Finger Use and Arithmetic Skills in Children and Adolescents: A Scoping Review

Abstract

Although the role played by finger use in children's numerical development has been widely investigated, their benefit in arithmetical contexts is still debated today. This scoping review aimed to systematically identify and summarize all studies that have investigated the relation between fingers and arithmetic skills in children. An extensive search on Ovid PsycINFO and Ovid Eric was performed. The reference lists of included articles were also searched for relevant articles. Two reviewers engaged in study selection and data extraction independently, based on the eligibility criteria. Discrepancies were resolved through discussion. Of the 4,707 identified studies, 68 met the inclusion criteria and 7 additional papers were added from the reference lists of included studies. A total of 75 studies were included in this review. They came from two main research areas and were conducted with different aims and methods. Studies published in the mathematical education field (*n*=29) aimed to determine what finger strategies are used during development and how they support computation skills. Studies published in cognitive psychology and neuroscience (*n*=45) specified the cognitive processes and neurobiological mechanisms underlying the fingers/arithmetic relation. Only one study combined issues raised in both research areas. More studies are needed to determine which finger strategy is the most effective, how finger sensorimotor skills mediate the finger strategies/arithmetic relation and how they should be integrated into educational practice.

Keywords

Finger use, arithmetic, mathematical education, cognitive development and neuroscience, scoping review.

Introduction

All over the world, children use their fingers to perform numerical processing. This recurrent use leads to the emergence of habits of counting on fingers that persist into adulthood (Hohol et al., 2018) and are embedded in local cultural practices (Bender & Beller, 2011; Lindemann et al., 2011). For example, European people raise each finger, one at a time, starting with the thumb and moving to the second hand to represent the numbers 1 to 10, whereas Chinese people prefer to start counting with their index finger and represent the numbers 1 to 9 with the same hand (Bender & Beller, 2012; Domahs et al., 2010). Fingers are commonly used in various mathematical contexts because they constitute a tool that is always available and easy to manipulate (Domahs et al., 2008). Fingers also have the advantage of being a multisensory representation of the quantity (i.e., tactile and visual) (Domahs et al., 2008; Soylu et al., 2018) and providing an embodied representation of ordinal and cardinal information conveyed by numbers (Wasner et al., 2015). For instance, representing quantities with fingers helps children to solve arithmetic problems (Björklund et al., 2019; Kullberg & Björklund, 2020) while tracing with the index finger over the surface of figures enhances geometry and spatial reasoning (Ginns et al., 2016) and facilitates transfer to new problems (Ginns et al., 2020).

The role played by finger counting in the development of children’s numerical and arithmetic skills has been explored in two main research areas: (1) mathematics education, and (2) cognitive psychology and neuroscience. The findings in these two research fields are often contradictory, and the place of fingers in mathematics education is still currently a matter of debate. In their narrative review, Moeller et al. (2011) state that educators recommend abandoning fingers in favor of abstract mental representations, whereas cognitive psychologists generally agree that fingers have a beneficial influence on children’s numerical development. On closer inspection, however, it would seem that data for and against the use of fingers in numerical and arithmetic activities come as much from mathematics education as from cognitive psychology and neuroscience. Over the last two decades, a great deal of evidence from both fields has fueled this debate.

Some of this evidence questions the benefit of finger use in children's numerical and arithmetic development. Interviews conducted with parents and educators show that many elementary school teachers prohibit finger-based strategies for calculating in class to promote the usage of mental strategies, arguing that finger-based strategies are unnecessary and should only be used by preschoolers (Boaler & Chen, 2017; Multu et al., 2020). Supporting this belief, there is behavioral evidence that questions the benefit of finger use. While some studies in the past have shown that finger sensorimotor skills such as finger gnosia are correlated with children's arithmetic skills (Costa et al., 2011; Noël, 2005), recent findings show conflicting results (Long et al., 2016; Malone et al., 2020; Newman, 2016). Moreover, recent specific training of finger recognition skills did not provide evidence of their predictive value for the development of computation skills (Schild et al., 2020, but see Gracia-Bafalluy & Noël, 2008, for contradictory results). For preschoolers, finger number gestures (e.g., number 3 shown by raising thumb, index and middle finger) have been shown to be initially learned as arbitrary symbols (Nicoladis et al., 2018), and the understanding of these number gestures was found to be less advanced than that of number words (Nicoladis et al., 2010).

Consequently, some authors recommend introducing mathematical concepts in school primarily through the abstract number word sequence rather than with manipulatives (Johansson, 2005) such as tokens or fingers, since teaching mathematical concepts with these manipulatives does not predict the children's numerical development (Morgan et al., 2015). Therefore, some common classroom teaching practices, such as the Cover, Copy and Compare program, promote learning computation through memory-based strategies at the expense of finger-based strategies (Skinner et al., 1989; for a review, see Stocker & Kubina, 2017). Moreover, some programs that openly discourage children from using their fingers to calculate in the early stage of learning arithmetic have been found to be more effective than traditional instructions (McKenna et al., 2005).

By contrast, many behavioral and neuroanatomical studies have indicated that fingers influence both children's and adults' numerical processing. Regarding behavioral evidence in adults, the structure of the Western finger counting system (i.e., successively raising each finger of the first hand before switching to the second hand) has been shown to influence number magnitude processing (Domahs et al., 2010; Morrissey et al., 2016) and mental computation (e.g., increasing split-five errors) (Domahs et al., 2008; Klein et al., 2011). When finger number gestures are canonical (i.e., consistent with counting habits, such as three shown by raising thumb, index and middle finger), their processing provides automatic access to number magnitude (Di Luca et al., 2010; Di Luca & Pesenti, 2008; Sixtus et al., 2017) and facilitates arithmetic problem solving (Badets et al., 2010; Barrocas et al., 2019; van den Berg et al., 2021). Similarly, passive (Imbo et al., 2011) or active (Michaux et al., 2013; but see Morrissey et al., 2020) motor interference disrupts problem solving, suggesting that, even in adults, fingers play a functional role in numerical contexts. This behavioral evidence is further supported by several neuroanatomical studies. The first data were described in adults with Gerstmann syndrome, in which brain lesions at the intraparietal sulcus result in a conjunction of four key symptoms: finger agnosia, acalculia, right-left disorientation and agraphia (Gerstmann, 1940; Mayer et al., 1999). Since then, studies using brain imaging techniques (Andres et al., 2012; Soylu &

Newman, 2016; Tschentscher et al., 2012) and transcranial magnetic stimulation (Andres et al., 2007; Rusconi et al., 2005; Sato et al., 2007) have confirmed the existence of common cerebral correlates supporting both finger abilities and numerical skills. All this evidence suggests that adults have internalized finger-based numeration learned in childhood during their early school years.

In 2015, Roesch and Moeller proposed a developmental model in an attempt to clarify the contribution of fingers at different stages of children’s numerical development. At the first developmental stage, when children learn the sequence of number words, fingers support the segmentation of this sequence by the association of each raised finger with a specific number word (Beller & Bender, 2011). In addition, fingers are involved in procedural counting, tagging each item counted and keeping track of those that have already been counted (Alibali & DiRusso, 1999; Graham, 1999). Procedural counting influences the learning of early conceptual knowledge (Fischer et al., 2018), such as cardinality. At the second developmental stage, when children learn the cardinal principal, number gestures can be used to communicate the cardinal of a set and learn the cardinal value of new number words (Gibson et al., 2019; Gunderson et al., 2015; but see Nicoladis et al., 2018; Nicoladis et al., 2010). Lastly, at the third developmental stage, when children start to calculate, they draw on their counting and cardinal skills to acquire their first arithmetic skills and solve problems, mobilizing fingers as an external support (Roesch & Moeller, 2015).

While a hot topic at all stages of numerical development, the benefit of finger use is mainly debated for arithmetic development. A focused summary of all the existing evidence about the specific contribution of finger use to arithmetic development in children is necessary, to provide a clearer picture of the current state of the field. To date, the five narrative reviews which have attempted to overview the evidence about the relationship between finger-use and numerical cognition suggest that various finger skills support numerical and arithmetic abilities (Barrocas et al., 2020; Berteletti & Booth, 2016; Kaufmann, 2008; Moeller et al., 2011; Soylu et al., 2018). However, two of them are dated and need to be updated with the findings of the last decade (Kaufmann, 2008; Moeller et al., 2011). Additionally, the majority of these narrative reviews addressed broader questions, beyond the scope of children's arithmetic development, or limited their report to typically developing children. In fact, all these reviews reported evidence across all numerical domains with no specific focus on arithmetics (where the role of fingers is most debated). Yet, while the influence of finger use is probably different as a function of numerical tasks, knowledge is predominantly lacking regarding the nature of the finger skills specifically involved in arithmetic development. As a related issue, none of the current narrative reviews specifically targeted the whole population of school-aged children, who are likely to use their fingers during arithmetic activities. Four of them reported evidence from children and adults (Berteletti & Booth, 2016; Kaufmann, 2008; Moeller et al., 2011; Soylu et al., 2018) and one focused on kindergartners (Barrocas et al., 2020). Moreover, only evidence from typically developing participants (Barrocas et al., 2020; Berteletti & Booth, 2016; Moeller et al., 2011; Soylu et al., 2018) or from participants with mathematical learning disabilities (Kaufmann, 2008) has been reported without addressing the full range of atypical development. Yet, there is still a considerable amount of work to be done to determine the best time window, and the profiles of children sensitive to finger use in arithmetic development.

There are also limitations in the reviews that have already been published. One limit concerns the terminology used as four of the current narrative reviews use the term "finger-use" without clarifying what specific concepts are encompassed by this term (Berteletti & Booth, 2016; Kaufmann, 2008; Moeller et al., 2011; Soylu et al., 2018). The latest review (Barrocas et al., 2020) has brought significant progress to the field by disclosing the terminological disagreement among researchers and defining the concepts underlying sensorimotor skills. The writers have provided interesting leads to refine the search around fine motor skills of relevance for numerical development, including focusing on the purest measures of fine motor skills (without tools, limited executive function and visuo-spatial processing). A second limit concerns the methodology of these narrative reviews as they do not follow any systematic process to identify, characterize and summarize evidence. Their study reports are possibly driven by the authors' knowledge and, thus, based on statements made in the restricted number of identified studies. As a result, some relevant data could have been dismissed or involuntarily ignored, leaving the door open for reported biases.

To sum up, although the existing narrative reviews provide important information about finger use in a mathematical context, there is currently no compelling focused synthesis of all existing evidence on the specific contribution of finger use to arithmetic development in typically, and atypically, developing children. Therefore, the current work presents a scoping review to fill this gap and to provide a robust synthesis of the evidence on this topic. This study design warrants the identification of evidence in a transparent and objective manner in order to counteract the selection biases present in current narrative syntheses. Furthermore, this scoping review prepares the ground for a systematic review, since it ensures that there is sufficient relevant evidence on a given question to start this work. The main objective of this scoping review is to identify, characterize and summarize all qualitative and quantitative evidence from the fields of mathematical education and cognitive psychology that has investigated the relationship between finger use and arithmetic skills in school-aged children and adolescents, with typical, or atypical, development.

Methods

Protocol and Registration

The research protocol was registered on May 25, 2021, in the Open Science Framework (OSF), see [https://osf.io/ek2gd/?view_only=c23029cdaae2437abeeaa5a3be93a32b]. This review followed the recommendations suggested in the JBI methodology for scoping reviews (Aromataris & Munn, 2020) and was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR) Checklist (Tricco et al., 2018).

Eligibility Criteria

The Participants, Concept, Context (PCC) eligibility criteria (Aromataris & Munn, 2020) are described in the following sections.

Population

Studies including children or adolescents aged between 3 and 17 years enrolled in either regular or special education systems were eligible for this review. Children with typical and atypical development were included. Atypical development entailed, here, the presence of a neurodevelopmental disorder resulting from unknown origin, as in many occurrences of learning disabilities (e.g., developmental language disorder, developmental coordination disorder, mathematics learning disorder) or from a non-progressive congenital pathology detected at birth or in the first months of life (e.g., genetic syndrome, cerebral palsy). Conversely, studies conducted of participants with acquired injuries (e.g., traumatic brain injury, neuroblastoma) or progressive neurological conditions (e.g., epilepsy) were excluded.

Concept

The concept examined in this scoping review was *the use of fingers*. Only studies involving a task requiring participants to use their fingers physically and assessing finger skills with no contamination by other irrelevant cognitive abilities were included (e.g., visuospatial processing, visual guidance, see Barrocas et al., 2020 for a discussion). This criterion resulted in two main types of measures, assessing either the utilization of *finger-based strategies* during calculation, both qualitatively (i.e., how are fingers used) and quantitatively (i.e., how frequently they are used), or *finger sensorimotor skills* (e.g., ability to perceive sensory input and to execute fine motor movements whith the fingers). Regarding *finger-based strategies*, only studies targeting motor outcomes (e.g., number of occurrences of finger-based strategies during problem solving; finger movement analysis during calculation) were included. Taking these criteria into account, studies focusing on the observance of finger movements performed by a third party (e.g., influence of teacher’s finger movements on children’s arithmetic performance) were excluded. With regard to *finger sensorimotor skills*, studies targeting graphomotor and writing skills were not deemed eligible because fine motor skills involving fingers were entangled with other cognitive abilities such as pencil manipulation or letter/word knowledge (Barrocas et al., 2020; Carlson et al., 2013; Suggate et al., 2018).

Context

This review is limited to studies examining finger use in the context of *arithmetic problem solving*. Only studies requiring participants to solve arithmetic problems on their own were selected. Arithmetic problems included single- or multi-digit problems of any type (i.e., addition, subtraction, multiplication, division) in any form (e.g., mental computation with or without time constraints, written computation, arithmetic verification task). Furthermore, studies assessing mathematical skills using a test battery were included only if and when arithmetic measures could be clearly identified and isolated from the other mathematical scores. Studies asking participants to solve other types of mathematical tasks (e.g., geometry, etc.) were excluded.

Types of Sources

Only peer-reviewed journal articles written in English, regardless of the publication date, were eligible for this review. All types of study designs were eligible with the exception of reviews and meta-analyses. This encompassed experimental or quasi-experimental studies (e.g., randomized controlled trials, non-randomized controlled trials, cluster randomized controlled trials), observational studies (e.g., longitudinal or cohort studies, case-control studies, cross-sectional studies, case reports) and qualitative studies. Only experimental and quasi-experimental studies were considered as providing high-level evidence since they established causal links between finger use and children’s arithmetic development. Observational and qualitative studies were considered as providing medium- or low-level evidence (Brighton et al., 2003; Murad et al., 2016).

Information Sources and Search

An extensive literature search was conducted in January 2021 and updated in November 2021. Two main electronic databases were consulted: Ovid PsycINFO and Ovid ERIC. The search strategies (described in Table S1 in the supplementary material), which combined text words and, when relevant, controlled vocabulary tailored to each database, were performed with the help of a specialist with experience in evidence synthesis (ND). The reference lists of all included documents were searched for any additional papers.

Selection of the Sources of Evidence

All identified records were uploaded into Covidence software (Covidence Systematic Review Software; Veritas Health Innovation, Melbourne, Australia) and duplicates were removed. Following a pilot test, titles and abstracts were screened by two independent reviewers (MG and MN) according to the eligibility criteria. Then, the full texts of selected studies were assessed by the same two reviewers. At both stages, discrepancies between the two reviewers during selection process were resolved through discussion or by consulting an additional reviewer (LR).

Data-Charting Process

Data Collection Process

The data were extracted by the two main investigators (MG and MN) using a data-charting form, which was first pretested on a small sample of studies (*n*=4). This form was then adjusted by adding or specifying data to be extracted. Thereafter, data on 20% of the included studies (*n*=14) were extracted blindly and compared to evaluate the inter-rater agreement. Since the agreement was high (i.e., Kappa index = 0.812), half the remaining included studies (40%) were randomly assigned to one of the two investigators, while the other half (40%) was assigned to the other investigator. When uncertainty about some of the extracted data existed, the article was set aside and reconsidered independently by both investigators until agreement was reached (*n*=1).

Data Charting

The data-charting form was built around five main topics: (1) studies' characteristics; (2) participants' characteristics; (3) description of the experimental tasks; (4) main results and, if relevant, the significance and effect size of the statistics used; and (5) the authors' interpretation of the results.

Effect size magnitudes were described using the Cohen's benchmarks (1988). Correlations (*r*) of .10, .30, .50, R-square of .02, .13, .26 and Eta-square of .01, .06, .14 were considered as small, medium and large, respectively. When multiple outcomes of interest were reported, range of effect sizes were then considered.

Data Items

Because the publication dates of the studies included range between 1938 and 2021, different terms were used to label the participants' cognitive or medical profiles. All of these terms are recorded in Table 1 and grouped under a single dedicated appellation based on the Medical Subject Headings (MeSH) (with the relevant abbreviation) used throughout this scoping review.

[Table 1]

Among finger sensorimotor skills, the terms *finger schema*, *finger gnosia*, *finger localization* and *finger differentiation* were grouped under the generic term *finger gnosia*, defined as the ability "to differentiate one's fingers when they are out of view" (Malone et al., 2020, p. 1168). The terms *fine motor skills/abilities/coordination, finger/manual dexterity*, *eye-hand coordination* and *hand skills,* were grouped under the generic term *fine motor skills,* defined as "small muscle movements requiring close eye-hand coordination" (Luo et al., 2007, p. 596) and distinguished from graphomotor and writing skills (Carlson et al., 2013; Suggate et al., 2018).

Critical appraisal of individual sources of evidence

Since this scoping review aimed to map all available evidence, no bias risk assessment or quality appraisal of the included studies was conducted. This approach is consistent with the methods manual published by the Joanna Briggs Institute (Aromataris & Munn, 2020).

Synthesis of Results

The synthesis focused on describing the characteristics and the results of the source of evidence.

Results

Selection of Sources of Evidence

Of the 4,707 studies identified in the two electronic databases, 68 studies met the eligibility criteria and were therefore included. The additional searches in the reference lists of these articles led to the addition of 7 relevant studies. At the end of the selection process, 75 studies were included. The full selection process is documented in the PRISMA flow chart (Figure 1).

[Figure 1]

Characteristics of Sources of Evidence

Study Designs

Ninety-two percent (*n*=69) of the included studies were conducted with quantitative methods while 8% used qualitative methods (*n*=6). Of the quantitative studies, 52.2% were cross-sectional studies (*n*=36), 21.7% were cluster, randomized, or non-randomized controlled trials (*n*=15), 20.3% were longitudinal or cohort studies (*n*=14), and 2.9% were case-control studies (*n*=2). Two study (2.9%) combined two designs. (See Table S2 in the supplementary material for further characteristics of the included studies.)

Countries of Origin

The studies were conducted in 19 different countries on four continents: the Americas (38%, *n*=29; most represented country: USA, *n*=24), Europe (43%, *n*=33; most represented country: UK, *n*=11), Asia (12%, *n*=9; most represented countries: Japan (*n*=2) and Turkey (*n*=2)) and Oceania (4%, *n*=3, all from Australia). Three percent of the studies (*n*=2) resulted from international collaborations between the USA and China (*n*=1) or India (*n*=1).

Participants

Sixty-two percent (*n*=46) of the included studies were carried out with typically developing children (TD children), 13% (*n*=10) were conducted only with children with atypical development (children with aTD) and 25% (*n*=19) were conducted with both TD children and children with aTD. In the following paragraphs, we summarize participant characteristics: cognitive profiles, grade level or age, and type of education in which they were enrolled. Because most studies did not focus on a single population, many were referenced multiple times.

With regard to studies conducted in TD children (*n*=67), participants were young preschoolers (6%, *n*=4), kindergartners or children in primary school (86.5%, *n*=58) and/or adolescents in secondary school (6%, *n*=4). One study (1.5%) did not report any information about the participants' grade level or age. When the type of education was specified (83.6%, *n*=56), participants were always enrolled in mainstream education.

Studies conducted in participants with aTD (*n*=46) included participants with motor disorders (32.6%, *n*=15), learning disorders (37%, *n*=17), intellectual disabilities (8.7%, *n*=4) or other congenital disorders (21.7%, *n*=10). These participants were preschoolers (2.2%, *n*=1), kindergartners or children in primary school (78.3%, *n*=36) and/or adolescents in secondary school (15.2%, *n*=7). Two studies (4.3%) provided no information about the participants' grade level or age. Of the studies that mentioned the type of education (65.2%, *n*=30), a majority of participants with aTD were enrolled in mainstream education (66.7%, *n*=20). The others were enrolled in special education (33.3%, *n*=10). See Figure 2 for further details.

[Figure 2]

Results of Individual Sources of Evidence

This section summarizes the results of the 75 studies included in this scoping review (see distribution in Figure 3). Firstly, 38.7% percent of them (*n*=29) sought to *determine what finger strategies are used by participants during computation throughout development and how they support arithmetic performance.* We have classified these studies as belonging to the research field of mathematical education. Then, 60% of them (*n*=45) aimed to identify *the cognitive processes and neurobiological mechanisms underlying the relation between fingers and arithmetic* and were classified as belonging to the research area of cognitive psychology and neuroscience. Only one study (1.3%) combined methods from the two research areas, bridging the gap between them. Throughout this section, the results of these three classes of studies are presented with consideration of the type of study design (quantitative studies are presented from high to low level of evidence (Brighton et al., 2003), followed by qualitative studies). The main results are listed in Table S3 in the supplementary material and summarized in Figure 4.

[Figure 3]

Mathematical Education

For the mathematical education studies (*n*=29), three main research objectives were identified. The first was to describe the finger-based strategies children use during calculation (classified in Figure 3 as “Finger strategies,” *n*=5, 17.2%). The second objective was to explore the efficiency of finger-based strategies as a tool to support children’s arithmetic performance (classified in Figure 3 as “Efficiency of finger strategies,” *n*=17, 58.6%). The last was to investigate how children switched from finger-based to memory-based strategies over time (classified in Figure 3 as “From fingers to memory retrieval,” *n*=6, 20.7%). One study (3.5%) that presented two separate experiments was classified in two categories.

Finger-Based Strategies in Calculation. Of the six studies focusing on finger-based strategies, one was a cross-sectional study and five were conducted with qualitative designs.

The cross-sectional study was carried out with TD children who were expert in the use of a mental abacus[1] (Brooks et al., 2018); the number of gestures and gesture sizes produced when calculating one- or two-digit additions were assessed. The results showed that the children gestured more when they solved complex addition problems than for simple addition.

Five qualitative studies were conducted in TD children. The main purpose of these studies was to document how children used their fingers spontaneously when they solved addition (Baroody, 1987; Fuson & Kwon, 1992; Kullberg & Björklund, 2020; Nwabueze, 2001) or subtraction problems (Björklund et al., 2019; Fuson & Kwon, 1992; Kullberg & Björklund, 2020; Nwabueze, 2001). The analyses revealed that participants used a variety of finger-based strategies constituting an embodied representation of ordinal and cardinal information conveyed by numbers including finger-counting strategies in which fingers were folded and unfolded

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[1] Mental computation technique in which children use specific gestures imitating bead manipulation on an abacus.

sequentially, cardinal strategies in which fingers were used as cardinal sets, or a combination of both.

Efficiency of Finger-Based Strategies in Calculation. The 18 studies conducted on the efficiency of finger-based strategies as a tool to support children's arithmetic performance comprised one cluster randomized controlled trials, two within-subject randomized controlled trials, five non-randomized controlled trials, one cohort study, one case-control study, seven cross-sectional studies and one qualitative study.

The cluster randomized controlled trial (Chao et al., 2000) was conducted in TD kindergartners and contrasted finger-users and non-finger-users**.** Arithmetic skills were trained in two programs using either abstract manipulatives (i.e., numbers were represented by sets of abstract objects such as dots) or concrete manipulatives (i.e., number were represented by sets of concrete objects such as cars or apples). The results showed that, among finger-users, training with concrete manipulatives was more effective in increasing their calculation performance than the use of abstract manipulatives.

The two within-subject randomized controlled trials aimed at clarifying which, and to what extent, finger strategies are necessary in performing arithmetic tasks with and without mental abacus in TD children. For mental abacus (Cho & So, 2018), the comparison of three experimental conditions (i.e., physical abacus, hands free during mental abacus use, hands restricted during mental abacus use) in beginning, intermediate and advanced learners showed that gesture was important for beginning and intermediate learners to solve computation but not for advanced leaners. In Brooks et al.'s (2018) study, participants were asked to calculate in four conditions: control condition, without visual feedback, without proprioceptive feedback, or without motor planning. Their results showed that children were less efficient in the fourth condition than the other three, suggesting that, more than gestures, it is motor planning that plays the most important role in advanced learners' computation with a mental abacus.

Five non-randomized controlled trials were conducted in TD primary school children. In four of them, participants were trained to explicitly use finger strategies to solve addition and subtraction problems (Fuson, 1986; Fuson & Secada, 1986; Fuson & Willis, 1988; Ollivier et al., 2020). A significant improvement in calculation performance was consistently observed after training. In the last study, Stegemann and Grünke (2014) trained children using the Chisanbop finger counting method.[2] This training yielded inconclusive results as second-graders did not show a significant improvement in their calculation performance, whereas fifth-graders in the control group improved their performance but not those in the training group.

In the cohort study, Jordan et al. (2008) followed TD kindergartners until the second grade and found small to large correlations between finger use and arithmetic performance, which decreased significantly over time.

In the experimental case-control study, three adolescents with ID were trained with a video intervention to solve addition and subtraction problems using finger strategies. The results showed an enhancement of their calculation performance following the intervention (Saunders et al., 2018).

Seven cross-sectional studies were carried out. Some of them showed how finger-based strategies can influence children's computation performance (*n*=3). Thus, Farrington-Flint et al. (2009) and Lucangeli et al. (2003) examined spontaneous finger-based strategies used to solve computation problems in TD participants enrolled in grades 1 to 5 and showed that the use of finger-based strategies was related to higher-level arithmetic performance. However, cluster

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[2] A Korean finger counting method in which each finger has a number value. The fingers of the right hand count as one except for the thumb, which counts as five, while the fingers of the left hand count as ten.

analyses carried out in TD children led to distinguishing three groups of finger users in arithmetic tasks: (1) an efficient-count group of children who made efficient use of fingers; (2) an inefficient-count group of children who used their fingers inefficiently; and (3) a flexible group of children with mixed performance (Canobi, 2004).

Other cross-sectional studies contributed to isolating cognitive or demographic factors that could influence the relationship between finger use and computation performance (*n*=4). Regarding demographic factors, Jordan et al. (1992) showed that middle-income TD children used finger-based strategies more often and more efficiently than low-income TD children. Concerning cognitive factors, Newman and Soylu (2014) compared the calculation skills of right-handed TD children who started counting with their right hand with those of children who started with their left hand and showed that right-starters are more efficient at solving single-digit addition problems than left-starters. Comparing kindergartners with a high working memory with children with a low working memory, Dupont-Boime and Thevenot (2018) showed, with strong correlations, that arithmetic performance and finger strategies were closely related and that children with a low working memory use less mature finger strategies than their peers with higher working memory. Comparing the computation skills of first-, third- and fifth-graders with MLD and working memory deficits to those of TD children, Geary et al. (2004) showed that children with MLD used finger counting more often but were less accurate than TD children.

Finally, one action research qualitative study conducted with TD children showed the effectiveness of a training program in which children learned to solve multiplication problems with finger strategies (Bahadir, 2017).

From Finger-Based to Memory-Based Strategies. Of the six studies conducted to describe how finger-based strategies evolve over time, four were longitudinal or cohort studies, one was a case-control study and one used a cross-sectional design.

The four longitudinal or cohort studies were conducted in children with TD or aTD. First, Svenson and Sjöberg (1982) followed TD children from the first to the third grade and showed that children switched from finger-based to memory-based strategies during this period. Geary et al. (1991) followed children with TD or MLD from the first to the second grade and showed that children with MLD used finger counting more often and made more counting errors than TD children. In the Wylie et al. (2012) and Jordan et al. (2003) studies, children with TD, DLD, MLD and DLD+LMD were followed from the second to the third grade (i.e., between 5 and 7 years of age). Wylie et al. (2012) showed that children with MLD and DLD+LMD made more frequent use of finger counting and switched to memory-based strategies later than children with TD and DLD. The difference between these groups was of medium effect size. Similarly, Jordan et al. (2003) showed that participants with MLD used finger counting more frequently and were more accurate than children with DLD+MLD. Moreover, children with MLD had more difficulty switching from finger-based to memory-based strategies than the other groups.

Koponen et al. (2007) conducted one experimental case-control study in which two children with DLD were trained to switch from finger-based strategies to memory-based strategies in solving single-digit addition problems. One of the two children improved his performance by substituting fact retrieval for finger counting.

Finally, one study used a cross-sectional design to compare calculation strategies used by Chinese and American TD kindergartners (Geary et al., 1993). Interestingly, this switch from finger-based to memory-based strategies occurred earlier in Chinese children than in their American peers. These group differences had medium to large effect sizes.

Cognitive Psychology and Neuroscience

Forty-five studies from the cognitive psychology and neuroscience field investigated the cognitive processes and neurobiological mechanisms underlying the relationship between finger abilities and arithmetic skills. Studies exploring cognitive processes (*n*=37, 82.2%) focused either on one finger sensorimotor skill (i.e., fine motor skills: *n*=20, finger gnosia: *n*=11, finger tapping: *n*=1; suppression of hand movements: *n*=2) or on a combination (i.e., fine motor skills + rhythmic movements: *n*=1, fine motor skills + hand preference: *n*=1; finger gnosia + hand preference: *n*=1). Eight studies (17.8%) explored the neurobiological mechanisms either by investigating the computation skills of children with fine motor disorders (*n*=6; children with DCD or CP) or by documenting the cerebral correlates underlying finger use and arithmetic abilities (*n*=2).

Cognitive Processes.

Fine Motor Skills and Arithmetic. The 22 studies focusing on fine motor skills (FMS) comprised one randomized controlled trial, three non-randomized controlled trials, seven cohort or longitudinal studies, and 11 cross-sectional studies.

In the randomized controlled trial (Asakawa et al., 2019), school-aged TD participants were trained in FMS. The results showed that children in the training group improved not only their FMS but also their arithmetic skills, unlike those in the control group. The improvements had medium to large effect sizes.

Three studies were non-randomized trials in which children with TD or aTD were trained in FMS. Zafranas (2004) gave TD children a piano training program and showed a joint improvement in FMS and arithmetic skills in the training group, but not in the control group. Conversely, two other studies reported no improvement in arithmetic skills following FMS training in children with TD (Costa-Giomi, 2004; piano lessons) or DCD (Alloway & Warner, 2008), but there was an enhancement in FMS, self-esteem or visuospatial working memory.

The seven cohort or longitudinal studies investigated whether early FMS predict the development of children's arithmetic skills several years later. Six of them showed that FMS were a significant predictor of arithmetic skills, with effect sizes ranging from very small to large (Asakawa & Sugimura, 2014; Barnes et al., 2011; Dinehart & Manfra, 2013; Jenks et al., 2009; Siegel, 1992; VanRooijen et al., 2015). However, one study showed that the predictive value of FMS failed to reach significance when executive functions were added to the statistical model (Michel et al., 2020).

Finally, 11 cross-sectional studies were conducted with children with TD and aTD. Comparative or correlational models showed a significant association between FMS and arithmetic skills in seven studies, with effect sizes ranging from small to large (Annett & Manning, 1990; Dielman & Furuno, 1970; Holsti et al., 2002; Pieters, Desoete, Roeyers, et al., 2012; Pieters, Desoete, Van Waelvelde et al., 2012;Raghubar et al., 2015;VanRooijen et al., 2012). Less conclusive results were found in two other studies, which reported a significant association between arithmetic and FMS of the right hand but not the left hand (Kiessling et al., 1983), or in first-graders but not in kindergartners (Pitchford et al., 2016). Only fine motor integration (i.e., "manual ability which requires synchronized hand-eye movements and the processing of visual stimulus in order to produce adequate motor output," assessed by drawing geometric shapes; Pitchford et al., 2016, p. 2) was correlated with calculation skills. Finally, two studies found no significant relationship between FMS and arithmetic skills (Carlson et al., 2013;

Ilardi & Lamotte, 2021). In these studies, calculation skills were respectively related to fine motor integration (after controlling for gender, age and IQ) and perceptual reasoning, processing speed and working memory, but not to FMS.

Finger Gnosia Abilities and Arithmetic. Among the 12 studies examining the relation between finger gnosia and arithmetic skills, there were one non-randomized trial, two longitudinal studies, eight cross-sectional studies and one combining cross-sectional and case report designs.

In the non-randomized controlled trial, TD participants followed finger gnosia training based on fine motor activities. In their results, Gracia-Bafalluy and Noël (2008) showed a concurrent improvement in both finger gnosia and arithmetic skills specific to the training group.

The two longitudinal studies yielded contrasting results about the predictive value of TD first-graders' finger gnosia on their arithmetic skills assessed one year later. The first showed that finger gnosia were a significant predictor of computation skills, with a medium effect size (Noël, 2005), while the second concluded that only number knowledge and numerosity discrimination were significant predictors of arithmetic development, but finger gnosia was not (Malone et al., 2020).

Nine studies were cross-sectional**,** comparing two groups of children with different cognitive profiles (i.e., TD vs. MLD and TD vs. ID) or focusing on the relationship between finger gnosia and arithmetic skills in a specific population (i.e., TD, MLD or ID children). The results of three studies showed a significant association between finger gnosia and arithmetic skills, with effect sizes ranging from small to medium (Costa et al., 2011; Lindgren, 1978; Wasner et al., 2016). Conversely, Long et al. (2016) concluded that there was no evidence concerning the relation between finger gnosia and arithmetic skills after the effect of age was controlled. Furthermore, in Newman's (2016) study, the results were mixed. The author concluded that a significant association existed between finger gnosia and computation skills in older children but not in younger ones. The results of the last four studies were contrasting. Two of them supported the finger gnosia/arithmetic relation (Kinsbourne & Warrington, 1963; Werner & Carrison, 1942), while the other two concluded that there was no relation (Benton et al., 1951; Strauss & Werner, 1938).

Finally, Strauss and Werner (1938) also provided a case report describing the cognitive profile of an adolescent who had both finger recognition and arithmetic impairments. The results were in line with the existence of a relation between the two deficits.

Other Finger Abilities and Arithmetic. Finally, of the seven last studies, one was a cross-sectional study focusing on finger tapping in which arithmetic skills and finger tapping in children with unspecified LD and their TD peers were assessed. Using a correlation model, Waber et al. (2000) showed that finger tapping was a predictor of the numerical skills in both populations.

Two studies aimed at examining the influence of finger movement suppression on arithmetic performance in deaf and TD children. Using a within-subject randomized controlled trial , Crollen and Noël (2015) asked to their participants to solve problems in three different interference conditions (i.e., squeezing a ball with a hand, squeezing a ball with a foot and a control condition) and showed that children were less efficient in the hand interference condition than in the other two conditions, suggesting that gestures play a functional role in calculation skills. The difference was of medium to large effect size. The second study showed, with a correlational models, that ability to suppress finger synkinetic movements during arithmetic task is positively associated with arithmetic performance both in deaf and typically developing children, with effect sizes ranging from small to large (Kohen-Raz & Masalha, 1988).

Two studies yielded contradictory evidence about the influence of hand preference in TD children through a cross-sectional design comparing right or left hand use and arithmetic skills. Annett and Manning's (1990) results showed that right-handers were more efficient than left-handers at calculation tasks, while Newman (2016) did not find a significant association between hand preference and arithmetic skills in participants.

Finally, one study with a longitudinal design explored the relation between rhythmic hand movements and arithmetic skills in TD children followed from 4 to 6 years old (Asakawa & Sugimura, 2014). Rhythmic hand movements were not found to have a predictive value regarding arithmetic skills.

Neurobiological Mechanisms.

Cerebral Correlates. Two of the included cross-sectional studies explored the cerebral correlates underlying finger use and arithmetic skills in TD children (Berteletti & Booth, 2015; Krinzinger et al., 2011). They examined brain activations in the motor cortex (i.e., intraparietal sulcus) involved in finger movements while children were solving arithmetic problems. Krinzinger et al. (2001) showed that finger-related brain areas were more activated during calculation than during a magnitude comparison task. Berteletti and Booth (2015) found that, in children between 8 and 13 years old, the "finger motor cortex" (i.e., brain areas related to FMS) was more activated during subtraction than the "finger somatosensory area" (i.e., brain areas related to finger gnosia). These results support the existence of a relation between finger movements and arithmetic skills.

Congenital and Neurodevelopmental Motor Disorders. Six studies were conducted with children with non-progressive congenital motor pathologies detected at birth (e.g., cerebral palsy, CP) or neurodevelopmental motor disorders (e.g., developmental coordination disorders, DCD) aged from 8 to 12. These cross-sectional studies compared the arithmetic skills of motor-disabled participants with those of TD children or children with other developmental pathologies. Roberts et al.'s (2011) results showed that preterm children with DCD had more arithmetic difficulties than those without DCD. Gomez et al.'s (2015) study produced contrasting results: children with DCD were significantly slower at solving calculation problems than TD children but no less accurate. Of the last four studies, two showed that children with DCD performed similarly to their peers with DLD and unspecified LD at solving calculation problems (Alloway & Archibald, 2008; Alloway & Temple, 2007). The two remaining studies came to the same conclusion comparing children with CP and DCD with their TD peers (Reynvoet et al., 2020; Thevenot et al., 2014).

Study Combining Mathematical Education and Cognitive Psychology and Neuroscience Methods

Ultimately, only one cross-sectional study (Reeve & Humberstone, 2011) of the 75 studies included here combined research methods applied in mathematical education and in cognitive psychology and neuroscience, building a bridge between these two research fields. This study was carried out with TD children aged from 5 to 7 years old in order to determine whether finger gnosia was associated with calculation efficiency and finger counting. First, using latent class analyses, the participants were split into four different subgroups based on both their accuracy in arithmetic and the finger strategy they used during calculation: (1) low finger use and low accuracy, (2) low finger use and successful performance, (3) high finger use and moderate accuracy, and (4) moderate finger use and moderate accuracy. The same kinds of analyses were done to develop four finger gnosia profiles: (1) finger/hand confusion, (2) finger confusion, (3) good finger gnosia, and (4) high finger gnosia. Multimodal logistic regression analyses were conducted and showed a significant relationship between finger gnosia, arithmetic performance and finger strategies beyond the contribution of visuospatial working memory, suggesting that a relation exists between finger gnosia and finger counting. The effect size for this association was large.

[Figure 4]

Discussion

The main objective of this scoping review was to identify all the qualitative and quantitative studies that have explored the relationship between finger use and arithmetic skills in school-aged children and adolescents. At the end of the selection process, 75 studies were included. Their results were discussed in two main sections, starting with the characteristics of the studies' samples and then conducting an analysis.

Analyses of Characteristics of Study Samples

Descriptive analysis of the study samples showed that there was no major imbalance in the proportion of studies conducted in TD children (59%) and in children with aTD (41%). In contrast, we found a large disparity in the age of participants: only a minority of studies were conducted in preschoolers (6%) or in adolescents enrolled in secondary school (6%). Regarding studies conducted in children with aTD, our results showed that participants with intellectual disabilities were under-represented (8.7%) compared with other children (i.e., motor disorders:

32.6%, learning disorders: 37% and other congenital disorders: 21.7%). A minority of these studies were conducted with children enrolled in special education (33.3%). Not surprisingly, since arithmetic skills are primarily taught in elementary school, the majority of studies published to date were conducted with children at this grade level. Given the predictive value of the pre-arithmetic skills for future computational abilities (Watts et al., 2014), longitudinal studies conducted from preschool through primary school grades would provide insight into whether the use of fingers should be promoted as a tool to prevent mathematics difficulties in younger children. Furthermore, a closer look at the influence of finger counting in children with aTD, especially when enrolled in special education, would inform us about whether finger counting can be used with this population as an appropriate accommodation during mathematics lessons. Such studies should be conducted more specifically with participants with intellectual disabilities who are under-represented compared to other participants with aTD.

Analyses of Individual Sources of Evidence

An initial analysis of individual sources of evidence from the 75 included studies showed that two main research topics were addressed in these studies: (1) What kinds of finger-based strategies do participants use during computation over the course of development, and how do they support arithmetic performance? (2) What cognitive processes and neurobiological mechanisms underlie the relationship between fingers and arithmetic?

What Kind of Finger Strategies Do Participants Use during Computation over the Course of Development and How Do They Support Arithmetic Performance?

The studies conducted in the mathematical education field had three main objectives: (1) describing the finger-based strategies children use when calculating (20%); (2) exploring how finger-based strategies support children’s arithmetic performance (60%); and (3) investigating how these finger-based strategies change during the child’s development (20%).

In studies describing strategies used to solve arithmetic problems, finger strategies were found to be used in various ways either to count (e.g., folding and unfolding fingers sequentially) or as cardinal sets (e.g., thumb, index and middle finger raised to indicate 3) (Baroody, 1987; Björklund et al., 2019; Fuson & Kwon, 1992; Kullberg & Björklund, 2020; Nwabueze, 2001). When children solved complex addition problems with a mental abacus, they made many gestures imitating the manipulation of beads on an abacus (Brooks et al., 2018). There was a strong imbalance in the proportion of studies conducted with qualitative designs (75%) versus quantitative designs (25%). Additional quantitative evidence is needed to confirm the observations made in the qualitative studies. With new evidence of that kind, it would be possible to clarify the most useful finger strategies in arithmetical contexts to inform teachers of best practices to be promoted in class.

In the studies conducted to explore how finger-based strategies might support children’s computational skills, the results indicated that finger-based strategies (Canobi, 2004; Dupont-Boime & Thevenot, 2018; Farrington-Flint et al., 2009; Jordan et al., 1992; Lucangeli et al., 2003; Newman & Soylu, 2014) or a mental abacus (Brooks et al., 2018; Cho & So, 2018) could promote TD participants’ computational performance. Moreover, computation skills were found to be improved by different kinds of explicit training of finger-based strategies (Fuson, 1986; Fuson & Secada, 1986; Fuson & Willis, 1988; Ollivier et al., 2020; but see Stegemann & Grünke, 2014, for inconclusive results of training with the Chisanbop method). The studies also showed that children with MLD use more finger-based strategies and make more calculation errors than their TD peers when solving addition problems (Geary et al., 2004). A minority of these studies were conducted using a high level of evidence design (i.e., cluster, non-randomized or randomized controlled trial) (44.4%) compared with research carried out with medium and low level of evidence designs (i.e., cohort study, case-control study, cross-sectional study or qualitative study) (55.6%). Only 33% of them showed, through a randomized controlled trial, an improvement of arithmetic skills following a finger-based strategies training. More randomized controlled trial would be necessary to confirm the results reported in case-control or cross-sectional studies and would provide stronger evidence of the functional links between finger-based strategies and arithmetic performance in TD children. Moreover, additional studies should be conducted with participants with MLD, who are still under-examined, to confirm the initial evidence. Finally, further training studies with TD children and participants with aTD could help identify the most effective finger-based strategies to be targeted as a function of cognitive profile. This evidence could also inform the most effective educational approaches to be used when teaching finger-based strategies in children with TD and aTD.

Finally, six studies were conducted to investigate how finger-based strategies change throughout childhood. These studies showed that, over time, TD children naturally switch from finger-based to memory-based strategies (Svenson & Sjöberg, 1982), but that children with MLD switch later in their development than their TD peers (Geary et al., 1991; Jordan et al., 2003; Wylie et al., 2012). However, no switching was found in children with DLD and mathematical difficulties, even after an explicit training program (Koponen et al., 2007). A separate body of literature showed that working memory is important for children’s arithmetic development, since good working memory is a prerequisite for detaching from external support (e.g., fingers or concrete manipulatives) in favor of mental strategies for solving computations. A working memory deficit in children with LMD could explain why they find it difficult to switch to abstract computation strategies such as memory retrieval (see David, 2012; Friso-Van Den Bos et al., 2013; Peng et al., 2016, for meta-analyses). Returning to the results of this scoping review, only one study was conducted with children with DLD to train them to switch from finger-based strategies to memory retrieval. Additional training studies involving children with MLD are needed to target interventions and therapeutic tools to be promoted to help them switch to memory-based strategies so that they can become more efficient at calculating and solve more complex problems. Finally, studies should be conducted to determine whether switching from fingers to memory strategies is mediated by finger sensorimotor skills such as fine motor skills or finger gnosia.

What Cognitive Processes and Neurobiological Mechanisms Underlie the Relation between Fingers and Arithmetic?

The studies conducted in the cognitive psychology and neuroscience research areas had one of two objectives: investigating the cognitive process (81.8%) or examining the neurobiological mechanisms (18.2%) that underlie the relation between finger movements and arithmetic skills.

With regard to *the cognitive process*, the impact of six finger abilities on arithmetic skills has been investigated. Fine motor skills (FMS) (55%) and finger gnosia (30%) were explored more often than finger tapping (2.5%), suppression of hand movements (5%), hand preference (5%) and rhythmic hand movements (2.5%).

The majority of studies of the relation between FMS and computation supported the existence of such a relation (68.2% favorable vs. 31.8% unfavorable). One randomized controlled trial (Asakawa et al., 2019) and one non-randomized controlled trial (Zafranas, 2004) were in line with this conclusion while two non-randomized controlled trials were not (Alloway

& Warner, 2008; Costa-Giomi, 2004). Similarly, the majority of studies focusing on finger gnosia supported the idea that it promotes children's arithmetic skills (66.7% favorable vs. 33.3% unfavorable). The study providing the highest level of favorable evidence was a non-randomized controlled trial (Gracia-Bafalluy & Noël, 2008). More randomized controlled trials should be conducted to examine the causal links between FMS or finger gnosia and computation skills. Indeed, although the vast majority of studies concluded that these two abilities support children's arithmetic development, only 60% of randomized and non-randomized controlled trials agreed with this conclusion. Moreover, further randomized controlled trials are needed to determine whether training of these two finger-based abilities should be integrated, in addition to finger counting training, into educational practices and tools. If so, more studies should be conducted to determine how and when such training should be implemented in the classroom.

Regarding the other finger skills, the results showed that finger tapping (Waber et al., 2000) and suppression of hand movements (Crollen & Noël, 2015; Kohen-Raz & Masalha, 1988) were correlated with children's computation skills. However, rhythmic hand movements (Asakawa & Sugimura, 2014) did not appear to predict the development of arithmetic skills. The role of hand preference (Annett & Manning, 1990; Newman, 2016) was unclear since only one study (out of two) suggested that it affected children's arithmetic skills. More generally, given that only six articles have investigated the influence of these finger abilities on children's arithmetic skills, more evidence is needed to gain a clearer picture of this relation.

Finally, in 19.4% of studies, other cognitive (executive functions, perceptual reasoning, processing speed, working memory, fine motor integration, or IQ), demographic (age, socioeconomic status (SES) and gender), or academic (early numerical skills: number knowledge and numerosity discrimination) factors were found to have a large effect on arithmetic development – more than the influence of finger abilities (Carlson et al., 2013; Ilardi & Lamotte, 2021; Long et al., 2016; Malone et al., 2020; Michel et al., 2020; Pitchford et al., 2016). It therefore seems critical to integrate these types of variables more systematically into statistical models to clarify their importance in children's arithmetic development, in comparison to finger abilities.

To investigate the *neurobiological mechanisms* that underlie the relation between finger movements and arithmetic skills, two different methods were used: (1) comparing the arithmetic performance of children with fine motor disorders (DCD and CP), either neurodevelopmental or acquired at birth, with that of children without motor deficits (75%); or (2) investigating the cerebral correlates supporting finger use and arithmetic skills (25%).

Using a behavioral approach, 83.3% of studies carried out in children with DCD or CP aged from 8 to 12 years showed that, despite their motor deficits, these children were able to develop similar calculation performance to their TD peers (Alloway & Archibald, 2008; Alloway & Temple, 2007; Gomez et al., 2015; Reynvoet et al., 2020; Thevenot et al., 2014). Thevenot et al. (2014) hypothesized that children with CP probably compensate for their fine motor disorders with other adaptive skills such as memory-based strategies. Additional studies should be conducted with children with DCD or CP to confirm these first indications and determine which cognitive processes (if any) they use to compensate for their disabilities.

Finally, using fMRI, two studies conducted in TD children supported the existence of a relation between finger use and arithmetic skills, showing brain activation in finger motor areas (within the intraparietal sulcus) during computation (Berteletti & Booth, 2015; Krinzinger et al., 2011). Currently, only these two studies have used fMRI to investigate the relation between finger use and arithmetic. More evidence is therefore necessary for a better understanding of the role of the fingers in arithmetic development.

Conclusions

In this scoping review, the relation between finger use and arithmetic skills was investigated in 75 studies.

Regarding the studies conducted in *mathematical education*, the results showed that children used a variety of finger-based strategies to support their computational performance and that these strategies tended to disappear during development in favor of memory-based strategies. More studies should be conducted to determine which finger-based strategies are the most effective, taking children's cognitive profile into account, and whether the transition from finger-based to memory-based strategies is mediated by finger sensorimotor skills.

The studies conducted in *cognitive psychology and neuroscience* showed that FMS, finger gnosia, finger tapping and hand movements might promote the development of children's arithmetic skills. Among children with aTD, studies showed that children with DCD and CP aged from 8 to 12 years produced similar computational performance to TD children, suggesting that, early in the child's arithmetic development, other cognitive factors supplant finger skills. Finally, functional neuroimaging data showed that finger-use and arithmetic skills share common, or at least very close, cerebral substrates, providing evidence of a link between these two abilities at the neuroanatomical level. More studies are needed to confirm this evidence and to determine if, when and how finger sensorimotor skill training should be integrated, in addition to finger-based strategy training, into educational practices and tools.

While 49% of the studies conducted in cognitive psychology and neurosciences reported effect sizes, only 21% of those conducted in the field of mathematical education did so. It is important to be able to generalize practices assessing effect sizes to estimate how closely finger counting and finger sensorimotor skills are linked to children's arithmetic performance.

Although these studies have investigated the direct influence of finger-based strategies or finger sensorimotor skills on arithmetic skills, they have not addressed how finger-based strategies are related to finger sensorimotor skills or how this relation influences children's arithmetic skills. Only one study has investigated the relation between finger gnosia and finger-based strategies during computation, bridging the gap between mathematical education research and studies in cognitive psychology and neuroscience. In that study, Reeve and Humberstone (2011) demonstrated the existence of a functional link between these three variables. Additional studies combining educational and cognitive approaches are necessary to confirm these isolated results.

Prospects for Future Research

This scoping review provides the first methodical summary published to identify all studies that have investigated the relation between finger use and arithmetic skills in children and adolescents. This scoping review lays the groundwork for a systematic review to answer more specific questions and provide teachers, therapists and researchers with clear guidelines for clinical and pedagogical practices. A critical appraisal of the studies included could also be conducted in future to explore the methodological quality of each study and complement the evidence examined here.

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Figure Captions

Fig. 1

PRISMA Flow Chart Illustrating the Selection Process

Fig. 2

Overview of Studies Involving TD Children and Children with aTD by Grade Level, Age and Type of Education

Note. SB = Spina Bifida; DCD = Developmental Coordination Disorders; CP = Cerebral Palsy; DLD = Developmental Language Disorders; Unspecified LD = Unspecified Learning Disorders; MLD = Mathematical Learning Disabilities; CHD = Congenital Heart Disease; Df = Deafness; PNA = Physical and Neurological Abnormalities

Fig. 3

Distribution of Included Studies

Fig. 4

Summary of Findings from Different Sources of Evidence

Table Caption

Table 1

List of Terms Identified and Their Corresponding Dedicated Appellations and Abbreviations

Note. [a] not indexed as MeSH term but the most frequently used term in the literature over the last 20 years; [b] not indexed as MeSH term but the term used by Strauss and Werner (1938).

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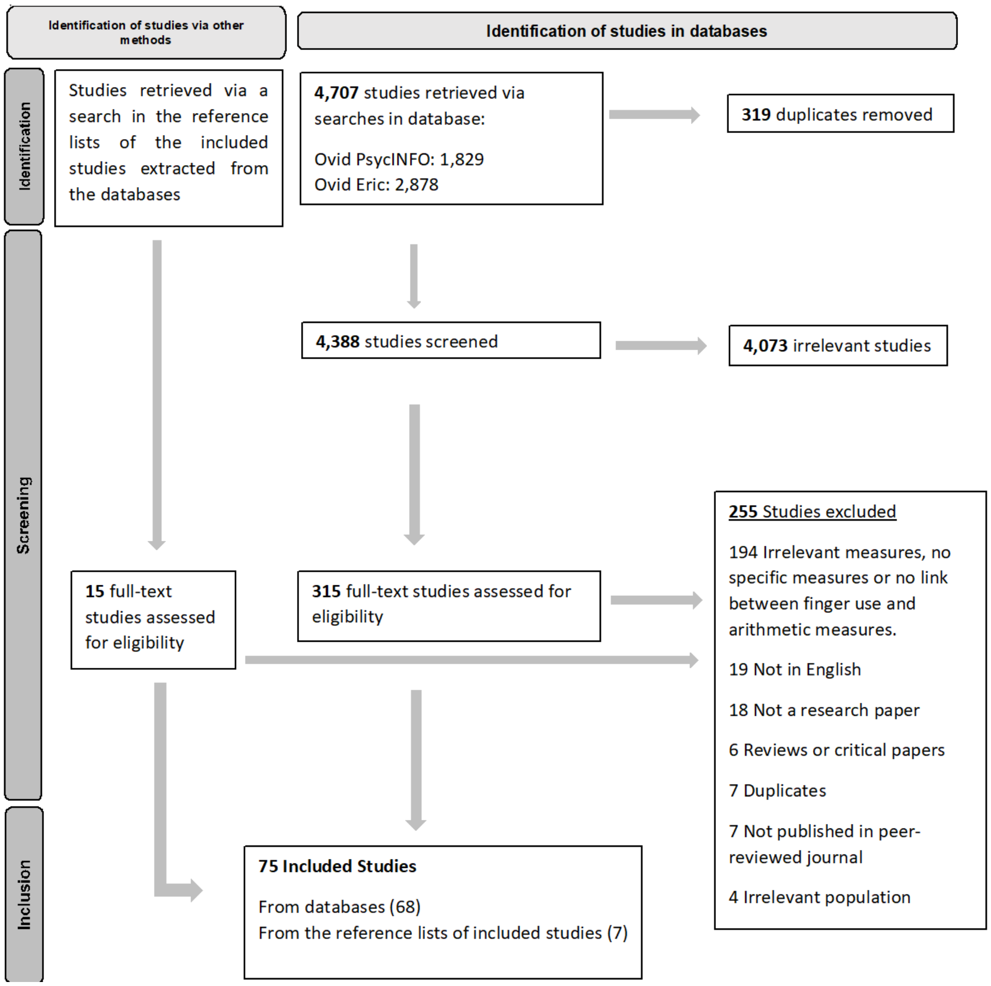

Identification of studies via other methods
Identification of studies in databases
Identification
Screening
Inclusion
Studies retrieved via a search in the reference lists of the included studies extracted from the databases
4,707 studies retrieved via searches in database:
Ovid PsycINFO: 1,829
Ovid Eric: 2,878
319 duplicates removed
4,388 studies screened
4,073 irrelevant studies
255 Studies excluded
194 Irrelevant measures, no specific measures or no link between finger use and arithmetic measures.
19 Not in English
18 Not a research paper
6 Reviews or critical papers
7 Duplicates
7 Not published in peer-reviewed journal
4 Irrelevant population
15 full-text studies assessed for eligibility
315 full-text studies assessed for eligibility
75 Included Studies
From databases (68)
From the reference lists of included studies (7)

Figure 1

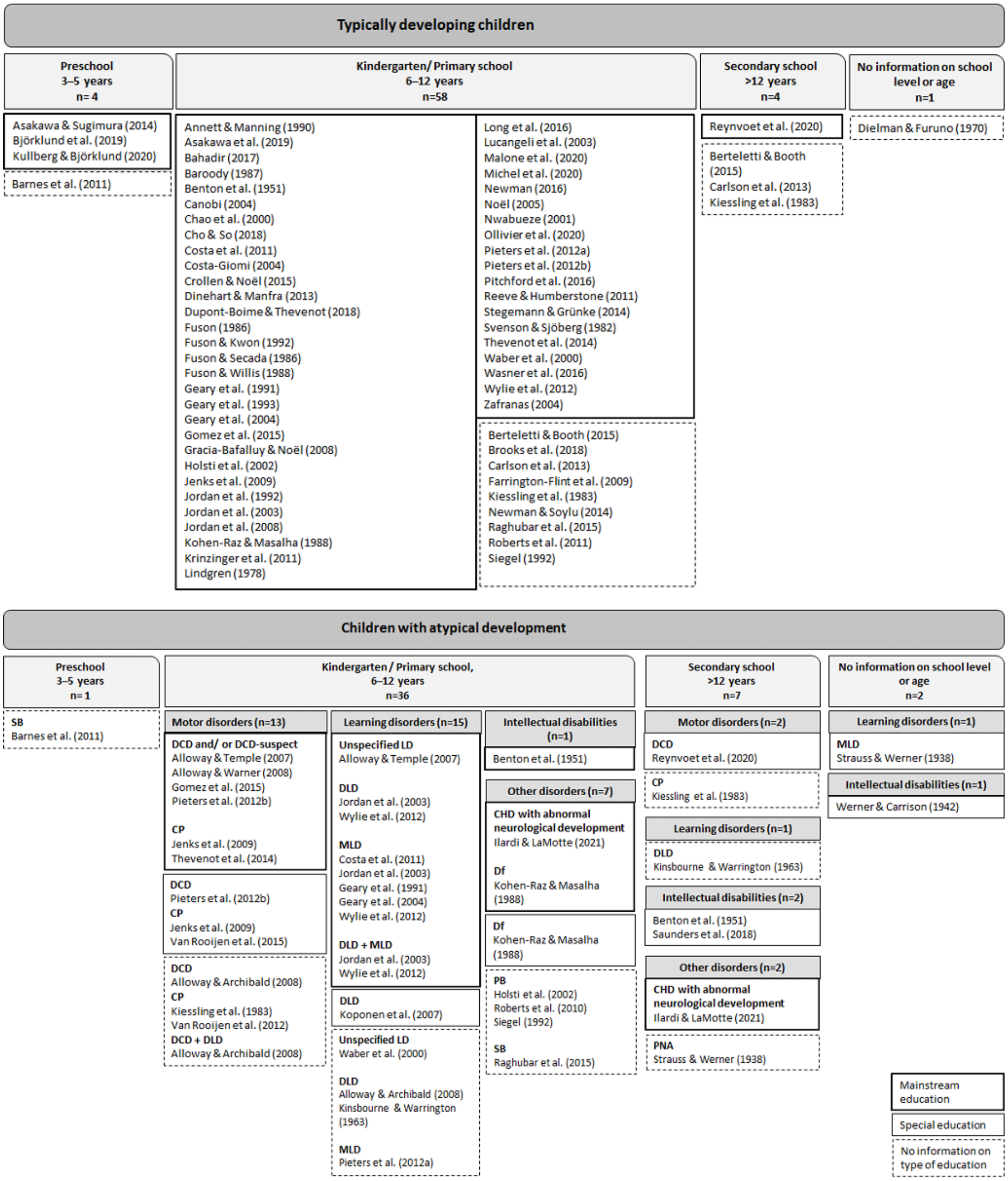

Typically developing children
Preschool
3–5 years
n= 4
Asakawa & Sugimura (2014)
Björklund et al. (2019)
Kullberg & Björklund (2020)
Barnes et al. (2011)
Kindergarten/ Primary school
6–12 years
n=58
Annett & Manning (1990)
Asakawa et al. (2019)
Bahadir (2017)
Baroody (1987)
Benton et al. (1951)
Canobi (2004)
Chao et al. (2000)
Cho & So (2018)
Costa et al. (2011)
Costa-Giomi (2004)
Crollen & Noël (2015)
Dinehart & Manfra (2013)
Dupont-Boime & Thevenot (2018)
Fuson (1986)
Fuson & Kwon (1992)
Fuson & Secada (1986)
Fuson & Willis (1988)
Geary et al. (1991)
Geary et al. (1993)
Geary et al. (2004)
Gomez et al. (2015)
Gracia-Bafalluy & Noël (2008)
Holsti et al. (2002)
Jenks et al. (2009)
Jordan et al. (1992)
Jordan et al. (2003)
Jordan et al. (2008)
Kohen-Raz & Masalha (1988)
Krinzinger et al. (2011)
Lindgren (1978)
Long et al. (2016)
Lucangeli et al. (2003)
Malone et al. (2020)
Michel et al. (2020)
Newman (2016)
Noël (2005)
Nwabueze (2001)
Ollivier et al. (2020)
Pieters et al. (2012a)
Pieters et al. (2012b)
Pitchford et al. (2016)
Reeve & Humberstone (2011)
Stegemann & Grünke (2014)
Svenson & Sjöberg (1982)
Thevenot et al. (2014)
Waber et al. (2000)
Wasner et al. (2016)
Wylie et al. (2012)
Zafranas (2004)
Berteletti & Booth (2015)
Brooks et al. (2018)
Carlson et al. (2013)
Farrington-Flint et al. (2009)
Kiessling et al. (1983)
Newman & Soylu (2014)
Raghubar et al. (2015)
Roberts et al. (2011)
Siegel (1992)
Secondary school
>12 years
n=4
Reynvoet et al. (2020)
Berteletti & Booth (2015)
Carlson et al. (2013)
Kiessling et al. (1983)
No information on school level or age
n=1
Dielman & Furuno (1970)
Children with atypical development
Preschool
3–5 years
n= 1
SB
Barnes et al. (2011)
Kindergarten / Primary school,
6–12 years
n=36
Motor disorders (n=13)
DCD and/ or DCD-suspect
Alloway & Temple (2007)
Alloway & Warner (2008)
Gomez et al. (2015)
Pieters et al. (2012b)
CP
Jenks et al. (2009)
Thevenot et al. (2014)
DCD
Pieters et al. (2012b)
CP
Jenks et al. (2009)
Van Rooijen et al. (2015)
DCD
Alloway & Archibald (2008)
CP
Kiessling et al. (1983)
Van Rooijen et al. (2012)
DCD + DLD
Alloway & Archibald (2008)
Learning disorders (n=15)
Unspecified LD
Alloway & Temple (2007)
DLD
Jordan et al. (2003)
Wylie et al. (2012)
MLD
Costa et al. (2011)
Jordan et al. (2003)
Geary et al. (1991)
Geary et al. (2004)
Wylie et al. (2012)
DLD + MLD
Jordan et al. (2003)
Wylie et al. (2012)
DLD
Koponen et al. (2007)
Unspecified LD
Waber et al. (2000)
DLD
Alloway & Archibald (2008)
Kinsbourne & Warrington (1963)
MLD
Pieters et al. (2012a)
Intellectual disabilities (n=1)
Benton et al. (1951)
Other disorders (n=7)
CHD with abnormal neurological development
Ilardi & LaMotte (2021)
Df
Kohen-Raz & Masalha (1988)
Df
Kohen-Raz & Masalha (1988)
PB
Holsti et al. (2002)
Roberts et al. (2010)
Siegel (1992)
SB
Raghubar et al. (2015)
Secondary school
>12 years
n=7
Motor disorders (n=2)
DCD
Reynvoet et al. (2020)
CP
Kiessling et al. (1983)
Learning disorders (n=1)
DLD
Kinsbourne & Warrington (1963)
Intellectual disabilities (n=2)
Benton et al. (1951)
Saunders et al. (2018)
Other disorders (n=2)
CHD with abnormal neurological development
Ilardi & LaMotte (2021)
PNA
Strauss & Werner (1938)
No information on school level or age
n=2
Learning disorders (n=1)
MLD
Strauss & Werner (1938)
Intellectual disabilities (n=1)
Werner & Carrison (1942)
Mainstream education
Special education
No information on type of education

Figure 2

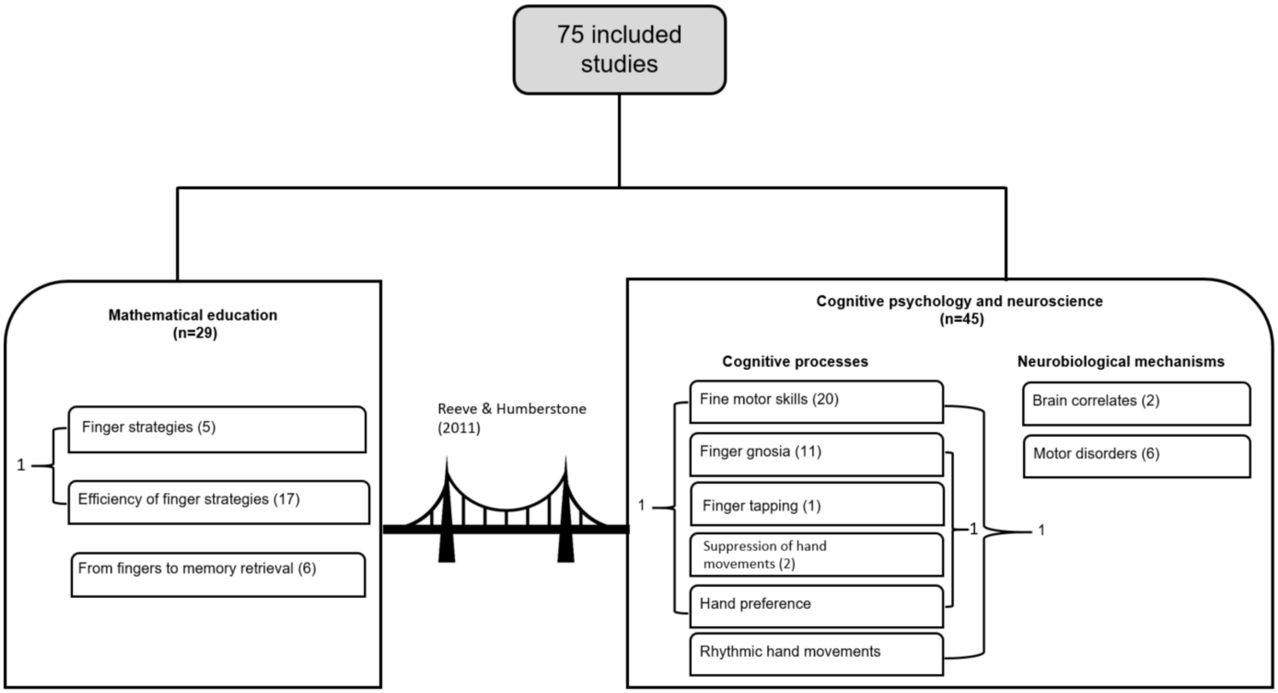
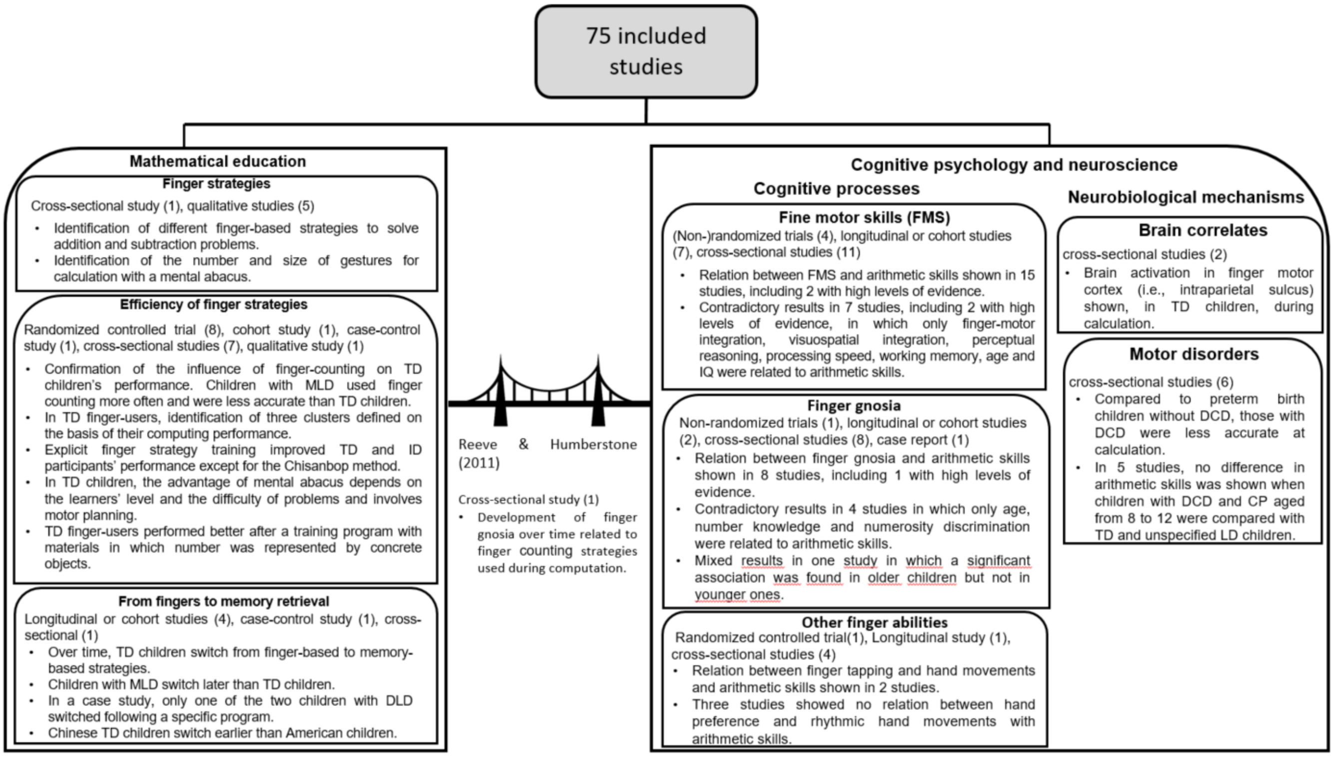

75 included studies
Mathematical education
(n=29)
1
Finger strategies (5)
Efficiency of finger strategies (17)
From fingers to memory retrieval (6)
Reeve & Humberstone
(2011)
Cognitive psychology and neuroscience
(n=45)
Cognitive processes
Neurobiological mechanisms
1
Fine motor skills (20)
Finger gnosia (11)
Finger tapping (1)
Suppression of hand movements (2)
Hand preference
Rhythmic hand movements
1
1
Brain correlates (2)
Motor disorders (6)

Figure 3



75 included studies

Mathematical education

Finger strategies

Cross-sectional study (1), qualitative studies (5)

- Identification of different finger-based strategies to solve addition and subtraction problems.
- Identification of the number and size of gestures for calculation with a mental abacus.

Efficiency of finger strategies

Randomized controlled trial (8), cohort study (1), case-control study (1), cross-sectional studies (7), qualitative study (1)

- Confirmation of the influence of finger-counting on TD children's performance. Children with MLD used finger counting more often and were less accurate than TD children.
- In TD finger-users, identification of three clusters defined on the basis of their computing performance.
- Explicit finger strategy training improved TD and ID participants' performance except for the Chisanbop method.
- In TD children, the advantage of mental abacus depends on the learners' level and the difficulty of problems and involves motor planning.
- TD finger-users performed better after a training program with materials in which number was represented by concrete objects.

From fingers to memory retrieval

Longitudinal or cohort studies (4), case-control study (1), cross-sectional (1)

- Over time, TD children switch from finger-based to memory-based strategies.
- Children with MLD switch later than TD children.
- In a case study, only one of the two children with DLD switched following a specific program.
- Chinese TD children switch earlier than American children.

Reeve & Humberstone (2011)

Cross-sectional study (1)

- Development of finger gnosia over time related to finger counting strategies used during computation.

Cognitive psychology and neuroscience

Cognitive processes

Fine motor skills (FMS)

(Non-)randomized trials (4), longitudinal or cohort studies (7), cross-sectional studies (11)

- Relation between FMS and arithmetic skills shown in 15 studies, including 2 with high levels of evidence.
- Contradictory results in 7 studies, including 2 with high levels of evidence, in which only finger-motor integration, visuospatial integration, perceptual reasoning, processing speed, working memory, age and IQ were related to arithmetic skills.

Finger gnosia

Non-randomized trials (1), longitudinal or cohort studies (2), cross-sectional studies (8), case report (1)

- Relation between finger gnosia and arithmetic skills shown in 8 studies, including 1 with high levels of evidence.
- Contradictory results in 4 studies in which only age, number knowledge and numerosity discrimination were related to arithmetic skills.
- Mixed results in one study in which a significant association was found in older children but not in younger ones.

Other finger abilities

Randomized controlled trial(1), Longitudinal study (1), cross-sectional studies (4)

- Relation between finger tapping and hand movements and arithmetic skills shown in 2 studies.
- Three studies showed no relation between hand preference and rhythmic hand movements with arithmetic skills.

Neurobiological mechanisms

Brain correlates

cross-sectional studies (2)

- Brain activation in finger motor cortex (i.e., intraparietal sulcus) shown, in TD children, during calculation.

Motor disorders

cross-sectional studies (6)

- Compared to preterm birth children without DCD, those with DCD were less accurate at calculation.
- In 5 studies, no difference in arithmetic skills was shown when children with DCD and CP aged from 8 to 12 were compared with TD and unspecified LD children.

Figure 4

Table 1

	Terms used in the included studies	MeSH terms (abbreviations) used in this scoping review
Motor disorders	Developmental coordination disorders	Developmental Coordination Disorders (DCD)
	Cerebral Palsy	Cerebral Palsy (CP)
Learning disorders	Moderate learning difficulties Learning disabilities Learning impairment	Unspecified Learning Disorders (Unspecified LD)
	Reading disabilities Reading difficulties Reading and writing backwardness Specific language impairment	Developmental Language Disorders (DLD)
	Mathematics disabilities Mathematics learning difficulties Mathematical difficulty Mathematics or mathematical learning disabilities Arithmetic disabilities	Mathematical Learning Disabilities (MLD)[a]
	Mentally defective children Moderate intellectual disabilities Mentally retarded children	Intellectual Disabilities (ID)
Other congenital disorders	Spina bifida Spina bifida myelomeningocele	Spina Bifida (SB)
	Extremely low birth weight children Extremely preterm children Preterm children	Preterm Birth Children (PB)
	Congenital heart disease with abnormal neurological development	Congenital Heart Disease (CHD) with abnormal neurological development
	Deafness	Deafness (Df)
	Physical and neurological abnormalities	Physical and Neurological Abnormalities (PNA)[b]