurring diagnoses of either ADHD, learning disability or specific language impairment. This may have masked some associations between mathematical capacity and candidate factors, especially since some co-occurring disabilities such as dyscalculia are typically underdiagnosed (Dickerson Mayes & Calhoun, 2007). However, including such a wide scope of clinical presentations of DCD strengthens the clinical generalizability of the results. Finally, only variables considered as common attributes of the DCD symptomatology were investigated as potential factors associated with mathematical capacity in this study. While we recognize not evaluating the full extent of the potential factors associated with mathematical capacity previously highlighted in the literature in TD children, our study provides a first important step in understanding the underlying mechanisms of mathematical capacity in children with DCD.

4.8. Conclusion

This study suggests that children with DCD frequently present with poor mathematical capacity, especially in measurement, geometry and problem-solving. The mathematical difficulties observed may be exacerbated by contextual factors such as writing requirements and time limits and should be carefully considered when evaluating mathematical abilities both in research and in clinical practice. Moreover, VP skills were strong factors associated with mathematical capacity in our study, and these findings support the need to provide individualized and early intervention to children with poor VP skills to support their academic achievement. Considering the study findings, we suggest that all children with DCD be systematically screened for mathematical difficulties to support academic success.

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4.10. Tables and Figures

Table 4.1 Descriptive statistics of the sample (n=55)

Group characteristics			% (n)
Mother tongue	French		93% (51)
	English		5% (3)
	Spanish		2% (1)
Past intervention services	Psychological intervention		16% (9)
	Motor intervention		71% (39)
	Mathematical intervention		35% (19)
Co-occurring diagnoses	Any co-occurring diagnosis		73% (40)
	ADHD	with medication	40% (22)
		without medication	18% (10)
	Language-based learning disability		25% (14)
	Mathematical learning disability		2% (1)
	Specific language impairment		13% (7)
School grade	Grade 1 (6-7 years of age)		16% (9)
	Grade 2		15% (8)
	Grade 3		27% (15)
	Grade 4		18% (10)
	Grade 5		18% (10)
	Grade 6		6% (3)
Maternal education	High School complete or not		7% (4)
	CEGEP or technical diploma		25% (14)
	Undergraduate Degree		27% (15)
	Graduate or Postgraduate Degree		40% (22)
Household income (yearly)	Declined to answer		4% (2)
	≤50 000$		4% (2)
	50 000 to 99 999$		16% (9)
	100 000 to 149 999$		16% (9)
	150 000 to 199 999$		25% (14)
	≥200 000$		35% (19)

ADHD, attention deficit hyperactivity disorder. CEGEP, college of general and professional teaching.

Table 4.2 Distribution and mean scores of mathematical capacity (n=55)

		Mean (SD)	Hedge's g	≤15th percentile (n)
Basic concepts	Numeration	8.73 (2.88)	-.42	35% (19)
	Algebra	9.15 (3.16)	-.28	28% (15)
	Geometry	8.47 (2.62)	-.51	40% (22)
	Measurement	7.40 (2.92)	-.87	55% (30)
	Data analysis	8.85 (2.50)	-.38	31% (17)
	Subtest score	90.35 (14.72)	-.64	38% (21)
Operations	Mental computations	9.55 (3.35)	-.15	24% (13)
	Additions and subtractions	8.73 (3.03)	-.42	33% (18)
	Multiplications and divisions	8.31 (2.81)	-.56	42% (23)
	Subtest score	93.76 (14.25)	-.42	25% (14)
Problem-solving	Foundations of problem-solving	8.58 (2.72)	-.47	40% (22)
	Applied problem-solving	8.65 (2.38)	-.45	28% (15)
	Subtest score	92.31 (13.47)	-.52	35% (19)
Overall mathematical capacity		91.13 (14.57)	-.59	38% (21)

SD, Standard deviations. To facilitate data identification, domain and overall scores are in bold.

Table 4.3 Distribution and mean scores of the measures of factors (n=55)

		Mean (SD)	Hedge's g	≤15th percentile (n)
TVPS-4	Visual discrimination	10.18 (2.76)	.06	13% (7)
	Visual memory	9.25 (2.81)	-.25	26% (14)
	Visuospatial relations	10.67 (3.12)	.22	11% (6)
	Form constancy	9.36 (2.83)	-.21	28% (15)
	Sequential memory	9.00 (2.50)	-.33	24% (13)
	Figure-ground discrimination	9.38 (3.40)	-.21	34% (19)
	Visual closure	9.55 (3.19)	-.15	24% (13)
	Overall score	97.98 (10.00)	-.15	9% (5)
Conners - Inattention scale		73.55 (12.34)	-2.16	82% (45)
Beery-VMI		82.60 (9.66)	-1.30	64% (35)
MABC-2		3.91 (1.78)	-2.07	94% (52)

SD, Standard deviation; MABC-2, Movement Assessment Battery for Children 2nd edition; TVPS-4, Test of Visual Perceptual Skills 4th edition; Beery-VMI, Beery-Buktenica Developmental Test of Visual-Motor Integration 6th edition

Table 4.4 Correlations between factors and mathematical outcomes

		Basic concepts	Operations	Problem-solving	Overall mathematical capacity
Co-occurring learning disability		.672*	1.009**	.464	.708*
Past mathematical intervention services		.666*	.405	.481*	.604*
Maternal education		.121	.177	.143	.117
Maternal employment		.202	.457**	.243	.268*
Paternal employment		.246	.354**	.291*	.285*
Household income		.282*	.530**	.365**	.360**
TVPS-4	Visual discrimination	.371**	.185	.314*	.333*
	Visual memory	.176	.108	.234	.195
	Visuospatial relations	.438**	.441**	.306*	.445**
	Form constancy	.176	-.012	.108	.124
	Sequential memory	.390**	.343*	.426**	.428**
	Figure-ground discrimination	.382**	.246	.499**	.391**
	Visual closure	.326*	.137	.246	.277*
	Total score	.484**	.309*	.457**	.468**
Conners - Inattention scale		-.176	-.196	-.032	-.169
Beery-VMI		.305*	.182	.331*	.287
MABC-2	Manual dexterity	.182	.170	.055	.157
	Ball skills	-.059	.047	-.066	-.030
	Balance	.092	.193	.104	.126
	Overall motor skills	.131	.156	.136	.139

MABC-2, Movement Assessment Battery for Children 2nd edition; TVPS-4, Test of Visual Perceptual Skills 4th edition; Beery-VMI, Beery-Buktenica Developmental Test of Visual-Motor Integration 6th edition

*: <.05

**: <.01

Table 4.5 Hierarchical regressions with factors associated with mathematical capacity and its domains

	Basic concepts				Operations				Problem-solving				Mathematical capacity			
	R^2	Adj R^2	ΔR^2	p-value	R^2	Adj R^2	ΔR^2	p-value	R^2	Adj R^2	ΔR^2	p-value	R^2	Adj R^2	ΔR^2	p-value
Household income	.104	.087	.104	.016*	.200	.184	.200	<.001**	.167	.151	.167	.002**	.154	.138	.154	.003**
VP skills	.293	.266	.189	<.001**	.255	.226	.056	<.001**	.321	.295	.154	<.001**	.319	.293	.165	<.001**
Inattention scale	.312	.272	.019	<.001**	.269	.226	.014	.001**	.322	.282	.001	<.001**	.332	.293	.013	<.001**
VMI	.318	.263	.006	<.001**	.271	.213	.002	.003**	.338	.285	.016	<.001**	.336	.283	.004	<.001**
Motor impairments	.320	.251	.002	.002**	.283	.210	.012	.005**	.338	.271	.000	<.001**	.339	.272	.003	<.001**

VP, visuoperceptual; VMI, visual-motor integration
*p≤.05
**p≤.01

Chapter 5. Manuscript 3, Occupational therapy for children with DCD and academic difficulties: A pan-Canadian survey

5.1. Preface

In the previous chapters, the mathematical difficulties faced by children with DCD were comprehensively described in a cross-sectional study. A thorough understanding of these difficulties is necessary to inform and support OT practices that address these difficulties. However, to effectively communicate these findings to clinicians and facilitate practice change where necessary, it is essential to have a good understanding of current OT practices. Therefore, the primary aim of Study 3 was to determine the nature and extent of Canadian OTs' assessment and intervention practices in terms of academic activities in school-aged children with DCD. A comprehensive understanding of current OT practices will guide best practice and research, ensuring that future studies are clinically relevant and aligned with the needs of clinicians, children and their families, and society.

Chapter 5 presents the third and last manuscript of this thesis. Manuscript 3 is a survey of Canadian OT practices regarding academic activities in children with DCD. The study found that most Canadian pediatric OTs assessed and intervened on academic activities, with a primary focus on handwriting and less attention given to mathematics, reading and writing. These practices varied based on the practice setting and province.

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Occupational therapy for children with DCD and academic difficulties: A pan-Canadian survey

Titre en français : **L'ergothérapie auprès des enfants ayant un TDC et des difficultés académiques : Un sondage pancanadien**

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5.2. Abstract

Introduction. Children with Developmental Coordination Disorder (DCD) often experience academic challenges. Although children with DCD are frequently referred to Occupational Therapy (OT) to help alleviate some of their motor and functional challenges, the actual practices of OTs regarding academic activities remain unexplored in this group. **Objectives.** This study aimed to describe the nature and extent of Canadian OT practices regarding academic activities in children with DCD. **Methods.** A survey was sent to pediatric OTs through national and provincial OT associations and licensing organizations, to gather information on assessment and intervention practices related to core academic activities in children with DCD. **Findings.** A total of 229 OTs completed the survey (170 females, 74%). OTs reported assessing or intervening on academic activities, most frequently handwriting (96% assessed and 85% intervened), writing (74% and 65%), mathematics (72% and 68%) and reading (66% and 59%). With respect to intervention services, up to 78% of OTs provided direct intervention, compared to 51% for indirect or consultative services. **Conclusion.** Most Canadian pediatric OTs typically assess and intervene on handwriting and, to a lesser extent, other academic activities. These practices vary depending on work setting and experience.

5.3. Résumé

Introduction. Les enfants ayant un trouble développemental de la coordination (TDC) présentent souvent des difficultés académiques. Bien que ces enfants soient fréquemment orientés vers l'ergothérapie pour atténuer leurs défis moteurs et fonctionnels, les pratiques des ergothérapeutes en lien avec les activités académiques restent peu explorées chez cette population. **Objectifs.** Cette étude vise à décrire la nature et l'étendue des pratiques des ergothérapeutes canadiens concernant les activités académiques des enfants avec un TDC. **Méthodes.** Un sondage a été envoyé aux ergothérapeutes en pédiatrie via leurs associations et ordres professionnels afin de recueillir des informations sur les pratiques d'évaluation et d'intervention liées aux activités académiques chez les enfants ayant un TDC. **Résultats.** Au total, 229 ergothérapeutes ont répondu au sondage (170 femmes, 74%). Les ergothérapeutes ont rapporté évaluer ou intervenir principalement sur les activités académiques suivantes : l'écriture manuelle (96% évaluent et 85% interviennent), les aspects non-moteurs de la rédaction (74% et 65%), les mathématiques (72% et 68%) et la lecture (66% et 59%). En ce qui concerne les services d'intervention, jusqu'à 78% des ergothérapeutes ont indiqué offrir des services d'intervention directs, comparativement à 51% pour les services indirects ou de consultation. **Conclusion.** La majorité des ergothérapeutes pédiatriques canadiens évaluent et interviennent principalement sur l'écriture manuelle, et sur d'autres activités académiques mais dans une moindre mesure. Ces pratiques varient en fonction du milieu de travail et de l'expérience des ergothérapeutes.

5.4. Introduction

Developmental coordination disorder (DCD) is a chronic condition that impacts motor skills and coordination and affects about five percent of the school-aged population worldwide (Blank et al., 2012). The symptoms of DCD include difficulties with balance, visual-motor integration, body awareness, visual perception, agility, and coordination, which can negatively affect participation in daily life to include school-based activities (Blank et al., 2012). As many as 90% of children with DCD experience handwriting or mathematical difficulties, while 40% have a co-occurring reading or writing learning disability (Dionne et al., 2022).

Occupational therapists (OTs) play a pivotal role in the rehabilitation of children with DCD, as they are uniquely positioned to assess the functional impacts of their motor difficulties and to deliver targeted and individualized interventions to alleviate these activity limitations. Specifically, OTs have a unique expertise to document and confirm the first two diagnostic criteria of the DSM-V for DCD which pertain to the identification of significant motor difficulties and their functional impacts during activities of daily living and/or academic productivity (American Psychiatric Association, 2013). While this second criterion explicitly includes academic activities as a potential area of difficulty for children with DCD, it remains unclear whether OTs actively address this area of functioning in their management of children with DCD.

Academic activities, which include writing (consisting of handwriting and the non-motor aspects of writing such as sentence construction, grammar, spelling, etc.), reading and mathematics, constitute the bases of scholarly competencies. Children with DCD experience difficulties performing these activities, with handwriting being the most widely recognized difficulty due to its motor-based nature (Dionne et al., 2024; Huau et al., 2015; Magalhaes et al., 2011; Rosenblum & Livneh-Zirinski, 2008). Nevertheless, a recent systematic review revealed that up to 90% of children with DCD also experience difficulties in mathematics, and that they perform approximately one standard deviation below their typically developing peers in non-motor aspects of writing, reading and mathematics (Dionne et al., 2022). Collectively, experiencing academic difficulties is associated with lower levels of education, socioeconomic status and quality of life (Cousins & Smyth, 2003; Patton et al., 1997). Therefore, it is crucial for OTs to be fully aware of the impacts of DCD on all academic activities to ensure effective management of all relevant activity limitations and make appropriate referrals to additional professionals when necessary.

An array of approaches is available to OTs to target the varied challenges experienced by children with DCD, such as task-specific training, cognitive, sensorimotor, functional, perceptual-motor, environmental, sensory integration, and behavioral approaches (Mandich et al., 2001; Withers et al., 2017). A survey of OT practices with in children with DCD in British Columbia (Canada) reported in 2014 that 90% of pediatric OTs intervened on self-care activities, while only 2% of OTs intervened on pre-printing and handwriting skills (Withers et al., 2017). This suggested that the frequent academic challenges encountered by children with DCD were not systematically addressed by OTs at that time. While OT practices may have changed since the publication of this survey, especially considering the increased recognition of evidence on children's academic difficulties in this population, these remain unclear (Dionne et al., 2022). A clear understanding of the role of Canadian OTs with children with DCD is a key steppingstone toward reinforcing their role as pediatric OTs and supporting the application of best practice.

5.4.1. Study objectives.

The primary objective of this study was to determine the nature and extent of Canadian OTs' assessment and intervention practices as related to academic activities in school-aged children with DCD. To identify potential trends in practices, associations between participant or service characteristics and OT practices were investigated as a secondary exploratory objective.

5.5. Methods

5.5.1. Participants

Canadian OTs with an active license at the time of the study (2023) were recruited. They had to be proficient in either French or English with a minimum of one year of pediatric clinical experience and to have had at least one client with DCD in their caseload during the previous year. Only participants who filled out at least one of the core sections, Assessment Practices or Intervention Practices, were included in the data analysis.

5.5.2. Procedures

This cross-sectional study surveyed a convenience sample, applying snowball sampling, of OTs across Canada. The study was conducted in accordance with the Declaration of Helsinki. Scientific and Ethical approval was obtained from the MUHC's Pediatric Research Ethics Board prior to recruitment. The survey was made accessible through the online Limesurvey platform (LimesurveyGmbH.). The survey was distributed by email between October 1st and December 3rd, 2023, to potential participants through the recognized professional OT colleges, associations, orders or societies of New Brunswick, Quebec, British Columbia, Prince Edward Island, Ontario, Alberta, Nova Scotia, and Manitoba. The Northwest territories, Yukon, Nunavut, Saskatchewan and Newfoundland and Labrador were reached through the Canadian OT Association (CAOT). Additionally, the survey was distributed within the research team's networks, including McGill University, University of British Columbia, Western University, Canchild from McMaster University, the *Dagobert et cie*, Association and targeted social media groups (e.g., Facebook pages for: McGill School of Physical and Occupational Therapy *SPOT*, *Ergothérapie-Quebec* and *Ergothérapie en milieu scolaire)*. Electronic consent was obtained at the beginning of the survey and prior to filling out any questions and eligibility was confirmed using self-report questions. After the recruitment phase, sixteen participants among those who had opted into the draw were selected to receive a 25$ gift card.

5.5.3. Survey development.

The survey was developed by a panel of OT researchers using the results of a systematic review on academic difficulties in children with DCD (Dionne et al., 2022). Then, four OTs, two francophone and two anglophone, each with a minimum of five years of experience in pediatrics, field-tested the survey by evaluating the clarity of each question using a three-point Likert scale (very clear, somewhat clear, unclear). If any item was deemed unclear, the OTs were asked to provide suggestions for improvement. Feedback was reviewed and revised versions of the questions were proposed for reevaluation. Iterative revisions were made until consensus was reached among the participating OTs and the survey developers. The survey was first developed in English and then translated to French. The French translation was carried out by a French native speaker and bilingual OT and subsequently back translated by an English native speaker and bilingual OT. Language revisions were made as necessary until the two versions were considered equivalent.

5.5.4. Survey content.

The survey comprised five sections: Participants' Characteristics, DCD Diagnostic Process, Assessment Practices, Intervention Practices, and Conclusion. The first section gathered generic information regarding personal factors (gender, age and highest degree of education achieved) and service characteristics (province or territory of employment, employment status and setting, clinical experience with children with DCD, and proportion of caseload of children with DCD), while the second section focused on the involvement of OTs in the DCD diagnostic process at the participant's institution. The Assessment Practices and Intervention Practices sections constituted the core of the survey and addressed approaches and modalities for each academic activity, for a maximum of six multiple-choice or short-ended questions per academic activity. The core sections focused on four specific academic activities, i.e., handwriting (including legibility and speed, and keyboarding), mathematics (including numeration, algebra, geometry, measurements, data analysis and probability, mental computation, arithmetic and equations, and problem-solving), writing (i.e., non-motor domains of writing such as grammar, punctuation, sentence composition, organization of ideas, spelling) and reading (including reading fluency and comprehension). The concluding section was an open-ended question designed to gather general comments or feedback on the survey. The survey's structure followed a logical progression from general to specific questions, with branching that led to sub questions where appropriate. Most response options were closed-ended, although open-ended comments were allowed (optional) in specific instances to add to the richness of the data. Depending on the branching of their answers, participants completed between 26 and 72 questions, for a duration of up to 30 minutes.

5.5.5. Data analysis.

Descriptive statistics were used to characterize the sample. Survey responses were quantified, coded and tabulated in SPSS to pool the data together and perform the analyses (Corp., 2016). For continuous variables, results were presented using means and standard deviations, while categorical variables were computed in proportions and frequencies. Thematic analyses were conducted on open-ended questions to identify emerging themes using inductive coding. The ranking question was analyzed by computing the average ranking and standard deviation for each possible response option and comparing each concurrent response option using independent t-tests. To better characterize the sample, Chi-square, and Fisher's exact tests were used to explore participant's personal factors and service characteristics. These same tests were used to investigate potential associations between personal factors or service characteristics and the type of academic activity assessed or intervened on. Following significant Chi-Square tests, post-hoc analyses with Bonferroni correction for multiple comparisons were conducted to identify potential differences between OT practices across provinces.

5.6. Results.

5.6.1. Participants.

Three hundred and seventy-four individuals consented to participate. Of these, 25 individuals (7%) were not eligible to participate after completing the eligibility questions and 120

(32%) did not complete the core sections of the survey (Assessment Practice and Intervention Practices sections) and were therefore excluded from the data analysis. The final sample included 229 participants, with three participants (1%) not completing the Intervention Practices section (Figure 5.1).

In all provinces, recruitment was facilitated through their respective OT professional agencies, except for British Columbia (BC), where consenting members were directly contacted by the study coordinator, which ended in a larger participation in BC (Table 5.1) than in the other provinces. Ten participants (4%) indicated working as an OT in more than one province.

The majority of the participants were English-speaking (n=175, 76%), self-identified as females (n=170, 74%), in their thirties (n=109, 48%), with a professional Masters of OT as highest degree of education (n=125, 55%). Francophone participants were all from the province of Quebec, except two (96%). Due to the OT University programs nationwide transitioning from a bachelor degree to a professional master degree in the early 2000s, participants with a bachelor degree as highest degree of education were at least 40 years of age and more likely to have extensive experience working with children with DCD. Hence, age and experience were negatively associated with higher levels of education in OTs ($X^2(12, n=229)=91.451$, $p<.001$ and $X^2(12, n=229)=60.825$, $p<.001$). Years of experience working with children with DCD was not significantly associated with the proportion of children with DCD on the participant's caseloads ($X^2(12)=19.833$, $p=.070$). Participants reported working on average 37±11 hours per week as pediatric OTs (ranging from 4 – 70 hours weekly, median = 36 hours). A total of 111 participants (48%) worked with a clientele mainly composed of children with DCD (≥50%). With regards to the type of service delivered, 52% of participants (n=118) indicated providing a combination of direct assessments, direct interventions and indirect services, such as consultative services, providing coaching and training, and participating in advocacy activities, 34% (n=78) indicated providing direct assessment and intervention, while only 1% (n=2) indirect service only (Supplemental Figure 7.5). The detailed nature of the assessment and intervention practices are reported in subsequent sections.

5.6.2. Survey.

5.6.2.1. DCD Diagnostic Process

Sixty-seven percent of all participants (n=153) considered to have at least an advanced level of knowledge of the DSM-V's diagnostic criteria for DCD. A total of 81% of participants indicated that OTs at their institution were involved in the diagnostic process for DCD most of the time, and only five participants reported no involvement in this capacity. When asked about potential reasons for their partial or non-involvement, the reasons included lack of awareness of the expertise of OTs among other health professionals (33%), limited access to OT or other multidisciplinary services (28%), systemic barriers (limited time or resources, long waitlists, not within their mandate) (19%) and poor knowledge of DCD (14%). Detailed answers regarding the DCD diagnostic process are available in Supplemental Table 7.5. Participants were asked to rank the professionals most involved (ranked first) in the diagnostic process of children with DCD in their practice, to least involved (ranked last). To the respondents' knowledge, the most involved professional was the physician (including pediatrician and family doctor) with a median ranking of 1.5, closely followed by OTs with a median ranking of 2. Physicians and OTs most often were ranked as first for their diagnostic involvement. They were followed by neuropsychologists (median =3), physiotherapists (median = 4), and psychologists (median = 4), all three of which ranked closely with no significant differences among them. Supplemental Table 7.6 provides detailed description of involvement of professionals in the diagnostic process, including median, mode and percentage of rankings.

5.6.2.2. Assessment Practices

All participants but three indicated that they directly assessed academic activities in children with DCD (n=226, 99%). Handwriting was the academic activity most frequently assessed (96%), followed by writing (74%), mathematics (72%) and reading (66%) (Table 5.2). The most common reasons provided for not assessing a specific academic activity included mandate limitations (42%), lack of knowledge and/or training (20%) and lack of requests (8%).

The components and modalities of assessments were not significantly different between each academic activity (Table 5.3). Assessments most often targeted activity performance (63%-85%) and personal factors (47-60%), which were defined as individual intrinsic characteristics independent of the health condition and included motivation towards the activity, perceived self-esteem or self-efficacy. Direct task observation (58-65%) and interviews (50-69%) were mostly used to assess academic activities. Usage of standardized assessments was reported in 39% of participants for handwriting, 7% for reading and writing, and 3% for mathematics. When questioned about the name of the standardized assessments used, participants identified 27 assessments for handwriting, six for writing, six for reading and three for mathematics, although not all of these were standardized (Supplemental Table 7.7).

5.6.2.3. Intervention Practices

Thirty-one of the 220 participants (14%) who filled out the Intervention Practices section did not provide intervention regarding academic activities to school-aged children with DCD, two of which (1%) specifically indicated not assessing these activities in children with DCD. For the 189 who did, handwriting was the academic activity most often intervened on (85%), followed by mathematics (79%), writing (77%) and reading (70%) (Table 5.2). The main reasons for not intervening on a specific academic activity were mandate limitations (62%), lack of requests to address this academic activity (14%), lack of knowledge and/or training from the OT (11%) and time constraints (3%).

To characterize their intervention practices, OTs detailed their practices with regards to direct intervention, which included remedial intervention and environmental or task modifications, and indirect intervention, which included consultative services, providing coaching and training, and participating in advocacy activities. A total of 78% of OTs reported providing direct intervention for handwriting difficulties, 60% for mathematics, 55% for writing and 50% for reading. Fifty-one percent of OTs reported delivering indirect intervention, such as coaching and training, for handwriting difficulties, 30% for mathematics, 35% for writing and 25% for reading, oriented mostly toward teachers and school personnel (88 to 91%) and parents and caregivers (71 to 85%). Among participants who intervened directly on academic activities, the CO-OP approach was the most frequently used for mathematics (70%), writing (62%) and reading (64%). For handwriting, motor learning approaches prevailed (87%). Across academic activities, the preferred modifications were adapted stationery, tools, and pencils (51 to 80%). The detailed intervention modalities are presented in Table 5.4. As for referral practices, up to 94% of participants indicated referring children with academic difficulties to other professionals, primarily to speech language therapists in presence of handwriting (32%) or reading difficulties (53%), and to teaching specialists for difficulties in mathematics (48%) or writing (51%) (Table 5.5).

5.6.2.4. Associations between personal factors or service characteristics and type of academic activities

Potential associations between personal or service characteristics and the type of academic activity assessed or intervened on were investigated to explore trends in OT practices. OTs those whose highest degree of education was a professional OT degree (Bachelor or Master's) were less likely to assess mathematics (only 68% of OTs whose highest degree was professional assessed mathematics, versus 92% of OTs with a post-professional degree, $p \leq .001$) and reading (61% vs 89%, $p \leq .001$), and to intervene on mathematics (64% vs 81%, $p = .005$), reading (51% vs 89%, $p \leq .001$), and writing (59% vs 89%, $p \leq .001$) than those with an additional post-professional degree (e.g., research or secondary Master's degree, or doctorate) ($\alpha_{adj} = .008$).

Additionally, OTs with a majority of children with DCD on their caseload (≥50%) were more likely to assess mathematics (90% of OTs with ≥50% of children with DCD on their caseload assessed mathematics versus 56% OTs with ≤30%, $X^2(1)=27.701$, $p<.001$), reading (89% vs 46%, $X^2(1)=50.704$, $p<.001$) and writing (86% vs 65%, $X^2(1)=8.737$, $p=.003$) or intervene on these activities (mathematics: 89% vs 49%, $X^2(1)=41.628$, $p<.001$; reading: 87% vs 33%, $X^2(1)=73.720$, $p<.001$; writing: 86% vs 46%, $X^2(1)=37.178$, $p<.001$) than OTs with a smaller number of children with DCD in their caseload (≤30%) ($\alpha_{adj} = .008$).

When comparing school-based OTs to those from other settings (i.e., community, rehabilitation centres, hospitals, and private practices all together), school-based OTs were found to assess significantly less often mathematics (only 44% of school-based OTs evaluated mathematics versus 76% of OTs from other settings, $p=.001$) or reading (41% vs 70%, $p=.004$) and to intervene significantly less often on handwriting (63% vs 88%, $p=.002$), mathematics (33% vs 73%, $p<.001$), reading (22% vs 64%, $p<.001$) and writing (37% vs 70%, $p=.002$) ($\alpha_{adj} = .01$). The main reasons listed by school-based OTs for not assessing or intervening on these activities were mandate limitations (68%), lack of knowledge and/or training from the OT (14%) or time constraints (11%).

Significant provincial differences were found in assessment practices for reading ($X^2(12)=35.254$, $p<.001$) and writing ($X^2(12)=54.230$, $p<.001$), as well as intervention practices for mathematics ($X^2(12)=26.805$, $p=.008$), reading ($X^2(12)=38.956$, $p<.001$) and writing ($X^2(12)=37.224$, $p<.001$). Post-hoc analyses revealed that participants from the province of Quebec less frequently assessed reading (only 41% of OTs from Quebec assessed reading versus 80% of OTs from BC; $X^2(1)=13.107$, $p=.0003$) and writing (44% vs 71%; $X^2(1)=33.835$, $p<.0001$) than those from British Columbia. Additionally, participants from Quebec less frequently assessed reading (41% vs 100%; $X^2(1)=12.984$, $p=.0003$) and less frequently intervened on reading (38% vs 100%; $X^2(1)=14.511$, $p=.0001$), and writing (40% vs 100%; $X^2(1)=13.389$, $p=.0002$) than those from Newfoundland & Labrador. All other pairwise comparisons were not significant after Bonferroni correction ($\alpha_{adj}=0.0006$).

5.7. Discussion

In addition to primary dysfunction in motor domains, children with DCD more frequently experience challenges in academic activities than typically developing peers (Dionne et al., 2022) and need appropriate interventions to support their participation and performance in these activities. As an initial step to ensure that Canadian children with DCD receive the appropriate services, we conducted the first extensive pan-Canadian survey on the assessment and intervention practices of OTs working with this population in diverse settings.

The survey revealed that almost all participants indicated assessing or intervening on at least one academic activity (99%). This widespread involvement aligns with current guidelines on the management of DCD, which recommend addressing all the activity-based needs of children with DCD, not just motor-based difficulties (Blank et al., 2019; Camden et al., 2015). The OTs sampled reported typically assessing performance in all academic activities, but only up to 60% included personal factors, such as motivation towards the activity or perceived self-esteem, in their assessment, despite the significant impact these may have on academic performance (Khanna et al., 2016). Standardized assessments were mostly used to evaluate handwriting (39%) as opposed to mathematics, reading and writing, logically aligning with the predominance of challenges in motor-based activities among children with DCD (Dhall, 2016). In terms of intervention practices, Cognitive Orientation to daily Occupational Performance (CO-OP) and motor learning approaches were preferred, consistent with evidence-based recommendations for intervention in children with DCD (Preston et al., 2017; Smits-Engelsman et al., 2013).

The survey revealed that for each academic activity, at least half of OTs reported providing interventions, yet they intervened directly and indirectly more frequently on handwriting than any other academic activity. This could be expected for reading and writing, given that in children with DCD, difficulties with these activities are much less frequently reported than for handwriting (Blank et al., 2012; Dionne et al., 2022; Tseng et al., 2007). However, difficulties in mathematics are prevalent, affecting 90% of children with DCD (Dionne et al., 2022), yet only 72% of respondents assessed mathematical performance and even fewer intervened on this activity. Given that mathematical challenges are often associated with language difficulties (Chow et al., 2021) and cognitive impairments (Schwenck et al., 2015), children facing these issues may already be receiving services from neuropsychologists or special educators for instance. Interestingly, OTs with a large proportion of children with DCD in their caseload tended to assess and intervene more on mathematics than those with fewer cases, possibly suggesting that OTs more specialized with children DCD have heightened awareness of their mathematical difficulties. Raising awareness in the broader OT community about the common mathematical challenges faced by children with DCD may be a simple yet effective solution to promote positive practice changes, encouraging OTs to either address mathematical difficulties or refer to other professionals.

Raising awareness can be effectively achieved through information dissemination initiatives as is currently recommended for physicians, teachers, and caregivers, but directed toward OTs [2, 11, 15]. For instance, these initiatives could involve organizing professional development seminars or workshops, or providing informational capsules in relevant OT electronic newsletters. OTs with a post-professional degree assessed and intervened more frequently in mathematics, reading and writing than those with a professional OT degree. Given that OTs with additional degrees tended to be younger and will eventually represent an increasingly significant portion of the OT workforce, a higher proportion of OTs incorporating all academic activities in their practices can be anticipated. Whether this reflects a change in OT curricula remains to be determined. Nevertheless, this trend, alongside ongoing information dissemination initiatives, could support better OT management of children with DCD and more holistic services for children with DCD.

Most survey participants indicated that OTs were generally involved in the diagnostic process for DCD, though not as frequently as physicians (and psychologists in some jurisdictions), who have diagnostic privileges. While the reported 30% of physicians knowledgeable about DCD in 2013 has likely increased over the following decade (B. N. Wilson et al., 2013), the fact that two-thirds of OTs self-reported having an expert or advanced level of knowledge regarding the DCD diagnostic criteria from the DSM-V validates the importance of involving OTs as experts in the DCD diagnostic process, as recommended by the Canadian Association of Occupational Therapy (CAOT, 2018). The main reason for not involving OTs was lack of awareness of their expertise among other health professionals, suggesting that advocacy efforts remain pertinent to sustain and potentially increase the frequency of OT involvement in diagnosing DCD.

Our findings indicated that the school-based OTs in our sample intervened less frequently in academic activities than those working in other settings, reporting mandate restrictions and time limitations as most frequent barriers to providing this service. Although this may highlight a potential gap in school-based OT services, this could also indicate that these children may be receiving support from other sources within the school system. Knowledge of health conditions is essential to provide inclusive and targeted instruction to support academic activities (Florian & Black-Hawkins, 2011), and children with DCD have multidimensional needs to reach success(Nabors et al., 2008; B. N. Wilson et al., 2013). Canadian OTs are recognized and for being very knowledgeable of DCD and their unique challenges (Karkling et al., 2017). Due to the nature of their training and the specificity of the profession, they are uniquely positioned to assess and support children's global functioning. Consequently, OTs should be integral members of the multidisciplinary team supporting children with DCD and academic difficulties.

Although further research is needed to identify the specific barriers that limit school-based OT interventions on academic activities in Canada, it is likely that improving the efficiency of OT services using consultative models such as "Partnering for change", a collaborative approach to service delivery that integrates OTs directly into school and community settings, could help OTs allocate more resources toward academic activities while supporting as many children as possible and fostering sustainable change (Campbell et al., 2016; Missiuna et al., 2006; Missiuna et al., 2012; Miyahara et al., 2009; Reid et al., 2006; Rens & Joosten, 2014; Wehrmann et al., 2006). However, the survey reported that Canadian OTs favored direct intervention (50% – 78%) as opposed to consultation or indirect intervention (25% – 51%). Therefore, future studies should look at exploring how to effectively implement consultative or indirect models of OT service delivery are essential in Canada. Implementing meaningful changes toward indirect service delivery will have a positive impact on OT services and will support OTs in addressing all academic activities for children with DCD.

5.7.1. Limitations.

Certain limitations in this study must be acknowledged. Firstly, using a convenience sample may have introduced a potential sampling bias, as the survey likely reached OTs that are involved or interested in academic activities, consequently providing different answers from nonparticipants. In this study, participants from British Columbia were overrepresented, whereas females, francophones, and school-based OTs were fewer than the proportion reported in the pool of Canadian OTs (Canada, 2023). To recognize these disparities, we explored associations between various personal and service characteristics, and presented the results by province, gender, language, education, experience, and setting where applicable. Secondly, the self-report nature of the survey may have introduced a respondent social desirability bias, with OTs potentially aligning their answers with best practices instead of reflecting their actual practices, as well as a recall bias, since OTs were reporting on their practices over time. These biases were likely consistent on each participant's answers, therefore skewing answers toward more desirable answers, but still allowing for individual differences to be apparent. Finally, the survey's length may have affected participant participation in the later sections of the survey. However, there were no significant differences between the personal factors or service characteristics of participants who partially completed the survey and those who completed it in full, indicating reliability in partial completions. Overall, the study's findings offer a cross-sectional take on OTs current practices across Canada, and therefore must be interpreted with caution when comparing to future studies.

5.8. Conclusion

Canadian OTs frequently assess and intervene on academic activities in children with DCD, and their practices focus predominantly on handwriting, and less on mathematics, writing and reading despite the high frequency of these difficulties in this high-risk population. Considering the study findings, we advocate for increased awareness among OTs regarding the range and extent of academic difficulties of children with DCD and the importance of assessing and intervening on all academic activities, especially among school-based OTs.

5.9. Key messages

- Most Canadian Occupational Therapists reported assessing and intervening on academic activities in children with Developmental Coordination Disorder.
- Canadian Occupational Therapists more frequently provided direct intervention for children with Developmental Coordination Disorder compared to consultative services or indirect intervention.
- Future initiatives should focus on continuing to raise Occupational Therapists' awareness of the numerous academic difficulties of children with Developmental Coordination Disorder and their role in supporting academic success.

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5.11. Tables and Figures

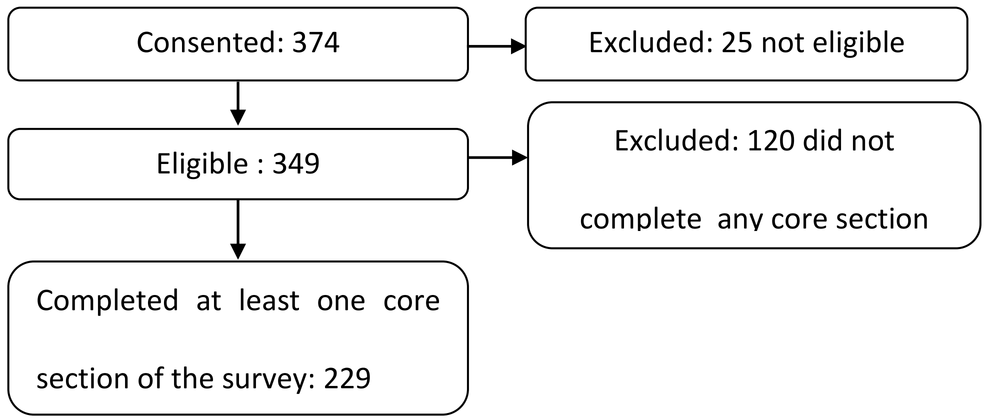

Figure 5.1 Participant flow diagram

Table 5.1 Participant personal factors and service characteristics (n=229)

			n	%
Participant's personal factors	Gender	Female	170	74
		Male	53	23
		Prefer not to answer	6	3
	Age (years)	20-29	49	21
		30-39	109	48
		40-49	44	19
		50 or more	21	9
		Prefer not to answer	6	3
	Highest degree of education achieved	Bachelors	56	24
		Professional Masters	125	55
		Research masters	40	17
		Doctorate	8	3
Service characteristics	Province or territory of employment	British Columbia	91	40
		Quebec	62	27
		Ontario	28	12
		Newfoundland and Labrador	15	7
		Alberta	12	5
		Manitoba	10	4
		Northwest Territories	8	3
		New-Brunswick	5	2
		Nova Scotia	5	2
		Nunavut	3	1
		Saskatchewan	3	1
		Prince Edward Island	2	1
		Yukon	1	0
	Employment status	Employed	194	85
		Self-employed	35	15
	Employment setting	Community-based services	57	25
		Rehabilitation centre	56	24
		Hospital	53	23
		Private clinic	36	16
		School board	27	12
	Clinical experience with children with DCD (years)	0-5	97	42
		6-10	79	35
		>11	53	23
	Proportion of caseload of children with DCD	>70%	38	17
		≈50%	73	32
		≈30%	86	38
		<10%	32	14

Table 5.2 Domains of academic activities addressed by OTs in school-aged children with DCD

		Assessment (n=229)		Intervention (n=220)	
		n	%	n	%
Handwriting		220	96	187	85
	Handwriting speed	186	81	135	61
	Handwriting legibility	160	70	147	67
	Keyboarding	102	45	94	43
	All domains	83	36	71	32
Mathematics		164	72	149	68
	Numeration	78	34	75	34
	Arithmetic and equations	68	30	66	30
	Measurements	57	25	58	26
	Problem solving	53	23	47	21
	Algebra	50	22	45	20
	Geometry	45	20	49	22
	Mental computation	36	16	44	20
	Data analysis and probability	29	13	35	16
	All domains	12	5	5	2
Writing		170	74	144	65
	Sentence composition	107	47	87	40
	Punctuation	96	42	74	34
	Organization of ideas	88	24	79	36
	Grammar	71	38	52	24
	Spelling	62	27	41	19
	All domains	28	12	16	7
Reading		151	66	130	59
	Reading fluency	114	50	71	32
	Reading comprehension	92	40	104	47
	All domains	55	24	45	20

Table 5.3 Assessment practices of OTs toward school-aged children with DCD (n=229)

		Handwriting n (%)		**Mathematics** n (%)		**Writing** n (%)		**Reading** n (%)	
Any type of assessment		220	96	164	72	170	74	151	66
Assessment component	Activity performance	187	85	111	68	116	68	95	63
	Personal factors	132	60	77	47	87	51	72	48
	Body function and structure	133	60	60	37	65	38	55	36
	Environmental factors	115	52	67	41	55	32	49	32
Assessment modalities	Direct task observations	143	65	95	58	101	59	87	58
	Interview	151	69	84	51	91	54	75	50
	Questionnaires completed by parent, child, teacher, other professional or other	112	51	64	39	64	38	62	41
	Prior documentation	107	49	68	41	62	36	44	29
	Questionnaires completed by OT	66	30	47	29	51	30	43	28
	Standardized assessments	85	39	5	3	12	7	10	7

Table 5.4 Intervention practices of OTs for school-aged children with DCD (n=220)

	Handwriting		Mathematics		Writing		Reading	
	n	%	n	%	n	%	n	%
Any type of intervention	**187**	**85**	**149**	**68**	**144**	**65**	**130**	**59**
Direct services	**171**	**78**	**131**	**60**	**122**	**55**	**111**	**50**
Environmental or task modifications	**142**	**65**	**107**	**49**	**101**	**46**	**88**	**40**
Adapted stationery	113	51	71	32	66	30	45	20
Adapted tools and pencils	111	50	69	31	64	29	45	20
Visual cues and memory aids	110	50	70	32	61	28	39	18
Technological aids	99	45	62	28	55	25	45	20
Task presentation modifications	90	41	57	26	57	26	39	18
Adapted furniture	90	41	38	17	42	19	28	13
Time modifications	77	35	47	21	45	20	24	11
Sensory tools	72	33	24	11	26	12	16	7
Remedial intervention	**109**	**50**	**84**	**38**	**66**	**30**	**55**	**25**
CO-OP	79	36	59	27	41	19	35	16
Motor learning (skill acquisition and training)	95	43	51	23	39	18	30	14
Cognitive approaches	62	28	51	23	40	18	24	11
Behavioral approaches	36	16	34	15	22	10	17	8
Biomechanical approaches	38	17	22	10	19	9	12	5
Neurodevelopmental therapy	27	12	21	10	13	6	19	9
Sensory integration therapy	36	16	15	7	12	5	12	5
Indirect services	**113**	**51**	**66**	**30**	**78**	**35**	**55**	**25**
To teachers and school personnel	99	45	58	26	71	32	48	22
To parents and caregivers	96	44	50	23	61	28	39	18
To school boards	32	15	19	9	24	11	11	5

CO-OP, Cognitive Orientation to daily Occupational Performance. To facilitate data readability, the main category responses are in bold.

Table 5.5 Referrals in presence of academic difficulties (n=220)

		Handwriting		Mathematics		Writing		Reading	
		n	%	n	%	n	%	n	%
Referral to any profession		167	76	181	82	193	88	190	86
Profession referred to	Speech-language pathologists	71	32	50	28	92	48	101	53
	Teaching specialists	67	30	87	48	98	51	84	44
	Neuropsychologists	47	21	46	25	36	19	41	22
	Psychologists	44	20	41	23	37	19	41	22
	OTs	6	3	1	1	0	0	0	0
	Optometrists	1	1	1	1	1	1	5	2

OTs, Occupational therapists.

Chapter 6. Discussion

The overarching aim of this thesis was to ascertain the nature and extent of mathematical difficulties in children with DCD and to explore OT practices in Canada related to academic activities for this population. The scientific literature on performance in academic activities in children with DCD was first reviewed. Then, the factors associated with mathematical capacity in this population were empirically investigated. Lastly, the assessment and intervention practices of Canadian OTs regarding academic activities in children with DCD were surveyed. This discussion chapter aims to highlight the novel contributions and theoretical implications of this thesis. Strengths and limitations are discussed in relation to the work, as well as implications for clinical practice and future research. The intention is that this collection of work will be hypothesis generating for future research and inform clinical best practice in supporting participation of children with DCD in their academic activities.

6.1. Evaluation of mathematical capacity

Handwriting difficulties in children with DCD are well recognized and have been extensively studied in comparison to other academic activities (Dionne et al., 2022). The review (Study 1) highlighted that handwriting difficulties are present in up to 85% of children with DCD. Although mathematical expectations for children vary greatly depending on their age, the few studies that investigated mathematical difficulties in school-aged children with DCD found prevalence rates of up to 90% and support the need to systematically assess mathematical capacity in this group of children. The literature review also revealed that in the few studies that evaluated mathematics, only the domains of numeration and arithmetic were assessed as proxies for overall mathematical capacity, while other mathematical domains, such as algebra and geometry, were overlooked, creating a gap in knowledge regarding the nature and extent of mathematical difficulties in children with DCD.

To address this gap, Study 2 utilized a wide-ranging mathematical assessment tool and found that the frequency of overall mathematical difficulties was 38%, which corresponds to half of the frequency previously identified in the review. This discrepancy in results was likely due to the use of an assessment tool free from handwritten answers and time constraints, the KeyMath 3rd edition. Since children with DCD have motor difficulties, using non-motor-based assessments may yield a more valid measure of their mathematical capacity. Although the impacts of time constraints may not be as apparent as those of handwriting in this population, studies on typically developing populations have shown that timed tasks can induce mathematics-related anxiety (Ashcraft, 2002; Faust et al., 1996; Mkhize, 2019). This type of anxiety develops from negative experiences with mathematics and tends to intensify over time, decreasing mathematical performance (Pellizzoni et al., 2022). Mathematics-related anxiety fosters avoidance behaviors, creating a negative feedback loop that further diminishes mathematical performance (Hembree, 1990; Pizzie & Kraemer, 2017; Pizzie et al., 2020). Mathematical anxiety acts by overloading working memory, diverting resources away from mathematical performance (Pizzie et al., 2020; Ramirez et al., 2013). Given that children with DCD are slow at completing numerical tasks such as equations (Gomez et al., 2017; Pieters et al., 2015) and tend to have poor working memory (Maziero et al., 2020) and a heightened risk of experiencing anxiety (Missiuna et al., 2014), they are likely to be particularly vulnerable to mathematics-related anxiety compared to their typically developing peers. However, no study to date has investigated the presence or extent of mathematics-related anxiety in children with DCD. Despite this gap in the literature, our assessment of mathematical capacity did not have time limits, minimizing the risk of inducing anxiety, and likely providing an accurate measure of mathematical capacity in the sample.

Interestingly, the findings indicated that the average performance in mathematics of children with DCD was lower than norms, although not significantly lower, with more pronounced difficulties in measurements and geometry. These specific domains of difficulties differed from those typically observed in children with a specific learning disability in mathematics, who primarily exhibit challenges in operations and numeration (Mazzocco et al., 2011; Tolar et al., 2016; Watson & Gable, 2013). This suggested that identifying the specific domains of mathematical difficulties using a comprehensive mathematical assessment may be key in distinguishing between mathematical difficulties associated with DCD and a primary learning disability in mathematics (e.g., dyscalculia).

Given that 38% of children with DCD experienced mathematical difficulties, systematic screening is recommended to identify children in need of a comprehensive assessment, thereby optimizing clinical time. Although no specific screening tool exists for mathematical challenges across its domains, initial screening can be conducted through parental or teacher interviews, direct task observation and/or a review of prior documentation such as report cards.

6.2. Underlying mechanisms of mathematical difficulties in children with DCD

In Study 2, the factors associated with mathematical capacity were investigated. Among visual-perceptual, visuo-motor integration, motor and attentional skills, visual-perceptual skills were most strongly associated with mathematical capacity and its subdomains, yet only explained a small portion of variance (15 to 18%). Although previous studies of typically developing children have emphasized the importance of visual-perceptual and visuo-spatial skills for arithmetic specifically (Lee, 2022; Yang et al., 2021), this study showed that all mathematical domains were associated with visual discrimination, visuo-spatial relations, sequential memory, and figure-ground discrimination. Understanding which individual visual-perceptual skills are linked to mathematical capacity in children with DCD may provide indirect insight into the neural mechanisms underlying mathematical performance. Indeed, the visual-perceptual impairments observed in Study 2 involve skills useful for object identification and memorization, as well as movement and spatial analysis. This suggests there may be associated dysfunction in both the ventral and dorsal visual processing streams in children with DCD (Emily et al., 2022), given evidence from neuroimaging studies that these areas of the brain are part of the neural substrates of visual perception (Uithol et al., 2021) .

A wide range of neurodevelopmental disabilities share visual memorization difficulties (Gorrie et al., 2019). Among these are children with attention-deficit/hyperactivity disorder, who performed significantly more poorly than controls on measures of visual memory, visuospatial relations and visual sequential memory. Even poorer visual-perceptual outcomes were found in children with attention-deficit/hyperactivity disorder and co-occurring conditions such as learning disabilities in reading and writing, sleep disorders and motor disabilities (Redondo et al., 2019). Children with autism spectrum disorder also showed impairments in visual memory and visual sequential memory, which were linked with the severity of their symptoms (Antoinette Sabatino et al., 2021). This suggests that visual memorization difficulties, which are associated with impairments in the ventral visual stream, are common to children with neurodevelopmental disabilities (Martin & Barense, 2023).

Visuospatial skills, which were significantly associated with mathematical capacity in the current work and are processed within the brain's dorsal visual stream (Macintyre-Beon et al.; Salimi et al., 2019), are similarly affected in children with a learning disability in mathematics (Lambert & Spinath, 2018; Sigmundsson et al., 2010). This suggests that there are likely to be shared neural pathways linking visual-perceptual skills and mathematical performance involving the dorsal visual stream. Interestingly, atypical structure and connectivity in the parietal lobes (connected to the occipital lobe through the dorsal visual stream) is also linked to poor numeration skills (Fletcher & Grigorenko, 2017; Matejko & Ansari, 2015) and action planning difficulties (Langner et al., 2019), both of which are found in children with DCD (Williams et al., 2008). Collectively, these observations point toward potential neural dysfunction that underlies DCD and mathematical learning disability. However, neuroimaging studies are needed to confirm the specific processes of neural dysfunction common to both conditions, particularly in the parietal lobes.

Overall, the mathematical difficulties of children with DCD may stem from dysfunction in both visual streams, with some visual-perceptual impairments shared with other neurodevelopmental disorders, and others specifically related to mathematics. Given that the aims of this thesis did not include identifying neural substrates, neuroimaging and behavioral studies are needed to clarify the neural basis and functioning of visual-perceptual skills in relations to mathematical capacity. Nevertheless, current evidence suggests that visual-perceptual impairments in children with DCD reflect poor neural organization and activation. This supports the broader theory of atypical brain development in this population, which posits that disruptions in neural maturation and connectivity lead to the impairments observed in children with DCD (Caeyenberghs et al., 2016; Debrabant et al., 2013; Pangelinan et al., 2013).

6.3. Intervention for mathematical difficulties in children with DCD

Given that mathematical difficulties can arise in any mathematical domain, intervention for such difficulties should be customized to meet children's needs based on mathematical or neuropsychological assessments and reports from other educational professionals, when available. Early intervention, particularly before the age of eight years, yields better automaticity in mathematical tasks, underscoring the importance of early identification and support for children with mathematical difficulties (Fletcher & Grigorenko, 2017; Fuchs et al., 2008). Specifically, top-down approaches such as task-specific training have been shown to be successful when applied in the context of mathematical rehabilitation, and should be prioritized (Frick, 2019; Haberstroh & Schulte-Körne, 2019; Lowrie et al., 2021; Lowrie et al., 2017). However, no approach specific to mathematical difficulties for children with DCD exists so far (Lemons et al., 2015). In typically developing children, research has identified strategies effective for improving mathematical capacity, including flexible teaching and using multiple means of representing mathematical concepts (Moleko & Mosimege, 2021), providing explicit instructions tailored to individual strengths and challenges (Connor et al., 2007), using functional tasks such as board games (Ramani & Siegler, 2008) and offering immediate feedback (Baker et al., 2002).

Research on very preterm babies (birth weight ≤1500grams or gestational age less than 32 weeks) and adults with neurological and visual-perceptual impairments has shown that visual-perceptual impairments can improve with functional intervention (Lind et al., 2020; Metzler et al., 2021). The enhanced visual-perceptual skills prevented adverse effects such as learning delays (Lind et al., 2020) and mitigated immediate impacts on daily functioning (Metzler et al., 2021). Given the association between visual-perceptual skills and mathematical capacity in children with DCD, intervention approaches for mathematical difficulties should be adapted to the children's visual perceptual challenges, and therefore use visualization tools. These tools, which are primarily computer-based or electronic, help visually represent mathematics while minimizing reliance on motor skills for drawing or manipulating instruments, and are effective for improving mathematical capacity in typically developing children (Babic et al., 2021; Karunasekara et al., 2022) and those with visual-perceptual impairments (Wuang et al., 2021). Concretely, online software allowing users to move shapes in space or visually deconstruct three-dimensional figures can facilitate a deeper understanding of geometry (Bülbül & Güler, 2021), such as BrainingCamp (BrainingCamp, n.d.). Visualization tools offer more benefits than traditional concrete manipulatives (i.e., tangible physical representations of numeracy concepts such as base-10 blocks) and have proven effective for use in children with autism spectrum disorder or mathematical difficulties (Satsangi & Raines, 2023; Shurr et al., 2021). While the efficacy of technological visualization tools in children with DCD has yet to be investigated, it is plausible that the reduced reliance on motor skills combined with enhanced visual support to compensate for visual-perceptual difficulties could be useful to modify mathematical tasks and improve mathematical performance in children with DCD. However, as technology is often negatively perceived, used inconsistently or abandoned in schools (Lamond & Cunningham, 2020), its integration into classrooms warrants the use of an implementation model, such as the systemic implementation framework. This framework accounts for all stakeholders and potential factors affecting technology use (Passey, 2010). Nevertheless, future research should focus on identifying strategies to effectively support the integration of technology into classrooms, specifically for mathematical tasks.

While targeted mathematical intervention tailored to the student level is logical to address mathematical difficulties, research has highlighted the benefits of complementary intervention that focuses on co-occurring challenges. For instance, self-regulation training can help alleviate the impact of attentional and organizational difficulties on mathematics (Graham et al., 2012), while cognitive restructuring or systematic desensitization can reduce the effects of mathematics-related anxiety (Ashcraft, 2002; Hembree, 1990). Ultimately, these studies support that holistic intervention for mathematical difficulties is crucial to ensure sustained improvements in mathematical performance.

6.1. Future directions in OT practices

In study 3, the findings indicate that OTs are broadly involved in assessing and intervening in academic activities, but focus predominantly on handwriting, with less emphasis on reading, writing, and mathematics. This lesser involvement in certain academic activities was recurringly attributed, in part, to a lack of knowledge and training regarding academic challenges in children with DCD among OTs, yet the potential barriers to OT practices remain to be thoroughly understood.

Considering that raising awareness and knowledge is a key determinant of practice change (Camden et al., 2015; Pellerin et al., 2019), it is essential to create professional development opportunities to address this lack of awareness of the academic difficulties associated with DCD. These professional development opportunities should be adapted to the learning climate, available resources and level of managerial involvement, as well as the knowledge state, beliefs, and individual stage of change of OTs, with a focus on disseminating knowledge adaptable to local contexts (Pellerin et al., 2019). Even though productivity standards often pose a barrier to professional development, research has shown that freeing up time for continuing education improves service efficiency and, ultimately, productivity (Johnson Coffelt & Gabriel, 2017). Among physical therapists, participation in active multi-component knowledge implementation research projects improved evidence-based knowledge (Caldwell et al., 2016), yet this effect has not been investigated among OTs even though it holds potential for bridging the gap between research and clinical practice by promoting evidence-based practice.

The survey demonstrated that OTs with a post-professional degree (e.g., research or secondary Master’s degree, or doctorate) intervened more frequently in mathematics, reading, and writing than OTs whose highest degree was at the professional OT level. Considering that post-professional degrees were negatively associated with age, this could suggest the presence of a potential shift in practice within the profession, with younger, and therefore newer, OTs including all academic activities in their practices. This pattern is not attributable to a lack of experience among younger OTs, as those with a high proportion of children with DCD on their caseload, and thus experienced with this population, were also more inclusive of academic activities than those with a smaller proportion of children with DCD on their caseload. This may be due to a change in content within the teaching curriculum, but this hypothesis would need a formal curriculum evaluation across time and training institutions to be confirmed. In any case, to sustain a greater recognition of the academic difficulties in children with DCD, targeted support is essential to ensure that the profession continues to evolve in response to the growing body of literature on academic difficulties in this population.

Lack of knowledge, which was cited by OTs across all sections of the survey, was just one of several limitations alongside mandate restrictions, time constraints and poor access to OT services. Addressing OTs' understanding of academic challenges is the first step toward improving services for children with DCD and positively influencing the other limitations reported by OTs through advocacy. Beyond professional development opportunities to change current OT practices, incorporating learning opportunities regarding academic activities in children into OT curriculums would help shape the practices of future OT clinicians. Furthermore, implementing consultative and indirect models would be a great option to address the time and access constraints and face the increasing demand for OT services in Canada (Campbell et al., 2016; G. o. Canada, 2021; Reid et al., 2006; Wehrmann et al., 2006). Examples of models include "Partnering for Change" or "Response to Intervention", which aim to optimize service efficiency by implementing universal strategies to meet the needs of a large number of children (Campbell et al., 2016; Reid et al., 2006; Wehrmann et al., 2006). However, expanding the OT workforce will eventually be warranted to overcome time constraints and improve access to services. This expansion will be influenced by systemic factors, such as professional development opportunities, educational policies, legislation, funding, and governmental priorities. Seeing as these parameters operate at a macroscopic level, a deep societal reflection on education as a fundamental priority is warranted; one that underpins the trajectory of society and fosters the socioeconomic, mental and physical well-being of all children.

6.2. Research implications and future directions

This thesis demonstrates that children with DCD face challenges across many academic activities. However, more studies on mathematical capacity in children with DCD are needed to explore factors beyond core symptoms of the disorder, such as mathematics-related anxiety, which may also contribute to academic difficulties. Since visual-perceptual skills only partly explained the mathematical difficulties observed in Study 2, future research should explore additional mathematical capacity factors beyond those specifically linked to the symptomatology of DCD, through twin studies, and investigating environmental influences such as early exposure to mathematical concepts. Addressing these areas would provide a comprehensive understanding of the etiological potential of the genetic, neurological and environmental factors contributing to DCD.

The survey of OT practices across Canada revealed that when asked about the assessment tools they used, OTs identified a greater number of assessment tools for handwriting than for mathematics, writing and reading. Among the identified assessment tools, none were appropriate for screening difficulties across all academic activities. Given that OTs frequently mentioned facing time constraints in their practices, developing an OT-specific academic performance screening tool designed for children with DCD could significantly enhance their efficiency. A few assessment tools targeting all academic activities exist, such as the *Wechsler Individual Achievement Test* (WIAT-III) (Wechsler, 2009) and the *Woodcock-Johnson Tests of Achievement* (WJ-IV) (Woodcock et al., 2014). However, these are not suited for screening purposes, were primarily designed for use by psychologists and rely on written or typed tasks, which typically hinder the performance of children with DCD. As such, designing and validating an OT-specific assessment tool to screen for academic difficulties would be instrumental in supporting practice changes that foster the inclusion of academic performance in OT practices.

6.3. Limitations

Despite the important clinical and research implication of this thesis, several limitations must be acknowledged. First, there is a potential recruitment bias due to the enrollment of children already diagnosed with DCD. Given that DCD is often underrecognized and underdiagnosed (B. N. Wilson et al., 2013), those who do obtain a diagnosis are more likely to present with severe symptoms (Peters et al., 2004). This recruitment bias may have impacted all phases of this thesis, resulting in a more homogeneous presentation of motor difficulties within the sample and excluding children with less severe DCD symptoms. Nevertheless, the large sample size in Study 2 likely partially mitigated this effect, even though mathematical difficulties were established in comparison to normative data. Although the thesis findings may not fully represent the entire spectrum of children with DCD, they capture children currently diagnosed, improving the clinical generalizability of our results.

In Canada, the diagnostic process for DCD, which can be lengthy (Dunford et al., 2004; Peters et al., 2004), may be expedited with private consultation services. These facilitate health services access only for children from high SES families. While we compared this across the studies included in the systematic review (Study 1), the participants from the cross-sectional study (Study 2) had a high average SES. Similarly, the responses from OTs surveyed in Study 3, particularly those in private practices, are likely representative of children with DCD from high SES backgrounds. Although this limits the generalizability of the study results, SES and household income were accounted for in the analyses and potential biases were highlighted where relevant. Additionally, participants for Study 2 were all schooled in French and came from only two Quebec regions, limiting the generalizability of the results. However, considering that these two regions account for 55% of the Quebec population (S. Canada, 2021) and that 91% of children in Quebec attend school in French (Office quebecois de la langue francaise, 2023), these results remain significant at the provincial level.

Seven in ten children with DCD have a co-occurring diagnosis (Dewey et al., 2002; S. Pieters, K. De Block, et al., 2012), and often negatively impact academic performance, complicating the investigation of DCD-specific manifestations. While it is possible to control for this through complimentary testing for co-occurring diagnoses, the time and resources constraints of this thesis prevented such an approach. Despite this limitation, including a wide range of children with DCD and potential co-occurring diagnoses has enhanced the clinical generalizability of the findings. Nevertheless, future studies should screen for co-occurring diagnoses to improve comparability across studies and possibly include a control group to better disentangle challenges specific to DCD from those related to other neurodevelopmental disabilities.

Even though direct assessment was prioritized for data collection, feasibility constraints necessitated the use of a caregiver-reported questionnaire for attentional skills in the 2nd study and self-reported answers in the OT practices survey (3rd study). This could have induced a respondent bias, which was likely consistent across participants in both studies. Although this limits the comparability of the findings, it ensured the collection of data on attentional skills for Study 2 and facilitated the recruitment of the largest possible sample size for Study 3, both contributing to the validity of the studies.

Lastly, the terminology related to academic activities, particularly in mathematics and visual-perceptual skills, was highly variable in the scientific literature, sometimes preventing study comparability. For example, performing calculations could be referred to as arithmetic, operations, or mental calculation. Similarly, visual-perceptual skills nomenclature lacked standardization, with studies assessing visuo-spatial skills and labelling it as visuo-spatial memory, spatial sense or skills, or visuo-spatial relations. To minimize this bias, similar concepts were carefully compared based on the type of assessment rather than the classification used in individual studies, and consistent definitions were applied across the studies in this thesis. This approach ensured a comprehensive evaluation of academic activities and their contributing factors, independent of terminology variations influenced by factors such as language or region.

Despite the several limitations to consider, the findings of these studies were relevant and therefore meaningfully contributed to the existing literature. Namely, the large sample size of Studies 2 and 3 enhanced the validity of the results. Furthermore, Studies 1 and 3 included all academic activities, allowing for comparisons across academic activity, and situating mathematical capacity within a broader academic context. Study 2 investigated mathematical capacity extensively using a comprehensive assessment tool, which was previously lacking in this research area. Finally, the pan-Canadian recruitment strategy for the survey (Study 3) yielded findings relevant at the national level, while offering a foundation for international comparisons.

6.4. Conclusion

Previous research on the academic difficulties of children with DCD has been mostly focused on activity limitations pertaining to handwriting. This thesis suggests that the limitations associated with DCD extend beyond the motor-based academic activities and impact academic performance in literacy and numeracy activities. Recognizing these impacts is essential for developing comprehensive assessment and intervention practices that address the full range of difficulties faced by children with DCD. This premise is fundamental for effectively managing DCD and providing adequate support to children with DCD, their families, and the health professionals and educators who work with them.

Regarding academic activities, this thesis has demonstrated that children with DCD experience academic difficulties in mathematics, reading and writing, not just handwriting. Overall mathematical capacity was slightly below that of their peers, with 38% experiencing difficulties, especially in measurements, geometry and problem-solving. Visual-perceptual skills explained a small proportion of mathematical capacity, yet appear as a relevant factor, contributing to the understanding of the mechanisms of neurological impairments in children with DCD. This supports the importance to tailor interventions for mathematical difficulties to individual visual-perceptual challenges using visualization tools. Thus, the findings emphasized the need to systematically screen children with DCD for academic difficulties, especially in mathematics, considering the importance of mathematics in various activities of daily living.

Regarding OT practices, this thesis showed that OTs frequently included academic activities in their practices, yet favored handwriting over mathematics, reading and writing in part due to mandate restrictions as well as lack of knowledge and time. The findings suggested a potential positive trend in incorporating academic activities into OT practices, yet that effective and efficient training opportunities should be made available to OTs to overcome the barriers that prevent OTs from various settings to assess and intervene in academic activities.

Ultimately, this thesis contributes to the recognition of the academic difficulties faced by children with DCD and supports the enhancement of OT practices to address these difficulties. These findings are crucial for both clinical applications and future research, as they aim to improve the lives of children with DCD and contribute to a broader reflection on education as a fundamental value in our society.

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Chapter 7. Appendices

7.1. DCD diagnostic criteria

Table 7.1 DCD diagnostic criteria according to the DSM-V

Criterion A	Acquisition and execution of coordinated motor skills are substantially below what would be expected given the child's age and opportunity for skill learning and use. Difficulties are manifested as clumsiness (e.g., dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (e.g., catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).
Criterion B	The motor skills deficit in Criterion A significantly and persistently interferes with activities of daily living appropriate to chronological age (e.g., self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocational activities, leisure, and play.
Criterion C	Onset of symptoms is in the early developmental period.
Criterion D	The motor skills deficits are not better explained by intellectual disability (Intellectual developmental disorder) or visual impairment and are not attributable to a neurological condition affecting movement (e.g., cerebral palsy, muscular dystrophy, degenerative disorder).

7.2. Consent forms

7.2.1. Parental consent form (Study 2)

Institut de recherche Centre universitaire de santé McGill | Research Institute McGill University Health Centre

INFORMATION AND CONSENT TO PARTICIPATE IN A CLINICAL STUDY

Study title: Determinants of mathematical performance in children with developmental coordination disorder

MUHC Study Code: 2019-4772

Study coordinator: Eliane Dionne, PhD candidate in rehabilitation

Principal investigators: Dr. Marie-Brossard-Racine and Dr. Miriam Beauchamp

Department/Division: School of Occupational and Physical Therapy at McGill University

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We would like to invite you to participate to a research study which aims to understand mathematics learning processes in children with developmental coordination disorder [DCD]. Before you decide if you would like to participate, we want you to know why we are doing the study, what you will be expected to do if you decide to participate, and we want you to know about any risks (anything unexpected that might happen) involved in participating in the study.

This research consent form will give you information about the study. The study staff will tell you about the study and answer any questions you have. We will ask you to sign this form after you have shown that you understand the study. Please take all the time you need to make your decision. In this form the use of the word "you" means you or your child.

A. PURPOSE AND GENERAL INFORMATION ABOUT THE STUDY

This research study seeks to understand mathematics learning processes in children with developmental coordination disorder [DCD]. DCD is a chronic condition with life-long implications where motor coordination is significantly affected and interfering with daily life activities. These children may also present with learning difficulties, especially in mathematics. We would like to identify some of the factors that make mathematics learning easier or more difficult for children with DCD. This understanding will hopefully guide education and health professionals on how to intervene. Our objective is to recruit a total of 55 children.

B. STUDY PROCEDURE

If you agree to participate in this study, we will arrange for you to have a 120-minute study visit, either at your home, in a clinical office in Gatineau (Hull sector) or at the Montreal Children's Hospital, at the time and place most convenient for you.

During your visits, we will:

- Perform standardized evaluations on your child to assess his/her motor, visuomotor, mathematics and visual perceptual skills and behavior.
- During your child's evaluation, we will ask you to complete questionnaires about your child's attention skills, as well as a short socio-demographic questionnaire.
- It is important that parents do not encourage or coach their child during these evaluations so that we get the most fair representation of the child's skills and behavior.

Following the study visit, we will:

- Compile the information from the evaluations.
- Draft a short summary of your child's strengths and challenges.
- Provide you with online resources and a list of generic health services that may be appropriate for children with DCD or difficulties in mathematics.
- Send you the summary and resources by email a maximum of three weeks following the study visit.

This constitutes the end of your participation in the current study.

C. RISKS AND POSSIBLE INCONVENIENCE

- Assessing motor skills involves activities including balancing on a beam of low height and throwing and catching a tennis ball or a bean bag. There is a small chance of slight physical injury related to these activities.
- Otherwise, there is no risk related to the administration of the evaluation, nor to the completion of the questionnaires.
- It is possible that we may identify challenges in mathematics, visual perception or motor coordination that may be more significant than you or your child might expect them to be, which could be emotionally upsetting.

D. VOLUNTARY PARTICIPATION

Your participation in this study is entirely voluntary. You may choose not to be in this study or decide to stop participation in the study at any time. If you decide not to be in the study, or stop participation in the study later on, this will not affect the quality of care you currently or may someday receive. If you withdraw from the study, we will keep and use any data already collected unless you specifically ask us to destroy it. If we make a significant change to the study, you will be informed and asked if you still want to participate in the study.

E. POTENTIAL BENEFITS

- Your child could benefit from the detailed motor, visuomotor, attentional, visual perceptual and mathematical assessments, as they might indicate the domains in which he or she faces more difficulties, or the domains in which his or her performance in strong. If any challenges are identified, they will be discussed with you and we will direct you to the appropriate recommendations and referrals.
- At the moment, the relationship between mathematics and DCD in children is not well understood. We hope that the results of this study will identify the determinants of mathematical difficulties in children, in the hope of developing tools to facilitate mathematical learning for children with DCD.

F. COSTS AND COMPENSATION

There is no cost for taking part in this study. Upon completion of the study visit, a complimentary gift card (value of $20) will be given to you. Parking expenses will be reimbursed with a parking voucher, if applicable.

G. CONFIDENTIALITY

All information obtained during the study will be kept confidential as required or permitted by law. Your child's identity and yours will be protected by replacing names with research numbers. Only the research team of this study will have access to the code linking your child's name to this number. If information from this study is published or presented at scientific meetings, your child's name and other personal information will not be used. The principal investigator will be responsible for securely storing all the research data for 7 years.

In order to ensure your child's protection and the quality control of the research project, the following organizations could consult your child's research record. Please note that these organizations all adhere to a confidentiality policy.

- The sponsor(s) of this project;
- Government regulatory bodies such as Health Canada;
- The research ethics committees of the Quebec hospitals where the research is happening, or a person mandated by one of them.

H. CONTACT PERSON

If you have any questions or are experiencing any issues related to this study, you may contact the study's principal investigator, Eliane Dionne, at 819-770-4392, ext. 1, or the research supervisor, Dr. Marie Brossard-Racine, at 514-934-1934, ext. 76295. If you need further information about your rights as a research subject, you may contact the hospital Ombudsman (Patient Representative) at: 514-412-4400 ext. 22223.

I. ADDITIONAL INFORMATION

You may visit the Advances in Brain and Child Development Research Laboratory (ABCD research laboratory) website (http://abcdresearch.ca/) where summaries and updates about the studies conducted at the ABCD research lab and by affiliated research team members will be posted, as they become available. Participating families will be informed of the study's results by e-mail via the principal applicant research laboratory's voluntary mailing list. No personal information will be available via the website.

J. RESEARCH ETHICS COMMITTEE

The research ethics committee of McGill University Health Center has approved this study and will monitor the project until its completion.

CONSENT FORM

Study title: Determinants of mathematical performance in children with developmental coordination disorder

MUHC Study Code: 2019-4772

Study coordinator: Eliane Dionne, PhD candidate

I have been explained what will happen during this study, have read the information included in the five pages consent form. All my questions were answered to my satisfaction. I agree that my child will participate in this research project. A copy of the signed and dated consent form will be provided to you.

Occasionally, we contact previous research study participants as we develop related research projects. In the event that a new research project, in which you or your child could participate in, is developed in the future, please indicate below if you accept to be contacted with information about the study.

Consent to participate:

[ ] I agree that my child and myself will participate to the current study. ______ (initials)

[ ] I refuse that my child and myself participate to the current study. ______ (initials)

Authorization for future contact:

[ ] I agree to be contacted for future relevant research projects. ______ (initials)

[ ] I do not wish to be contacted for future relevant research projects. ______ (initials)

In no way does consenting to participate in this research study waive my legal rights, nor release the sponsor or the institution from their legal or professional responsibilities if I am harmed in any way.

____

Name of participant (child)

____

Name of parent(s) or legal guardian Signature Date

I have explained to the parent/legal guardian all the relevant aspects of this study. I answered any questions they asked. I explained that participation in a research project is strictly voluntary and that they are free to stop participating at any time.

____

Name of person obtaining consent Signature Date

7.2.2. Assent form (Study 2)

Institut de recherche Centre universitaire de santé McGill | Research Institute McGill University Health Centre

ASSENT FORM

Study title: Determinants of mathematical performance in children with developmental coordination disorder

MUHC Study Code: 2019-4772

Principal Investigator: Dr. Marie Brossard-Racine

Study coordinator: Eliane Dionne, PhD candidate

We are asking you to take part in a research project that will help us understand how children with Developmental Coordination Disorder learn mathematics. If you agree to take part in this study, you will meet with the principal investigator, Eliane Dionne, for a total of two sessions. During these sessions, you will be asked to participate in exercises which will focus on your motor skills, your visual perceptual skills and your mathematical performance. What you say and do will be observed and you will be able to ask any question that you would like.

We talked to your parents about allowing you to take part in this project. You can still say no even if your parents say yes. It is up to you if you want to participate, and if at any time you want to stop, you can do so for any reason. Feel free to ask questions at any time.

To indicate that I understand what the study entails, I will check the following statement.

[ ] The study has been explained to me. I had a chance to ask questions about the study and I understood the answers. I am signing my name to say yes, I want to be in the study.

____

Name of participant (child) Signature Date

[ ] I have explained to the child all the relevant aspects of this study. I answered any questions they asked. I explained that participation in a research project is strictly voluntary and that they are free to stop participating at any time.

____

Name of person obtaining consent Signature Date

7.2.3. Third party consent form (Study 2)

Institut de recherche Centre universitaire de santé McGill
Research Institute McGill University Health Centre

THIRD PARTY CONSENT FORM

Study title: Determinants of mathematical performance in children with developmental coordination disorder

MUHC Study Code: 2019-4772

Principal Investigator: Dr. Marie Brossard-Racine

Study coordinator: Eliane Dionne, PhD candidate

I, ______________________________, hereby authorize Eliane Dionne, Occupational Therapist, study coordinator and PhD student, to contact the following professional to confirm my child's current diagnoses and, if applicable, to provide the scores of either the MABC-2, TVPS4, Beery VMI or KeyMath3 that were completed with my child in the last three months:

Name of the health professional: ____

Institution: ____

Contact info: ____

Information to be obtained: ____

____

____

Name of participant (child)

____

Name of parent(s) or legal guardian Signature Date

____

Name of person obtaining consent Signature Date

7.2.4. Clinician participant consent form (Study 3)

Institut de recherche Centre universitaire de santé McGill — Research Institute McGill University Health Centre

INFORMED CONSENT FORM

Study title: The role of Occupational Therapists towards academic difficulties in children with Developmental Coordination Disorder

Study coordinator: Eliane Dionne, PhD candidate in rehabilitation

Principal investigator: Dr. Marie Brossard-Racine

Department/Division: School of Physical and Occupational Therapy at McGill University

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We would like to invite you to participate to a research study which aims to understand the current practices of Occupational Therapists (OTs) with regards to academic difficulties in children with Developmental Coordination Disorder [DCD]. Before you decide if you would like to participate, we want you to know why we are doing the study and what you will be expected to do if you decide to participate in the study. If you have any question, please contact the study coordinator (see Section G). Please read the following information to ensure that you can properly decide if you would like to participate in this study.

A. PURPOSE AND GENERAL INFORMATION ABOUT THE STUDY

This research study seeks to understand the current practices of OTs working with children with developmental coordination disorder [DCD]. DCD is a chronic condition with life-long implications where motor coordination is significantly affected and interfering with daily life activities. These children may also present with learning difficulties. We would like to identify the practices that OTs use to assess and intervene on the academic difficulties that children with DCD face. We hope that such knowledge will enable us to make practice recommendations.

B. STUDY PROCEDURE

If you agree to participate in this study, you will be asked to answer a series of questions. We estimate that you will need approximately 20 minutes to complete the survey.

C. RISKS AND POTENTIAL BENEFITS

There are no expected risks associated with the study.

D. COSTS AND COMPENSATION

There are no costs for taking part in this study. At the end of the survey, you will be asked if you wish to enter the draw for four Visa gifts cards (value of $50). In order to enter the draw, you must provide your personal contact information. This information will not be associated with your answers and will only be used to contact you if you win the draw. We expect that you have a 1/250 chance of winning a gift card. Winners will be contacted approximately six months after the beginning of the study.

E. VOLUNTARY PARTICIPATION

Your participation in this study is entirely voluntary. You may choose not to be in this study or decide to stop participation in the study at any time. If you do not wish to answer to a question, you may proceed to the next one. Since no personal identification information is associated with your answers, you may not retrieve them or modify them once they are submitted.

F. CONFIDENTIALITY

All information obtained during the study will be kept confidential as required or permitted by law. Your identity will not be associated with your answers. If information from this study is published or presented at scientific meetings, no personal identification information will be used. The principal investigator will be responsible for securely storing all the research data for 7 years.

In order to ensure your protection and the quality control of the research project, the following organizations could consult your answers. Please note that these organizations all adhere to a confidentiality policy.

- The sponsor(s) of this project;
- Government regulatory bodies such as Health Canada;
- The research ethics committees of the Quebec hospitals where the research is happening, or a person mandated by one of them.

G. CONTACT PERSON

If you have any questions or are experiencing any issues related to this study, you may contact the study's coordinator, Eliane Dionne, at eliane.dionne@mail.mcgill.ca or at 819-770-4392, ext. 1, or the principal investigator, Dr. Marie Brossard-Racine, at 514-934-1934, ext. 76295. If you need further information about your rights as a research subject, you may contact the hospital Ombudsman (Patient Representative) at: 514-412-4400 ext. 22223.

I. ADDITIONAL INFORMATION

You may visit the Advances in Brain and Child Development Research Laboratory (ABCD research laboratory) website (http://abcdresearch.ca/) where summaries and updates about the studies conducted at the ABCD research lab and by affiliated research team members will be posted, as they become available. Participants will be informed of the study's results by e-mail via the principal applicant research laboratory's voluntary mailing list. No personal information will be available via the website.

J. RESEARCH ETHICS COMMITTEE

The research ethics committee of McGill University Health Center has approved this study and will monitor the project until its completion.

BY CLICKING ON THE *CONTINUE* BUTTON, YOU INDICATE THAT YOU AGREE FREELY AND VOLUNTARILY TO PARTICIPATE TO THE PRESENT STUDY.

7.3. Recruitment documents

7.3.1. Recruitment poster (Study 2)

Does your child have developmental coordination disorder (DCD)?

If so, this study is for you!

We are looking for children with DCD in grades 1 through 6 to participate in a study titled: *Determinants of mathematical performance in children with DCD.*

For more information, please contact Eliane Dionne, PhD candidate (McGill University) at 819-770-4392, extension 1 or at eliane.dionne@mail.mcgill.ca

Eliane Dionne (819) 770-4392, ext 1 eliane.dionne@mail.mcgill.ca

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Eliane Dionne (819) 770-4392, ext 1 eliane.dionne@mail.mcgill.ca

Determinants of mathematical performance in children with DCD

Study conducted by Eliane Dionne, PhD candidate (McGill University) and Dr. Marie Brossard-Racine.

The objective of this study is to understand the association between mathematical performance and DCD. We anticipate that visual-perceptual abilities will be an important factor of mathematical learning in school-aged children.

In order to participate in this study, your child must be enrolled in Grades 1 through 6 and have a diagnosis of developmental coordination disorder (DCD), also known as motor dyspraxia. If you and your child agree to be part of this study, we will ask you to participate in a two-hour testing session, either in a clinical office or at your home. You will be offered a $20 monetary compensation and parking expenses will be reimbursed if applicable. Assessments of attention, visual-motor integration, visual perceptual skills, motor coordination and mathematical performance will be completed. Following the assessments, a short personalized summary of your child's strengths and weaknesses in mathematics, including online resources, will be provided to you.

For more information, please do not hesitate to contact Eliane Dionne, PhD candidate (McGill University) at **819-770-4392, extension 1** or at **eliane.dionne@mail.mcgill.ca**

7.3.2. Recruitment pamphlet (Study 2)

Our study

Our research project aims to understand why some children with motor difficulties face challenges when learning mathematics.

Who can participate?

We are looking for children enrolled in Grades 1 through 6 with a confirmed diagnosis of Developmental Coordination Disorder.

What does my participation involve?

Your participation to this study involved a single two to three hour study visit. During this visit, we will assess your child's visual perceptual skills, visuomotor integration, motor skills and mathematical performance. During this time, you will be asked to complete two questionnaires regarding your child's attentional skills and personal characteristics.

Where will the study take place?

We are recruiting children in the greater Montreal and Gatineau area. Study visits can occur at a clinical office or at your home, depending on your preference.

Will I be compensated for my participation?

At the end of the visit, a monetary compensation will be offered ($20 gift card for Amazon per visit). We will reimburse parking expenses if applicable. Following the study visits, we will provide you with a personalized summary of your child as well as a list of resources available to support your child.

If myself or my child want to stop?

Yours and your child's participation in our research study is completely voluntary, which means that *you* decide if you want to take part in it. You or your child may choose to stop at any point during the study.

I am interested! Who can I contact?

Do not hesitate to contact Eliane Dionne, study coordinator for this study.

eliane.dionne@mail.mcgill.ca

(819)770-4392, extension 1

Does your child have motor difficulties?

This study could be for you!

7.3.3. Recruitment letter (Study 3)

Object: The role of OTs towards academic activities in children with DCD

Dear Occupational Therapists,

We would like to invite you to participate in a study that investigates the assessment and intervention practices of Occupational Therapists (OTs) in Canada working with children with Developmental Coordination Disorder (DCD), also known as motor dyspraxia. Specifically, we are interested in increasing awareness with regards to the common academic challenges in children with DCD and the OTs' role as agent of change with this clientele. Our research project is entitled "The role of Occupational Therapists towards academic activities in children with Developmental Coordination Disorder". This study is approved by the Research Ethics Board of the McGill University Health Centre and is available until January 31st, 2023.

Who can participate?

1. Occupational Therapists fluent in French or English licensed to work in Canada or any of its provinces.
2. With at least one year of clinical experience with a school-aged pediatric clientele.
3. Who had at least one client with DCD or suspected DCD in the past year.

If you are eligible to participate, we ask that you complete the following online survey. Your participation to this study is only voluntary; if you do not wish to participate, this will not have any impact on your status at your professional association or your license to practice as an Occupational Therapist. The consent form will first be presented to you; read it carefully. You will not be asked to provide personal identifying information, and the answers you provide will be strictly confidential.

Compensation: At the end of the survey, you may decide to provide a valid email address as well as your name for a chance to win one of 16 $25 Guusto gift cards for the merchant of your choice.

If you have any questions regarding this survey or the research study, please contact the study coordinator at eliane.dionne@mail.mcgill.ca, or the principal investigator, Dr. Marie Brossard-Racine at marie.brossardracine@mcgill.ca.

Thank you for your time. Sincerely,

Eliane Dionne, study coordinator
Dr. Marie Brossard-Racine, co-principal investigator
Project funded by the Canadian Occupational Therapy Foundation – McMaster Legacy Grant

7.4. Study questionnaires

7.4.1. Sociodemographic questionnaire (Study 2)

Sociodemographic questionnaire

Study ID: ____

Birth date of the child (mm/yyyy): _____________________

Gender of the child: female ☐ male ☐

Mother tongue of the child: ______________________________

Primary language used at school: ________________________

Language that the child is most comfortable with: ________________________

In which grade is your child? ___________________________________

Your child is: ☐ right-handed ☐ left-handed

Does your child have a confirmed diagnosis of developmental coordination disorder (y/n): ☐yes ☐no

Does your child have a confirmed diagnosis of attention deficit hyperactivity disorder (ADHD) (y/n): yes ☐ no ☐

Does your child take medication to control his ADHD (y/n): yes ☐ no ☐

Has your child taken his or her medication today? (y/n): yes ☐ ☐ no NA ☐

Does your child have a visual impairment (y/n): ☐yes ☐no

If yes, list your child's visual impairments: ____

____

If yes, is your child's visual impairement corrected (i.e. glasses, lenses, etc.)?☐yes ☐ no

Check the situation that applies to your child. My child has…

- ☐ Repeated a school grade (which grade: _________)
- ☐ Skipped a school grade (which grade: _________)
- ☐ My child did not skip or repeat any school grade

Please list any other confirmed conditions or diagnosis that your child has (e.g., intellectual disability, genetic condition, autism spectrum disorder, language disorder). Include any learning disabilities :

____

____

____

____

Has your child ever received intervention targeting his motor difficulties? ☐ yes ☐ no

If yes, please indicate what type of intervention (i.e. occupational therapy, physiotherapy, etc.), when and how long intervention lasted: ____
____
____
____

Has your child ever received intervention targeting mathematical difficulties? yes ☐ no ☐

If yes, please indicate what type of intervention (i.e. occupational therapy, speech language therapy, private tutoring, etc.), and when and how long the intervention lasted: _____________________________
____
____
____

Parent 1, please specify your relationship with the child: _______________________________________

What is parent 1's highest level of education completed? (circle one)

1. Elementary school (6th grade) or less
2. Partial high school (9th grade completed)
3. Partial school completed (10th grade completed)
4. High school completed
5. CEGEP, College certification, or technical program completed
6. University graduation or standard 4-year college (undergraduate degree)
7. Graduate or Professional training (graduate degree)

What is parent 1's usual employment? (circle one)

0. Unemployed
1. Farm laborer/Menial service workers (e.g., custodians, gardeners, dishwashers)
2. Unskilled workers (e.g., bartenders, cooks, food service, laborers)
3. Machine operators, semiskilled workers (e.g., truck drivers, assemblers, hairdressers)
4. Skilled manual workers, craftsmen (e.g., electricians, mechanics, receptionists)
5. Clerical and sales workers (e.g., bank tellers, cashiers, therapy assistants)
6. Technicians, semiprofessionals (e.g., administrators, therapists, technicians)
7. Small business owners, minor professionals, managers (e.g., computer programmers, real estate agents, sales managers)
8. Medium business owners, lesser professionals (e.g., accountants, pharmacists, registered nurses)
9. Major business owners, higher professionals, higher executives (e.g., lawyers, doctors, professors)

Specify Job Title: ____

If parent 1 is a business owner, please describe the business and number of employees: ______________

____

Parent 2, please specify your relationship with the child: _____________________________________

What is parent 2's highest level of education completed? (circle one)

What is parent 2's highest level of education completed? (circle one)

1. Elementary school (6th grade) or less
2. Partial high school (9th grade completed)
3. Partial school completed (10th grade completed)
4. High school completed
5. CEGEP, College certification, or technical program completed
6. University graduation or standard 4-year college (undergraduate degree)
7. Graduate or Professional training (graduate degree)

What is parent 2's usual employment? (circle one)

0. Unemployed
1. Farm laborer/Menial service workers (e.g., custodians, gardeners, dishwashers)
2. Unskilled workers (e.g., bartenders, cooks, food service, laborers)
3. Machine operators, semiskilled workers (e.g., truck drivers, assemblers, hairdressers)
4. Skilled manual workers, craftsmen (e.g., electricians, mechanics, receptionists)
5. Clerical and sales workers (e.g., bank tellers, cashiers, therapy assistants)
6. Technicians, semiprofessionals (e.g., administrators, therapists, technicians)
7. Small business owners, minor professionals, managers (e.g., computer programmers, real estate agents, sales managers)
8. Medium business owners, lesser professionals (e.g., accountants, pharmacists, registered nurses)
9. Major business owners, higher professionals, higher executives (e.g., lawyers, doctors, professors)

Specify Job Title: ____

If parent 2 is a business owner, please describe the business and number of employees: ______________

____

What is your total combined household income for the past 12 months, before taxes? If you do not know your exact income, estimate.

- ☐ Less than $25,000
- ☐ $25,000 to $34,999
- ☐ $35,000 to $49,999
- ☐ $50,000 to $74,999
- ☐ $75,000 to $99,999
- ☐ $100,000 to $149,999
- ☐ $150,000 to $199,999
- ☐ $200,000 or more
- ☐ Unsure
- ☐ Choose not to answer

If you have any concerns or questions regarding this questionnaire, please speak with the main researcher, using the contact information provided on the consent form of this study. All information will be kept confidential.

This questionnaire was filled by :

Child's study ID : ___________________________

Relation with the child: _____________________________

Date: ____________________________

7.4.2. Survey (Study 3)

The role of Occupational Therapists in the assessment and treatment of children with Developmental Coordination Disorder and academic difficulties

This survey aims to describe the Canadian practices of Occupational Therapists (OT) working with elementary school aged children (6-12 years of age) with Developmental Coordination Disorder (DCD). This survey has a particular focus on how OT involvement translates to improved academic performance. This survey will take approximately 20 minutes to complete. Once completed, you will be eligible to enter a draw to win one of 16 $25 gift certificates at the merchant of your choice through Guusto.

Throughout the survey, refer to the following abbreviations:

*OTs: Occupational Therapists

* DCD: Developmental Coordination Disorder (diagnosed, suspected or likely) or motor dyspraxia

Eligibility criteria

1. Are you currently a licensed OT in Canada?
   - ☐ Yes
   - ☐ No
2. Do you have at least one year of clinical experience with a paediatric clientele?
   - ☐ Yes
   - ☐ No
3. In the last year, did you perform at least one assessment or intervention session with a school-aged client with DCD?
   - ☐ Yes
   - ☐ No

Demographics

4. How do you currently self-identify?
   - ☐ Male
   - ☐ Female
   - ☐ Other: _______________
   - ☐ Prefer not to answer
5. What is your age?
   - ☐ 20-29 years
   - ☐ 30-39 years
   - ☐ 40-49 years
   - ☐ 50 or more
   - ☐ Prefer not to disclose.

6. Select the highest degree of education you obtained:
   - ☐ Bachelors
   - ☐ Masters (professional)
   - ☐ Masters (research)
   - ☐ Doctorate
   - ☐ Other, please specify: ____________________
7. In which province or territory do you work ~~in~~ as a pediatric OT?
   - ☐ Alberta
   - ☐ British Columbia
   - ☐ Manitoba
   - ☐ New-Brunswick
   - ☐ Newfoundland and Labrador
   - ☐ Northwest Territories
   - ☐ Nova Scotia
   - ☐ Nunavut
   - ☐ Ontario
   - ☐ Prince Edward Island
   - ☐ Quebec
   - ☐ Saskatchewan
   - ☐ Yukon
8. How many hours per week do you work as a pediatric OT?
   - ☐ Number of hours: ____________________
9. What is your employment status where you most often work with children with DCD (if you are currently on leave, please answer according to your latest status)?
   - ☐ Employed
   - ☐ Self-employed
   - ☐ Other, please specify: ____________________
10. Which setting best describes where you most often work with children with DCD?
    - ☐ Rehabilitation centre
    - ☐ Community-based services (e.g., CLSC/community health centres, community services)
    - ☐ Hospital setting (i.e., inpatient or outpatient)
    - ☐ Private practice
    - ☐ School board
    - ☐ Other, please specify: ____________________
11. How many years of clinical experience do you have as an OT working in a paediatric setting?
    - ☐ 1 to 5 years
    - ☐ 6 to 10 years
    - ☐ 11 to 20 years
    - ☐ 21 years and more
12. How many years of clinical experience do you have as an OT working with children with DCD?
    - ☐ < 1 year
    - ☐ 1 to 5 years
    - ☐ 6 to 10 years

- ☐ 11 to 20 years
- ☐ 21 years and more

13. Select the roles that best describe your mandate as an OT providing services to children with DCD. *Check all that apply.
    - ☐ Consultation or indirect services (e.g., consultative services with school boards or teachers, providing training to teachers and/or parents, lobbying)
    - ☐ Direct assessment of the child
    - ☐ Direct intervention (e.g., 1:1 or group)
    - ☐ Other, please specify: ____________________
14. Approximately what percentage of your clientele are children with DCD?
    - ☐ Most of my clientele has DCD (i.e., ≥ 70% of my clientele)
    - ☐ Approximately half of my clientele has DCD (i.e., ≈50% of my clientele)
    - ☐ Some of my clientele has DCD (i.e., ≈30% of my clientele)
    - ☐ Very few of my clientele has DCD (i.e., ≤10% of my clientele)

DCD Diagnosis

For your information, here are the official DCD criteria from the DSM-V:

A. The acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and opportunity for skill learning and use. Difficulties are manifested as clumsiness (e.g., dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (e.g., catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).

B. The motor skills deficit in Criterion A significantly and persistently interferes with activities of daily living appropriate to chronological age (e.g., self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocational activities, leisure, and play.

C. Onset of symptoms is in the early developmental period.

D. The motor skills deficits are not better explained by intellectual disability (Intellectual developmental disorder) or visual impairment and are not attributable to a neurological condition affecting movement (e.g., cerebral palsy, muscular dystrophy, degenerative disorder).

15. How would you describe your level of knowledge regarding the diagnostic **criteria** for DCD from the DSM-V?
    - ☐ Expert level
    - ☐ Advanced level
    - ☐ Intermediate level
    - ☐ Beginner level
    - ☐ No knowledge
16. To your knowledge, how frequently are OTs involved in the diagnostic **process** for the children with DCD that you see in your practice?
    - ☐ Always
    - ☐ Most of the time
    - ☐ Sometimes
    - ☐ Never

17. Why do you think OTs in your practice are not always involved in the diagnostic **process** of children with DCD?
18. Rank in order of frequency in terms of the involvement of all the professionals who, to your knowledge, are involved in the diagnostic **process** of the children with DCD you see in your practice. Exclude any professionals who are not involved in the diagnostic process.
    #1 would be most involved, then #2 next most involved and so forth (involved based on number of hours of service provided), leaving out those not involved at all.
    - ☐ Physician, pediatrician or family doctor
    - ☐ Occupational Therapist
    - ☐ Physiotherapist
    - ☐ Speech language pathologist
    - ☐ Psychologist
    - ☐ Neuropsychologist
    - ☐ Psychiatrist
    - ☐ Kinesiologist
    - ☐ Special educators
    - ☐ Social worker
    - ☐ Nurse
    - ☐ Case manager
    - ☐ Neurologist
    - ☐ Other:

Assessment approaches

This survey focuses on **academic activities**, which are the scholarly competencies (not school subjects) that children typically acquire in school (e.g., literacy and numeracy, which include learning to write, read, spell, and count). This excludes activities that pertain to daily living skills (e.g., walking, dressing, eating).

19. Do you assess elementary school-aged children with DCD?*
    - ☐ Yes
    - ☐ No.
        - ☐ Why don't you assess elementary school-aged children with DCD? _______

Ask the following 3 questions for each following academic activity:

a) Handwriting (and/or keyboarding)
b) Writing (i.e., non-motor aspects of writing such as grammar, punctuation, sentence composition, organization of ideas, spelling)
c) Reading
d) Mathematics (e.g., numeration, arithmetic, problem solving)

20. Do you assess a,b,c,d ? If so, how often?
    - ☐ Most of the time (i.e., ≥ 70% of the time)
    - ☐ Many times (i.e., ≈ 50% of the time)
    - ☐ Sometimes (i.e., ≈ 30% of the time)
    - ☐ Rarely (i.e., ≤ 10% of the time)

- ☐ No, I do not assess this activity.
    - ☐ Why don't you assess this activity? ________________

21. Which aspects of _a,b,c,d___ do you assess in elementary school-aged children with DCD?
    - ☐ Handwriting
        - ☐ Handwriting legibility
        - ☐ Handwriting speed
        - ☐ Keyboarding
    - ☐ Writing skills
        - ☐ Grammar
        - ☐ Punctuation
        - ☐ Sentence composition
        - ☐ Organization of ideas
        - ☐ Spelling
    - ☐ Reading
        - ☐ Reading comprehension
        - ☐ Reading fluency
    - ☐ Mathematics
        - ☐ Numeration
        - ☐ Algebra
        - ☐ Geometry
        - ☐ Measurements (e.g.: time, money, distance)
        - ☐ Data analysis and probability
        - ☐ Mental computation
        - ☐ Arithmetic and equations (Additions, subtractions, multiplications and divisions)
        - ☐ Problem-solving
22. When you assess _a,b,c,d____, what do you assess specifically? *Check all that apply.
    - ☐ Activity performance (e.g., speed, positioning, reading proficiency, neatness of work, use of tools)
        - ☐ Please specify which components of activity performance you assess: ____
    - ☐ Personal factors (e.g., motivation towards the activity, perceived self-esteem or self-efficacy)
        - ☐ Please specify which personal factors you assess: ____
    - ☐ Environmental factors (e.g., accessibility restrictions, teaching methods)
        - ☐ Please specify which environmental factors you assess: ____
    - ☐ Underlying components or deficits (e.g., attention span, visuomotor integration, memory)
        - ☐ Please specify which underlying components you assess: ____
    - ☐ Other
        - ☐ Please specify what other components you assess: _____
23. How do you assess _a,b,c,d___? *Check all that apply.
    - ☐ Interview (e.g., structured or semi-structured, with parents, teachers, other professionals or other)
    - ☐ Questionnaires completed by OT
    - ☐ Questionnaires completed by parent, child, teacher, other professional or other
    - ☐ Direct Task observations (e.g., during schoolwork)
    - ☐ Prior documentation (e.g., report cards, professional reports, school samples)
    - ☐ Standardized assessments

☐ Which ones: _________

☐ Other; please specify: ______________

I assess: ______

Followed by question 19, 21 and 22.

Additional questions

24. Do you assess an academic activity outside of those previously mentioned (I.e., handwriting and/or keyboarding, mathematics, reading and writing)?
    - ☐ Yes; please specify using the box below.
    - ☐ No

25. If you have any additional comments regarding your assessment practices of academic activities in school-aged children with DCD, please write them here. (OPEN TEXT BOX)

Treatment approaches for school-based activities

This survey focuses on **academic activities**, which are the scholarly competencies (not school subjects) that children typically acquire in school (e.g., literacy and numeracy, which include learning to write, read, spell, count). This excludes activities that pertain to daily living skills (e.g., walking, dressing, eating).

26. Do you treat (directly, or indirectly by consultation) elementary school-aged children with DCD?*
    - ☐ Yes
    - ☐ No.
        - ☐ Why don't you treat elementary school-aged children with DCD? ______

Ask the following 2 questions for each following academic activity:

a) Handwriting (and/or keyboarding)
b) Writing (i.e., non-motor aspects of writing such as grammar, punctuation, sentence composition, organization of ideas, spelling)
c) Reading
d) Mathematics (e.g., numeration, geometry, mental computation, problem solving)

27. Do you provide treatment for children who experience __a, b, c, d__ difficulties? *Check all that apply.
    - ☐ Yes; I use remediation approaches. *Check all that apply.
        - ☐ Cognitive Orientation to daily Occupational Performance (CO-OP)
        - ☐ Motor learning (skill acquisition and training)
        - ☐ Cognitive approaches
        - ☐ Behavioral approaches
        - ☐ Biomechanical approaches
        - ☐ Neurodevelopmental therapy

- ☐ Sensory integration therapy
- ☐ Other: ______________

☐ Yes; I use environmental or task modifications. *Check all that apply.

- ☐ Technological aids (e.g.: computer, tablets, cell phone and/or applications)
- ☐ Adapted tools and pencils (e.g.: adapted or specific pencil, erasers, protractors)
- ☐ Adapted stationery (e.g.: specialized paper, graph paper, legal-size paper)
- ☐ Visual cues and memory aids (e.g.: visual cues to sequence or organize the task or sequencing memory aids)
- ☐ Task presentation modifications (e.g.: one exercise per page, one-sided paper, size of writing on paper, verbal explanations)
- ☐ Adapted furniture (e.g.: desk, chair, cushion)
- ☐ Time modifications (e.g.: sequencing the task, additional time)
- ☐ Sensory tools (e.g.: fidget tools, noise-cancelling headphones)

☐ Yes; I provide education, coaching and/or consultation services. *Check all that apply.

- ☐ For school boards
- ☐ For teachers and school personnel
- ☐ For parents and caregivers
- ☐ Other, please specify: _________

☐ No.

- ☐ Why don't you intervene on this activity? __________

☐ Other; please specify: ________________

28. Which aspects of _a, b, c, d___ do you intervene on ?

☐ Handwriting

- ☐ Handwriting legibility
- ☐ Handwriting speed
- ☐ Keyboarding

☐ Writing skills

- ☐ Grammar
- ☐ Punctuation
- ☐ Sentence composition
- ☐ Organization of ideas
- ☐ Spelling

☐ Reading

- ☐ Reading comprehension
- ☐ Reading fluency

☐ Mathematics

- ☐ Numeration
- ☐ Algebra
- ☐ Geometry
- ☐ Measurements (e.g.: time, money, distance)
- ☐ Data analysis and probability
- ☐ Mental computation
- ☐ Arithmetic and equations (Additions, subtractions, multiplications and divisions)

☐ Problem solving

29. Do you refer children with _a, b, c, d___ difficulties elsewhere?
    - ☐ Psychologists
    - ☐ Neuropsychologists
    - ☐ Speech language pathologists (SLPs)à
    - ☐ Teaching specialists
    - ☐ Other:______
    - ☐ No; I don’t typically refer these children to other professionals or specialists (I.e., for any reason, including not part of your mandate or not necessary to refer).

Additional questions

30. Do you intervene on an academic activity outside of those previously mentioned (I.e., handwriting and/or keyboarding, mathematics, reading and writing)?
    - ☐ Yes
    - ☐ No

I intervene on: ______ Followed by questions 26 and 28.

If you have any additional comments regarding your treatment practices for school-aged children with DCD, please write them here. (OPEN TEXT BOX)

Conclusion

31. Do you have any comments regarding this survey? (OPEN TEXT BOX)

This completes the series of questions of this survey. We wish to thank you for participating in this survey and providing your responses.

If you wish to enter the draw for a chance to win one of 16 $25 gift cards for the merchant of your choice through Guusto, please provide your name and a valid email address. This information will be stored separately from your answers to the survey in order to protect the confidentiality of your answers. (OPEN TEXT BOX)

7.5. Supplementary tables and figures

Supplementary table 7.2. Search strategy (Manuscript 1)

	Academic outcome	DCD	Pediatric population	Thematic coordination
Embase	1. academic achievement/ 2. academic * achievement.mp. 3. academic underachievement/ 4. academic failure/ 5. academic failure.mp. 6. academic performance.mp. 7. academic success/ 8. academic success.mp. 9. academic activit*.mp. 10. academic difficult*.mp. 11. academic participation.mp. 12. physical education/ 13. physical education.mp. 14. reading/ 15. reading.mp. 16. writing/ 17. writing.mp. 18. handwriting/ 19. handwriting.mp. 20. education* measurement$.mp. 21. learning disorder/ 22. learning disorder*.mp. 23. learning disabilit*.mp. 24. dyslexia/ 25. dyslexi*.mp. 26. acalculia/ 27. acalculi*.mp. 28. dyscalculia/ 29. dyscalcul*.mp. 30. or/1-29	31. developmental coordination disorder/ 32. developmental co?ordination disorder.mp. 33. dyspraxia.mp. 34. motor dyspraxia.mp. 35. clumsy child syndrome.mp. 36. clums*.mp. 37. DCD.mp. 38. inco?ordinat*.mp. 39. perceptu?motor dysfunction.mp. 40. development* dyspraxia.mp. 41. disorder* of motor function*.mp. 42. development* right hemisphere syndrome.mp. 43. minor neuro* dysfunction*.mp. 44. minimal brain dysfunction*.mp. 45. development* apraxia.mp. 46. development* apractic.mp. 47. physical* awkward*.mp. 48. motor* awkward*.mp. 49. perceptual motor difficult*.mp. 50. motor-perceptual dysfunction*.mp. 51. motor learn* disabilit*.mp. 52. or/31-51	53. exp child/ 54. child$.mp. 55. exp pediatrics/ 56. pediatric$.mp 57. paediatric$.mp. 58. or/53-57 59. boy$.mp. 60. elementary student/ 61. elementary student$.mp. 62. girl$.mp. 63. kid$1.mp. 64. school$.mp. 65. juvenil$.mo. 66. underage$.mp. 67. under age$.mp. 68. teen$.mp. 69. minor$.mp. 70. youth$.mp. 71. pubesc$.mp. 72. or/59-71 73. child$.jw. 74. pediatric$.jw. 75. paediatric$.jw 76. or/73-75	77. 58 or 72 or 76 78. 30 and 52 and 77 79. limit 78 to ((english or french) and yr="1980 - Current")

MEDLINE	1. Academic Performance/ 2. academic performance.mp. 3. academic failure/ 4. academic failure$.mp. 5. Academic Success/ 6. academic success.mp. 7. academic activit*.mp. 8. academic difficult*.mp. 9. academic participation.mp. 10. academi*.mp. 11. "Physical Education and Training"/ 12. physical education.mp. 13. Learning Disorders/ 14. dyslexia/ 15. dyslexi*.mp. 16. dyscalculia/ 17. dyscalcul*.mp. 18. learn* disorder*.mp. 19. learning disabilit*.mp. 20. Handwriting/ 21. handwriting.mp. 22. Writing/ 23. writing.mp. 24. Reading/ 25. reading.mp. 26. educational measurement/ 27. education* measurement$.mp. 28. or/1-27	29. developmental co?ordination disorder.mp. 30. dyspraxia.mp. 31. motor dyspraxia.mp. 32. clumsy child syndrome.mp. 33. clums*.mp. 34. DCD.mp. 35. inco?ordinat*.mp. 36. perceptuo?motor dysfunction.mp. 37. development* dyspraxia.mp. 38. disorder* of motor function*.mp. 39. development* right hemisphere syndrome.mp. 40. minor neuro* dysfunction*.mp. 41. minimal brain dysfunction*.mp. 42. development* apraxia.mp. 43. development* apractic.mp. 44. physical* awkward*.mp. 45. motor* awkward*.mp. 46. perceptual motor difficult*.mp. 47. motor-perceptual dysfunction*.mp. 48. motor learn* disabilit*.mp. 49. or/29-48	50. exp child/ 51. child$.mp. 52. exp pediatrics/ 53. pediatric$.mp. 54. paediatric$.mp. 55. or/50-54 56. boy$.mp. 57. girl$.mp. 58. kid$1.mp. 59. school$.mp. 60. juvenil$.mp. 61. underage$.mp. 62. under age$.mp. 63. teen$.mp. 64. minor$.mp. 65. youth$.mp. 66. pubescen$.mp. 67. or/56-66 68. child$.jw. 69. pediatric$.jw. 70. paediatric$.jw. 71. or/68-70	72. 55 or 67 or 71 73. 28 and 49 and 72 74. limit 73 to (yr="1980 - Current" and (english or french))

PsychInfo	1. academic achievement/ 2. academic * achievement.mp. 3. academic overachievement/ 4. academic underachievement/ 5. academic aptitude/ 6. academic aptitude*.mp. 7. academic failure/ 8. academic failure.mp. 9. academic performance.mp. 10. academic success.mp. 11. academic activit*.mp. 12. academic difficult*.mp. 13. academic participation.mp. 14. mathematics education/ 15. math* education.mp. 16. mathematics achievement/ 17. mathematic* achievement.mp. 18. reading achievement/ 19. read* achievement.mp. 20. science achievement/ 21. scien* achievement.mp. 22. science education/ 23. scien* education.mp. 24. art education/ 25. art* education.mp. 72. developmental coordination disorder/ 73. developmental co?ordination disorder.mp. 74. dyspraxia/ 75. dyspraxia.mp. 76. motor dyspraxia.mp. 77. clumsy child syndrome.mp. 78. clums*.mp. 79. DCD.mp. 80. inco?ordinat*.mp. 81. perceptu?motor dysfunction.mp. 82. development* dyspraxia.mp. 83. disorder* of motor function*.mp. 84. development* right hemisphere syndrome.mp. 85. minor neuro* dysfunction*.mp. 86. minimal brain dysfunction*.mp. 87. development* apraxia.mp. 88. development* apractic.mp. 89. physical* awkward*.mp. 90. motor* awkward*.mp. 91. perceptual motor difficult*.mp. 92. motor-perceptual dysfunction*.mp. 93. motor learn* disabilit*.mp. 94. or/72-93 95. exp child/ 96. child$.mp. 97. exp pediatrics/ 98. pediatric$.mp. 99. paediatric$.mp. 100. or/95-99 101. boy$.mp. 102. girl$.mp. 103. kid$1.mp. 104. school$.mp. 105. elementary school students/ 106. elementary school student$.mp. 107. primary school students/ 108. primary school student$.mp. 109. juvenil$.mo. 110. underage$.mp. 111. under age$.mp. 112. minor$.mp. 113. youth$.mp. 114. pubescen$.mp. 115. or/101-114 116. child$.jw. 117. pediatric$.jw. 118. paediatric$.jw. 119. or/116-118 120. 100 or 115 or 119 121. 71 and 94 and 120 122. limit 121 to ((english or french) and yr="1980 - Current")

26. music education/
27. music* education.mp.
28. academi*.mp.
29. physical education/
30. physical education.mp.
31. reading/
32. reading.mp.
33. reading ability/
34. reading abilit*.mp.
35. reading speed/
36. reading speed.mp.
37. writing/
38. writing.mp.
39. writing skills/
40. writing skill*.mp.
41. handwriting/
42. handwriting.mp.
43. handwriting legibility/
44. handwriting legibility.mp.
45. readability/
46. readabilit*.mp.
47. cursive writing/
48. cursive writing.mp.
49. "printing (Handwriting)"/
50. printing.mp.
51. educational diagnosis/
52. educational diagnos*.mp.
53. educational measurement/
54. education* measurement$.mp.
55. achievement measures/
56. achievement measure*.mp.

	57. performance tests/ 58. performance tests.mp. 59. learning disorder/ 60. learning disorder*.mp. 61. learning disabilities/ 62. learning disabilit*.mp. 63. reading disabilities/ 64. reading disabilit*.mp. 65. dyslexia/ 66. dyslexi*.mp. 67. acalculia/ 68. acalculi*.mp. 69. dyscalculia/ 70. dyscalcul*.mp. 71. or/1-70

CINAHL	S1: "developmental co?ordination disorder" S2: "developmental co?ordination disorder" S3: "dyspraxia" S4: "motor dyspraxia" S5: "clumsy child syndrome" S6: "clums*" S7: "DCD" S8: "inco?ordinat*" S9: "inco?ordinat*" S10: "perceptuo?motor dysfunction" S11: "perceptuo?motor dysfunction" S12: "development* dyspraxia" S13: "disorder* of motor function*" S14: "development* right hemisphere syndrome" S15: "minor neuro* dysfunction*" S16: "minimal brain dysfunction*" S17: "development* apraxia" S18: ""development* apractic"" S19: "development* apractic" S20: "physical* awkward*" S21: "perceptual motor difficult*" S22: "motor-perceptual dysfunction*" S23: "motor-perceptual dysfunction*" S24: "motor learn* disabilit*" S25: S1 to S24	S26: (MH "Academic Achievement") S27: (MH "Academic Performance") S28: "academic performance.mp" S29: "academic achievement" S30: "academic success" S31: "academic difficult*" S32: "academic activit*" S33: "academic particip*" S34: (MH "Student Performance Appraisal") S35: "student performance appraisal" S36: (MH "Education, Physical Education") S37: "physical education" S38: (MH "Mathematics") S39: "math*" S40: (MH "Reading") S41: "reading" S42: (MH "Writing") S43: "writing" S44: (MH "Handwriting") S45: "handwriting" S46: (MH "Reading Disorders") S47: "reading disorder*" S48: (MH "Learning Disorders") S49: "learning disorder*" S50: "learning disabilit*" S51: (MH "Educational Measurement")	S65: S25 AND S64 S66: child* S67: pediatrics S68: paediatrics S69: boy$ S70: girl$ S71: kid* S72: school$ S73: elementary school student* S74: primary school student* S75: juvenil* S76: underage* S77: under age* S78: minor* S79: youth* S80: pubescent* S81: (MH "Child") S82: (MH "Pediatrics") S83: (MH "Students, Elementary") S84: S66 to S83	S85: S65 AND S84 S86: S65 AND S84 with Limiters - Published Date: 19800101-; Peer Reviewed; Research Article; Language: English, French

	S52: "education* measurement$" S53: (MH "Academic Failure") S54: "academic failure" S55: "academic *achievement" S56: "dysgraphia" S57: (MH "Agraphia") S58: "agraphi*" S59: (MH "Dyslexia") S60: "dyslexi*" S61: (MH "Dyscalculia") S62: "dyscalculi*" S63: "acalculi*" S64: S26 to S63	

ERIC

S1: academic performance
S2: DE "Academic Achievement"
S3: DE "Academic Education"
S4: DE "Academic Failure"
S5: academic *achievement
S6: academic education
S7: academic failure
S8: academic success
S9: academic difficult*
S10: academic activit*
S11: academic participation
S12: DE "Performance Based Assessment"
S13: DE "Dyslexia"
S14: DE "Learning Disabilities"
S15: dyscalculi*
S16: dyslexi*
S17: learning disabilit*
S18: learning disorder*
S19: learning difficult*
S20: DE "Learning Problems"
S21: learning problem*
S22: DE "Mathematics"
S23: DE "Mathematics Achievement"
S24: DE "Mathematics Education"
S25: math* education
S26: math* achievement
S27: math*
S28: DE "Writing Ability"
S29: DE "Writing Achievement"
S30: DE "Writing Difficulties"
S31: writing abilit*
S32: writing achievement

S66: "developmental co?ordination disorder"
S67: "developmental co?ordination disorder"
S68: "dyspraxia"
S69: "motor dyspraxia"
S70: "clumsy child syndrome"
S71: "clums*"
S72: "DCD"
S73: "dysgraphia"
S74: (MH "Agraphia")
S75: "agraphi*"
S76: "inco?ordinat*"
S77: "inco?ordinat*"
S78: "perceptuo?motor dysfunction"
S79: "perceptuo?motor dysfunction"
S80: "development* dyspraxia"
S81: "disorder* of motor function*"
S82: (MH "Psychomotor Disorders")
S83: "psychomotor disorder*"
S84: "sensorimotor difficult*"
S85: "sensory integrat*"
S86: "development* right hemisphere syndrome"
S87: "minor neuro* dysfunction*"
S88: "minimal brain dysfunction*"
S89: "development* apraxia"
S90: ""development* apractic""
S91: "development* apractic"
S92: "physical* awkward*"

S104: DE "Children"
S105: child*
S106: DE "Pediatrics"
S107: pediatrics
S108: paediatrics
S109: boy$
S110: girl$
S111: kid*
S112: school$
S113: DE "Elementary School Students"
S114: elementary school student*
S115: primary school student*
S116: juvenil*
S117: underage*
S118: under age*
S119: minor*
S120: youth*
S121: pubescent*
S122: S104 to S121

S123: S103 AND S122
S124: S103 AND S122 with Limiters - Peer Reviewed; Date Published: 19800101-; Language: English, FrenchERIC

S33: writing difficult*
S34: reading
S35: DE "Reading Diagnosis"
S36: DE "Reading Difficulties"
S37: DE "Reading Failure"
S38: DE "Reading Fluency"
S39: DE "Reading Ability"
S40: DE "Reading Achievement"
S41: DE "Reading"
S42: DE "Educational Diagnosis"
S43: reading diagnosis
S44: reading difficult*
S45: reading failure
S46: reading fluency
S47: reading abilit*
S48: reading achievement
S49: educational diagnosis
S50: DE "Handwriting"
S51: DE "Handwriting Skills"
S52: DE "Handwriting Ability"
S53: DE "Handwriting Ability"
S54: DE "Handwriting Difficulties"
S55: DE "Handwriting Difficulties"
S56: handwriting
S57: handwriting skills
S58: handwriting abilit*
S59: handwriting difficult*
S60: DE "Elementary School Mathematics"
S61: DE "Elementary School Science"
S93: "motor delay*"
S94: "motor skill* disorder*"
S95: (MH "Motor Skills Disorders")
S96: "motor impair*"
S97: "perceptual motor difficult*"
S98: "motor-perceptual dysfunction*"
S99: "motor-perceptual dysfunction*"
S100: "psychomotor disorder*"
S101: "motor learn* disabilit*"
S102: S66 to S101
S103: S65 AND S102

	S62: elementary school mathematic* S63: elementary school math* S64: elementary school science* S65: S1 to S64

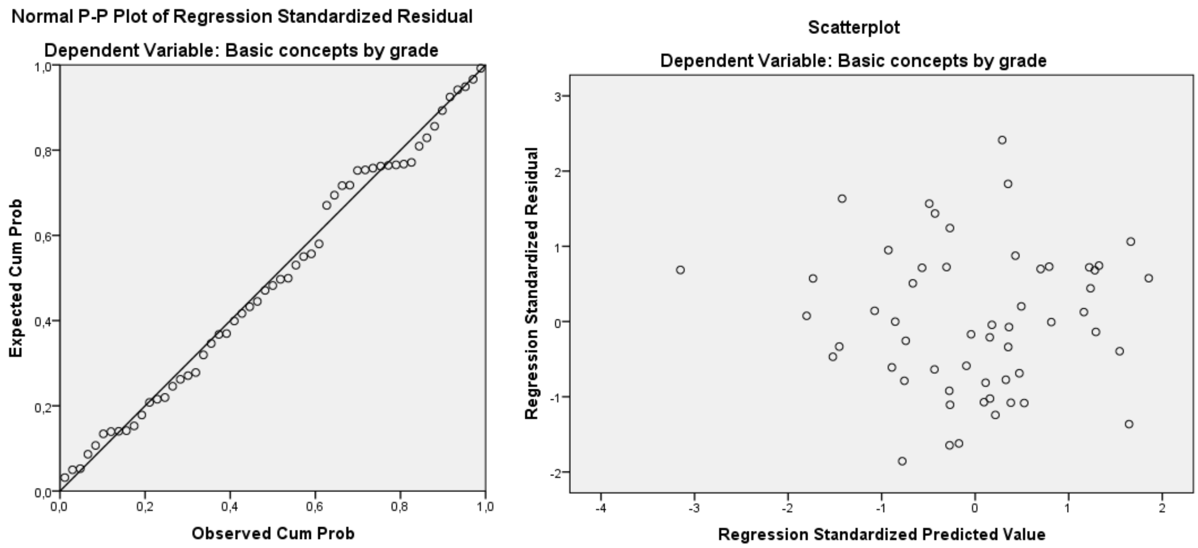
Supplementary Table 7.3. Quality assessment of reviewed studies (Manuscript 1)

Type of bias		Sampling		Statistical	Selection	Statistical	Measurement		Statistical	
Author	Year	1. Was the sample frame appropriate to address the target	2. Were the study participants sampled in an appropriate way?	3. Was the sample size adequate?	4. Were the study subjects and the setting described in detail?	5. Was the data analysis conducted with sufficient coverage of the identified	6. Were valid methods used for the identification of the condition?	7. Was the condition measured in a standard, reliable way for all participants?	8. Was there appropriate statistical analysis?	9. Was the response rate adequate, and if not, was the low response rate managed appropriately?
Alloway	2007	Unclear	Unclear	Yes	No	Yes	Yes	Yes	Yes	Yes
Alloway	2011	Yes	Unclear	Yes	No	Yes	Yes	Yes	Yes	Unclear
Alloway	2008	Yes	Unclear	Yes	No	Yes	Yes	Yes	Yes	Unclear
Cacola	2018	No	Unclear	No	No	Yes	yes	yes	yes	unclear
Cox	2015	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Dunford	2005	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Farhat	2016	No	Yes	Yes	No	No	Yes	Yes	Yes	No
Flapper	2006	No	Unclear	Yes	No	Yes	yes	yes	Yes	Yes
Gomez	2017	Unclear	Unclear	Yes	No	Yes	Yes	Yes	Yes	Unclear
Gomez	2015	Unclear	Unclear	Yes	No	Yes	Yes	Yes	Yes	Unclear
Ho	2005	Unclear	Unclear	Yes	No	Yes	Yes	Yes	Yes	Yes
Lopez	2018	No	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Missiuna	2008	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pieters	2012	Unclear	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pieters	2015	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Unclear	Yes
Prunty	2013	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Prunty	2016	No	No	Yes	No	Yes	Yes	Yes	Yes	Unclear
Prunty	2020	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Richardson	2005	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Rosenblum	2008	Unclear	Unclear	Yes	No	Yes	Yes	Yes	Yes	Yes
Rosenblum	2013	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tseng	2007	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Vaivre-Douret	2011	Yes	Yes	Yes	No	Unclear	yes	Unclear	yes	Unclear
Wang	2009	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No
% of “Yes”		25	38	96	29	88	100	96	96	63
% of “Unclear” or “No”		75	63	4	71	13	0	4	4	38

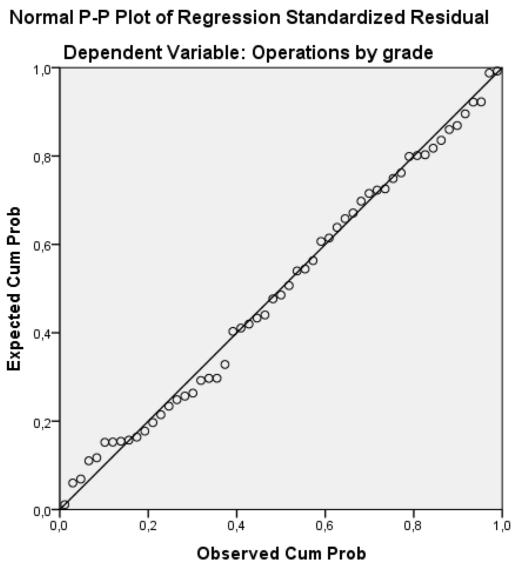
Supplementary Table 7.4 Correlations between all individual and clinical characteristics and outcomes of mathematical capacity and its domains (Manuscript 2)

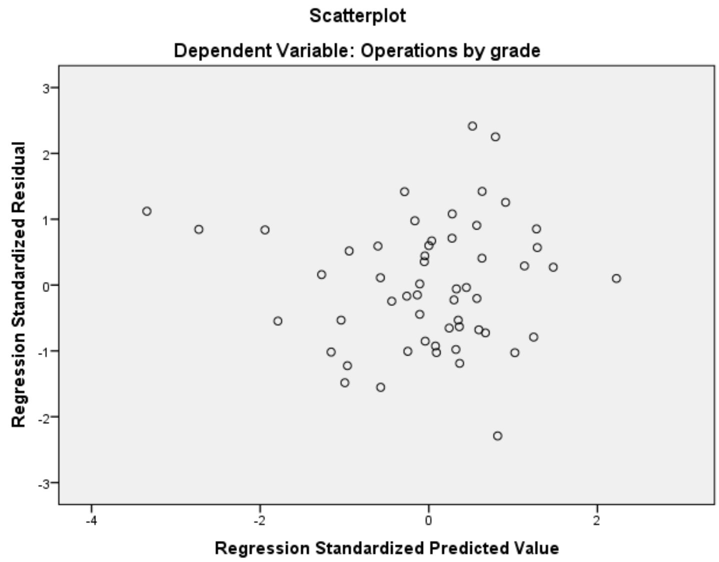
	Basic concepts	Operations	Problem-solving	Mathematical capacity
Age	-.025	.129	.063	.061
Sex	-.246	-.133	-.354	-.210
Grade	.053	.215	.199	.156
Grade repetition	.803**	.938**	.856**	.924**
Mother tongue	.222	-.035	.044	.183
Maternal education	.121	.177	.143	.117
Maternal employment	.202	.457**	.243	.268*
Paternal education	.113	.195	.230	.144
Paternal employment	.246	.354**	.291*	.285*
Household income	.282*	.530**	.365**	.360**
Any co-occurring diagnosis	.236	-.020	-.063	.107
Co-occurring ADHD	.188	.081	-.118	.118
Use of ADHD medication	.148	.148	-.049	.102
Co-occurring learning disability	.672*	1.009**	.464	.708*
Co-occurring specific language impairment	-.603	-.437	-.464	-.579
Past psychological intervention services	.065	.241	.048	.095
Past motor intervention services	-.083	.006	.269	.008
Past mathematical intervention services	.666*	.405	.481*	.604*

ADHD, attention deficit hyperactivity disorder
*: <.05
**: <.01

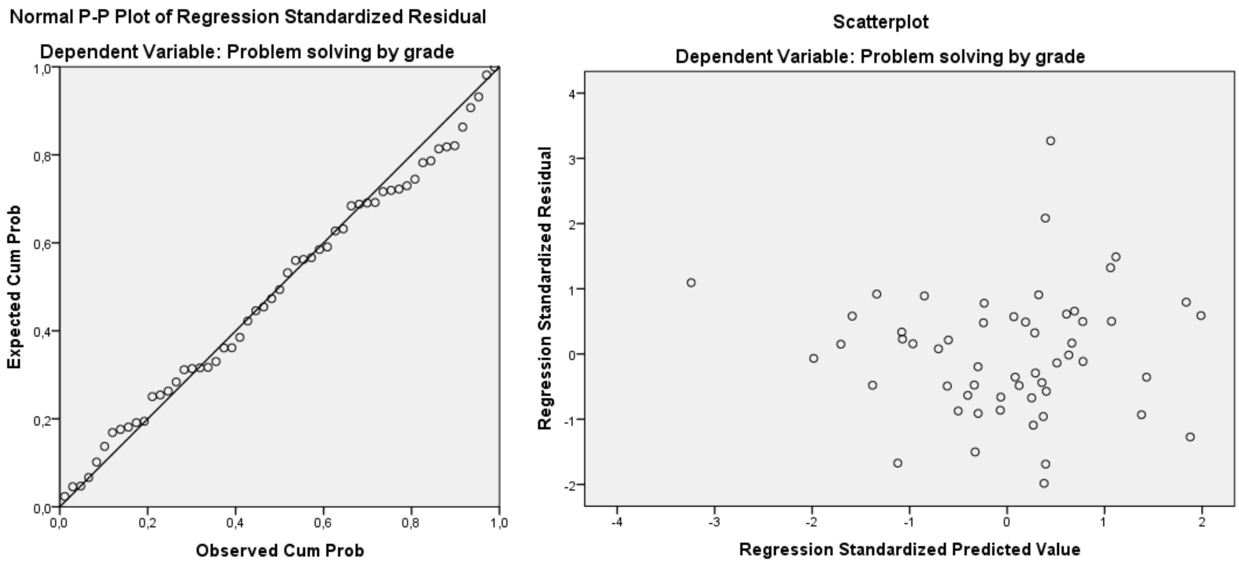


Supplementary Figure 7.1 Normal p-p plot and scatter plots of household income, VP skills, inattention scale, VMI and motor impairments for basic concepts (Manuscript 2)

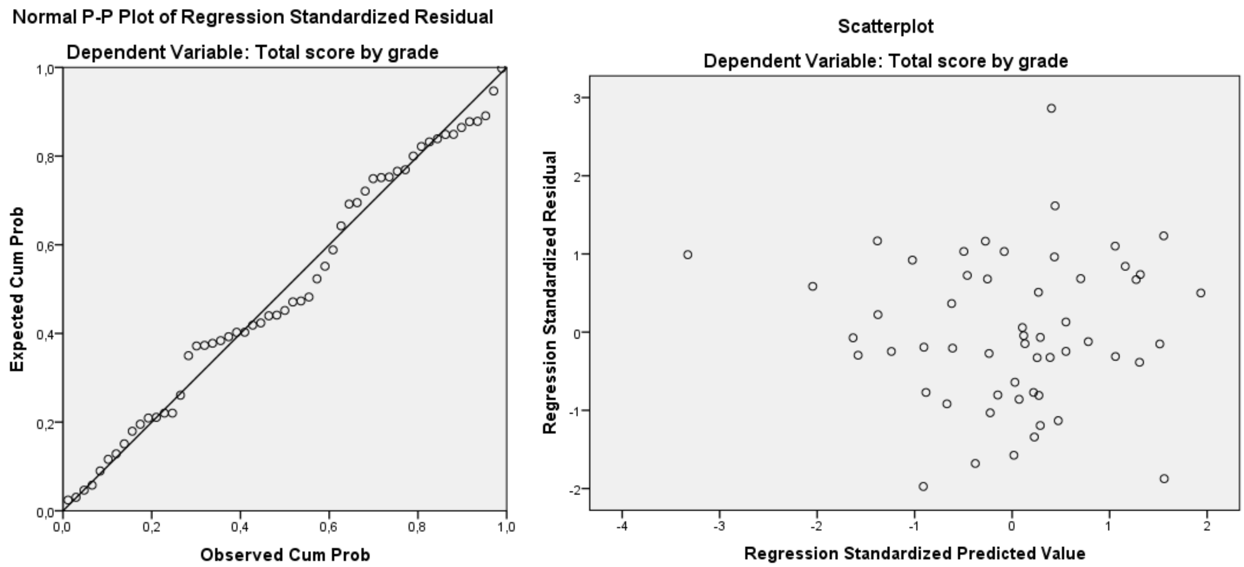




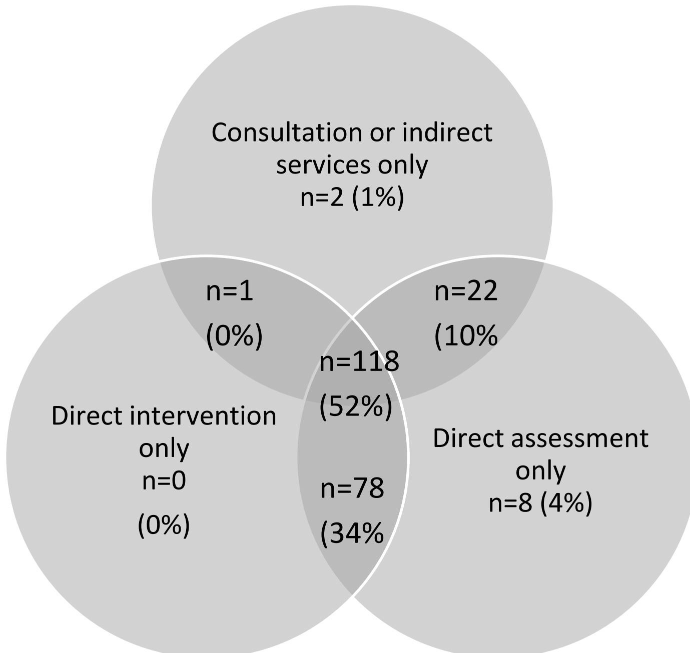
Supplementary Figure 7.2 Normal p-p plot and scatter plots of household income, VP skills, inattention scale, VMI and motor impairments for operations (Manuscript 2)



Supplementary Figure 7.3 Normal p-p plot and scatter plots of household income, VP skills, inattention scale, VMI and motor impairments for problem-solving (Manuscript 2)



Supplementary Figure 7.4 Normal p-p plot and scatter plots of household income, VP skills, inattention scale, VMI and motor impairments for mathematical capacity (Manuscript 2)



Supplemental Figure 7.5 Venn diagram of the type of services offered by the participants (Manuscript 3)

Supplemental Table 7.5 DCD diagnostic knowledge and involvement (n=229) (Manuscript 3)

		n	%
Level of knowledge of DCD diagnostic criteria from DSM-V	Expert	33	14
	Advanced	120	52
	Intermediate	64	28
	Beginner	11	5
	No knowledge	1	0
Frequency of OT involvement in diagnostic process	Always	100	44
	Most of the time	85	37
	Sometimes	39	17
	Never	5	2

Supplemental Table 7.6 Ranking distribution by professionals most involved in the diagnostic process for DCD according to participants (n=229) (Manuscript 3)

	Mean (SD)	Median	Mode	1st rank frequency n(%)	2nd rank frequency n(%)	3rd rank frequency n(%)
Physician, pediatrician or family doctor	2.4(2.2)	1.5	1	93(41%)	37(16%)	17(7%)
OT	3.2(3.0)	2	1	67(29%)	30(13%)	22(10%)
Physiotherapist	4.7(2.7)	4	3	7(3%)	20(9%)	34(15%)
Neuropsychologist	4.8(3.2)	3	3	4(2%)	29(13%)	38(17%)
Psychologist	4.9(3.3)	4	4	16(7%)	14(6%)	13(6%)
Special educator	5.8(3.6)	5	3	10(4%)	11(5%)	14(6%)
Neurologist	6.0(3.4)	6	2	4(2%)	13(6%)	3(1%)
Teacher	6.6(4.2)	5	5	4(2%)	13(6%)	10(4%)
Psychiatrist	6.6(3.8)	6	4	4(2%)	7(3%)	10(4%)
Speech language pathologist	7.2(3.7)	7	5	7(3%)	1(0%)	6(3%)
Nurse	7.4(3.8)	8	11	4(2%)	9(4%)	2(1%)
Kinesiologist	7.6(3.6)	8	10	3(1%)	7(3%)	0(0%)
Case manager	8.0(4.0)	8	5	1(0%)	3(1%)	3(1%)
Social worker	8.1(3.9)	8	13	5(2%)	2(1%)	2(1%)

Supplemental Table 7.7Assessment tools listed by academic activity (Manuscript 3)

	Assessment tool	Abbreviation	Construct assessed	Frequency (n)	Standardized or not	Reference
Handwriting	McMaster Handwriting Assessment Protocol*	MHA	Handwriting	67	NS	(Pollock et al., 2009)
	Beery-Buktenica Developmental Test of Visual-Motor Integration*	Beery-VMI	Visual-motor integration	36	S	(Beery & Beery, 2010)
	Movement Assessment Battery for Children	M-ABC	Motor skills	16	S	(Brown & Lalor, 2009)
	Bruininks-Oseretsky Test of Motor Proficiency	BOT	Motor skills	10	S	(Bruininks, 2005)
	Evaluation Tool of Children's Handwriting*	ETCH	Handwriting	8	S	(Amundson, 1995)
	Test of Visual Perceptual Skills	TVPS	Visual perception	5	S	(Martin, 2017)
	ABC Boum Handwriting Assessment Procedure	N/A	Handwriting	4	NS	
	Detailed Assessment of Speed of Handwriting*	DASH	Handwriting speed	3	S	(Barnett et al., 2007)
	Developmental Coordination Disorder Questionnaire	DCDQ	Motor coordination	3	S	(Wilson et al., 2007)
	Handwriting without tears' Screener of Handwriting Proficiency	N/A	Handwriting Proficiency	3	NS	(Olsen, 2003)

Miller Function & Participation Scales	M-FUN	Functional motor skills	3	S	(Miller, 2006)
Échelle d'évaluation rapide de l'écriture chez l'enfant	BHK	Handwriting	2	S	(Charles & Michel, 1986)
Developmental Test of Visual Perception*	DTVP	Visual perception and visual-motor integration	2	S	(Frostig et al., 2013)
Handwriting Interactive Assessment Tool*	HIAT	Handwriting performance	2	NS	(*Handwriting Interactive Assessment Tool*, N.D.)
Test de Manipulation des outils scolaires	Man.OS	Handwriting	2	NS	(Lefévère, 2010)
Perceived Efficacy and Goal Setting System	PEGS	Self-efficacy and goal setting	2	NS	(Missiuna et al., 2004)
Brock String Assessment	N/A	Oculomotor skills	1	NS	(Brock, 1950)
Developmental Coordination Disorder Checklist	DCD checklist	Motor coordination	1	NS	(Wilson, 2007)
Daily Questionnaire for Developmental Coordination Disorder	DCDDaily-Q	Motor coordination	1	S	(Schoemaker & van Netten, 2012)
Échelle Victor-Doré	N/A	Motor development	1	S	(Victor-Dore, 2016)
Épreuve de Vitesse d'Écriture de Dauphin	EVEDP	Handwriting speed	1	S	(Alexandre, 1981)

	Penmanship Test					
	Minnesota Handwriting assessment	MHA	Handwriting	1	S	(Reisman, 1999)
	Schoodles School Fine Motor Assessment	Schoodles	Fine motor skills	1	NS	(Frank, 2019)
	Sensory Profile	SP	Sensory processing	1	S	(Dunn, 2014)
	Sensory Processing Measure	SPM	Sensory processing	1	S	(Henry et al., 2007)
	This is how I write: A Child's Self-Assessment of Handwriting	N/A	Handwriting	1	NS	(Goldstand et al., 2013)
	Vestibular/Ocular Motor Screening	VOMS	Vestibular and oculomotor functions	1	S	(*Vestibular/Ocular Motor Screening*, N.D.)
Writing	McMaster Handwriting Assessment Protocol*	MHA	Handwriting	9	NS	(Pollock et al., 2009)
Writing	Test of Written Language	TOWL	Written language	2	S	(Hammill & Larsen, 2009)
Writing	Detailed Assessment of Speed of Handwriting*	DASH	Handwriting speed	1	S	(Barnett et al., 2007)
Writing	Evaluation Tool of Children's Handwriting*	ETCH	Handwriting	1	S	(Amundson, 1995)
Writing	Handwriting Interactive Assessment Tool*	HIAT	Handwriting performance	1	NS	(*Handwriting Interactive Assessment Tool*, N.D.)
Writing	Wilson Assessment of Decoding and Encoding*	WADE	Reading and spelling	1	NS	(Wilson, 1996)

Reading	Developmental Eye Movement Test	DEM	Oculomotor skills	3	S	(Richman, 1987)
	Northeastern State University College of Optometry Oculomotor Test	NSUCO	Oculomotor skills	3	S	(Optometry, N.D.)
	McMaster Handwriting Assessment Protocol*	MHA	Handwriting	2	NS	(Pollock et al., 2009)
	Cognitive Abilities Test	CogAT	Cognitive abilities	1	S	(Lohman, 2011)
	Peabody picture vocabulary test	PPVT	Receptive language	1	S	(Dunn, 2020)
	Wilson Assessment of Decoding and Encoding	WADE	Reading and spelling	1	NS	(Wilson, 1996)
Mathematics	KeyMath Diagnostic Assessment	KeyMath	Mathematical skills	3	S	(Conolly, 2007)
	Developmental Test of Visual Perception*	DTVP	Visual perception and visual-motor integration	2	S	(Frostig et al., 2013)
	Beery-Buktenica Developmental Test of Visual-Motor Interation*	Beery-VMI	Visual-motor integration	1	S	(Beery & Beery, 2010)

N/A, not available; NS, non-standardized; S, standardized.
*Assessment used for more than one academic activity.
Note: Words in *italics* are the official names of the assessments in French that have not been formally translated to English.