Accepted for publication in Progress in Brain Research

Individual differences in children's mathematics achievement: The roles of symbolic numerical magnitude processing and domain-general cognitive functions

Kiran Vanbinst and Bert De Smedt

Parenting and Special Education Research Unit, Faculty of Psychology and Educational Sciences, University of Leuven, Belgium

Corresponding author:

Bert De Smedt, Parenting & Special Education Research Unit, University of Leuven

Leopold Vanderkelenstraat 32, box 3765, B-3000 Leuven, BELGIUM

Tel. +32 16 32 57 05; Fax. +32 16 32 59 33

e-mail: Bert.DeSmedt@ppw.kuleuven.be

Abstract

This contribution reviewed the available evidence on the domain-specific and domain-general neurocognitive determinants of children's arithmetic development, other than non-symbolic numerical magnitude processing, which might have been overemphasized as a core factor of individual differences in mathematics and dyscalculia. We focused on symbolic numerical magnitude processing, working memory and phonological processing, as these determinants have been most researched and their roles in arithmetic can be predicted against the background of brain imaging data. Our review indicates that symbolic numerical magnitude processing is a major determinant of individual differences in arithmetic. Working memory, particularly the central executive, also plays a role in learning arithmetic, but its influence appears to be dependent on the learning stage and experience of children. The available evidence on phonological processing suggests that it plays a more subtle role in children's acquisition of arithmetic facts. Future longitudinal studies should investigate these factors in concert to understand their relative contribution as well as their mediating and moderating roles in children's arithmetic development.

Key words: arithmetic; dyscalculia; development; symbolic numerical magnitude processing; working memory; phonological processing; fact retrieval

Introduction

The investigation of the cognitive determinants of individual differences in mathematics achievement has a long-standing tradition in developmental and educational research (Dowker, 2005). These determinants can be categorized as domain-specific, i.e. exclusively relevant for learning mathematics per se (e.g., numerical magnitude processing skills; De Smedt et al., 2013), vs. domain-general, i.e. skills that are also relevant to learning other academic domains, such as reading (i.e. phonological processing; Vellutino et al., 2004), or more general cognitive skills that are relevant for all cognitive learning, such as working memory (e.g., Baddeley, 2003). Understanding these determinants is educationally relevant because it might help to tailor the instructional approach to the needs of a specific learner (Dowker, 2005).

The last five years, research on individual differences in mathematics achievement has largely focused on non-symbolic numerical magnitude processing as a core factor that determines these individual differences (e.g., Feigenson et al., 2013; Piazza, 2010). However, as criticized by Fias (2016), this focus on one core factor has led to a strong bias towards investigations of non-symbolic numerical magnitude processing skills as the primary explanation for individual differences in mathematics achievement and learning disorders in mathematics, i.e. dyscalculia (American Psychiatric Association, 2013), and largely ignored other critical cognitive functions and processes that play a role in mathematical development. On the other hand, recent meta-analytic data on the association between non-symbolic numerical magnitude processing and mathematics showed that the size of this association is significant but small (Chen & Li, 2014: $r = 0.20$, 95%CI = [0.14, 0.26]; Fazio et al., 2014: $r = 0.22$, 95%CI = [0.20, 0.25], explaining less than 5% of variability in mathematical performance and indicating the involvement of other determinants that could be cognitive (as we explain below) as well as non-cognitive factors, such as mathematics anxiety (e.g., Ma, 1999; Maloney & Beilock, 2012; Ramirez et al., 2013) or home numeracy (e.g., Kleemans et al., 2012; Skwarchuk et al., 2014). Furthermore, the primacy of non-symbolic numerical magnitude processing skills as a core for formal mathematics development has been debated, against the background of studies who have failed to observe such an association (De Smedt et al., 2013, for a narrative review).

Although neuroimaging research might have narrowed our attention to non-symbolic quantity representations as a core in explaining individual differences in mathematical performance by its exclusive focus on intraparietal sulcus (IPS) activity during mathematical tasks (Ansari, 2008; Dehaene et al., 2003; Nieder & Dehaene, 2009), other brain areas, such as the dorsolateral prefrontal cortex, the temporo-parietal cortex, including the angular as well as supramarginal gyri, the ventral-occipital cortex, and the medial temporal lobe (Menon, 2015) typically show (specific) increases in activity when people engage in mathematical tasks (see Arsiladou & Taylor, 2010; Kaufmann et al., 2011, for meta-analyses). Also, individual differences in brain activity of these areas outside the IPS (e.g., Cho et al., 2012; Grabner et al., 2007) as well as individual differences in brain connectivity between (combinations of) these areas, as revealed through diffusion tensor imaging (Matejko & Ansari, 2015, for a review) have been related to variability in mathematical performance. On the other hand, activity in the IPS has been interpreted as reflecting not only numerical magnitude based processing but also other cognitive functions (see Fias, 2016, for a discussion), such as (visuo-spatial) working memory (e.g., Dumontheil & Klingberg, 2012; Todd & Marois, 2005), serial order (e.g., Marshuetz, 2005) or (visual) attention (e.g., Corbetta and Shulman, 2002). These observations point to the relevance of cognitive processes other than non-symbolic numerical magnitude representations. Even though such cognitive processes cannot be directly inferred from existing brain imaging data (Berch et al., 2016), they might provide plausible hypotheses that can be tested in behavioral research (De Smedt & Grabner, 2015).

Against this background, the aim of the present chapter was to discuss the available evidence on cognitive correlates of individual differences in mathematics achievement, other than one core factor, i.e. non-symbolic numerical magnitude processing. We focused on symbolic numerical magnitude processing, working memory, and phonological processing, as the effects of these cognitive determinants have been the most documented. In reviewing these cognitive determinants, we restricted our analysis to one particular mathematical skill. This was done because measures of general mathematics achievement typically reflect a score averaged across different mathematical domains, yet the mathematical domains (e.g. spatial concepts, counting, word problem solving, measurement, geometry, arithmetic, mathematical language) of these tests vary across ages as well as countries. It is not unlikely that cognitive determinants of mathematics achievement change as a function of the mathematical domain under investigation. Recent meta-analyses indeed show that the association between one cognitive factor and mathematical performance, for example working memory (Peng et al., 2015) or numerical magnitude processing (Schneider et al., 2015), is very strongly moderated by the type of mathematical competence under investigation. In order to make theoretical headway and to build neurocognitive models of mathematical development, it is therefore important to narrow down the mathematical subskill under investigation.

We focused on (single-digit) arithmetic, because this is a core element of the mathematics curriculum in (early) primary school (e.g., National Mathematics Advisory Panel, 2008) and represents a major building block for future growth in more complex calculation and algebra (Kilpatrick et al., 2001). Difficulties in learning arithmetic facts are considered to be the hallmark of children with dyscalculia, who experience persistent deficits in acquiring basic mathematical competencies (American Psychiatric Association, 2013; Geary, 2004). Finally, most of the existing brain imaging studies, in particular fMRI research, have focused on brain activity during the execution of (single-digit) arithmetic tasks (Kaufmann et al., 2011; Menon, 2015).

The remainder of this chapter is organized as follows. First, we briefly describe the neurocognitive development of arithmetic in children. Second, we focus on the role of symbolic numerical magnitude processing as one domain-specific predictor of individual differences in arithmetic development. Thirdly, we discuss the role of working memory, one domain-general factor that is important for mathematics learning, which has received a lot of research attention over various decades. Finally, we elaborate on the influence of phonological processing, which might play a role in arithmetic, against the background of overlapping neural networks for reading and arithmetic in the temporo-parietal cortex (De Smedt et al., 2010).

Neurocognitive development of arithmetic in children

The development of (single-digit) arithmetic is characterized by the acquisition of different arithmetic strategies (e.g., Geary, 2004; Jordan et al., 2003; Siegler, 1996). Initially, children use various counting procedures to solve answers to basic arithmetic problems (Geary, Bow-Thomas, & Yao, 1992), but gradually, through the repeated use of these counting strategies, children build problem-answer associations or arithmetic facts that are stored in long-term memory (Siegler & Shrager, 1984). These facts can be used to decompose problems into smaller problems, as is the case in procedural strategies, such as transformation or decomposition (e.g. 6 + 8 = ?, 6 + 4 = 10 + 4 = 14). Over development, there is a change in the distributions of strategies children use, with a decreased reliance on (effortful, time-consuming and error prone) procedural strategies and an increased reliance on (direct, fast, and accurate) fact retrieval (Geary et al., 2004; Jordan et al., 2003; Siegler, 1996), but both types of strategies continue to exist throughout adulthood. There are large individual differences in the development as well as the mix of these arithmetic strategies (Geary et al., 2004; Jordan et al., 2003), and one important goal of developmental science is to understand the neurocognitive underpinnings of these individual differences (Dowker, 2005).

Brain imaging studies have indicated the involvement of a widespread fronto-parietal network during arithmetic problem solving in adults (Zamarian & Delazer, 2015, for a review) as well as in children (Menon, 2015, for a review). Activity in this network is modulated by problem size (i.e. small vs. large problems) and operation (e.g. subtraction vs. multiplication), or more broadly the strategy that is used to solve arithmetic problems (i.e. retrieval vs. procedural strategies). Relatedly, activity in this network is affected by expertise and such individual differences can be observed in adults (Grabner et al., 2007) as well as in children (De Smedt et al., 2011). For example, Grabner et al. (2007) showed that in healthy adults, the brain activity in the angular gyrus during calculation was linearly related to their level of mathematical expertise. De Smedt et al. (2011) showed that 10-12-

year-old children with dyscalculia showed an atypical modulation of the right IPS activity during the solution of small and large addition and subtractions, compared to typically developing children. Interestingly, when the term "developmental dyscalculia" was coined for the first time, it was already proposed that the origin of these arithmetical difficulties was situated at the neural level: "*a definition of developmental dyscalculia, stressing the hereditary or congenital affection of the brain substrate of mathematical functions is put forth*" (Kosc, 1974, p. 164), although at that time it was not possible to directly examine this issue in children without manifest brain damage. To date, only but a few MRI-studies have been executed so far (Kucian, 2015, for a review), and they converge indeed to the conclusion that these children might have an abnormal development of the brain circuitry that supports the elementary arithmetic.

During calculation, the (dorsolateral) prefrontal cortex has mainly an auxiliary role and reflects the involvement of working memory and attentional resources. This part of the network is particularly active during the execution of procedural strategies and the initial stages of arithmetic learning. Over developmental time, activity in this area decreases (Rivera et al., 2005) and similar decreases have been observed as a result of training in adults (Zamarian & Delazer, 2015), all reflecting the decrease in working memory resources needed to solve single-digit arithmetic problems.

In the parietal cortex, two sites appear to be important, both of which have distinct roles in calculation, and activity in these areas increases with development and skill acquisition (Rivera et al., 2005). The intraparietal sulcus (IPS) is more active during the use of procedural strategies, and this activity might reflect the increased involvement of quantity-based processing during the execution of such strategies. Importantly, it is currently unclear whether this activity refers to the processing of non-symbolic representations of quantity, symbolic representations of quantity or both (Ansari, 2016). On the other hand, the angular gyrus appears to show specific increases in brain activity during the retrieval of arithmetic facts from semantic memory (e.g. Grabner et al., 2009). Originally, this increase in activity was interpreted as reflecting the involvement of phonological processes during fact retrieval (Dehaene et al., 2003), but recent data have questioned this functional interpretation in calculation. Specifically, Ansari (2008) hypothesized that this brain region supports the mapping between mathematical symbols at their semantic referents (see also Ansari, 2016), as is the case in processing single-digit numerals (e.g. Holloway et al., 2010; Price & Ansari, 2011). Consequently, the differential activation of the left AG in mathematically more and less competent adults may reflect differences in their capability to process symbolic mathematical representations (see also Grabner, 2009). This might suggest a specific role for symbolic representations in the development of mathematical competencies.

It is important to emphasize that these brain imaging data have largely been obtained in adults and cannot be merely generalized to developmental populations (Ansari, 2010; Menon, 2015). For example, De Smedt et al. (2011) observed that brain activity in 10-12-year-old children during the solution of small problems and additions, that is those problems that are typically solved via fact retrieval, revealed a different pattern from what is observed in adults. Different from data in adults (Dehaene et al., 2003; Grabner et al., 2007), the angular gyrus did not show specific changes in activity during fact retrieval. Instead, the medial temporal lobe, in particular, the hippocampus was particularly active (De Smedt et al., 2011). Recent developmental brain imaging data have confirmed the role of the hippocampus in learning arithmetic facts (e.g. Qin et al., 2014; see Menon, 2015, for a review). One potential hypothesis, based on the observation that the hippocampus has a time-limited role in semantic memory (Smith & Squire, 2009), is that the hippocampus plays an important role in the initial encoding and retrieval of arithmetic facts, after which its role might diminish and the angular gyrus might take over for the retrieval of fully consolidated facts (see Menon, 2015, for a discussion).

To summarize, the development of (single-digit) arithmetic is characterized by the acquisition of different arithmetic strategies, which are associated with specific brain networks, the role of which changes during development. These networks are not restricted to one core area and suggest the involvement of various cognitive processes in (individual differences in) arithmetic. Against the background of these neuroimaging data, it can be hypothesized that, in addition to non-symbolic representations of quantity, the ability to process symbolic numerical magnitudes, working memory as well as phonological processing, constitute plausible candidates of cognitive determinants of individual differences in arithmetic , as we will review below.

Symbolic numerical magnitude processing

Many studies have shown that people's elementary intuitions about quantity, aka their ability to represent non-symbolic magnitudes, is related to individual differences in mathematics achievement (De Smedt et al., 2013, for a review). However, the primacy of this ability has been questioned. For example, De Smedt et al. (2013) showed in their narrative review that 11/25 or 44% of the studies revealed a significant association between mathematics and non-symbolic numerical magnitude processing, whereas the others did not. On the other hand, 13/17 or 76% of the studies showed a significant association with symbolic numerical magnitude processing, leading De Smedt et al. to conclude that symbolic numerical magnitude processing might be a more robust predictor of individual differences in mathematics achievement. Such descriptive comparisons could be, however, misleading as they do not take into account the effect sizes or sample sizes under investigation.

In an attempt to resolve this issue, Schneider et al. (2015) conducted a meta-analysis and statistically contrasted the effect sizes of non-symbolic as well as symbolic numerical magnitude processing as predictors of mathematics achievement. Their data revealed that the association between symbolic numerical magnitude processing and mathematics achievement $r = 0.302$, 95%*CI* = [0.243, 0.361], was significantly larger than the association with non-symbolic numerical magnitude processing $r = 0.241$, 95%*CI* = [0.198, 0.284].

It is, however, important to think about the degree of overlap between non-symbolic and symbolic numerical magnitude processing in individuals, and their respective neural correlates (see Ansari, 2016, for a discussion). The dominant theory assumes that numerical magnitude representations of Arabic digits are grounded in pre-existing core representations of non-symbolic magnitudes (e.g. Piazza, 2010, for a review). Recent brain imaging findings are not entirely compatible with this idea (see Ansari, 2016, for an extensive discussion). For example, Bulthe et al. (2014) as well as Lyons et al. (2015) used multivariate analytic techniques to investigate the neural overlap between non-symbolic and symbolic numerical magnitude representations. Both studies found no association between the (distributed) brain activity patterns of individual symbolic numbers and their corresponding non-symbolic dot arrays, although these data only consider adults and need to be replicated in children. Furthermore, studies in children with dyscalculia have observed consistent deficits in symbolic processing in these children, while deficits in nonsymbolic processing are not always observed (De Smedt et al., 2013, for a review). On the other hand, it has been argued that non-symbolic and symbolic numerical magnitude processing develop independently from each other and might constitute different systems (Le Corre & Carey, 2007), whose associations with mathematical competence might differ. Future work is clearly needed, but at least there is now considerable evidence to give a prominent role to symbolic numerical magnitude processing, the reason for which we focus on this domain-specific correlate in the remainder of this section.

Schneider et al. (2015) showed in their meta-analysis that the association between numerical magnitude processing and mathematical competence was very strongly modulated by the type of mathematical competence under investigation. Is symbolic numerical magnitude processing related to arithmetic and its strategies? Vanbinst et al. (2012) investigated this question in typically developing third graders by means of a cross-sectional design. They discovered that children with more proficient symbolic numerical magnitude processing skills relied more frequently on facts for solving single-digit additions and subtractions, and retrieved these facts faster and more accurately. These associations remained when potential confounds, such as intellectual ability or the ability to name digits, were taken into account. These data were cross-sectional and do not inform us about the direction of the association between symbolic numerical magnitude processing and arithmetic.

Interestingly, Vanbinst, Ghesquière, et al. (2015) investigated with a longitudinal design whether symbolic numerical magnitude processing is a precursor of future individual differences and developmental changes in children’s arithmetic fact mastery. Specifically, children’s symbolic numerical magnitude processing skills at primary school entrance were predictively related to their future competence in single-digit arithmetic as well as their reliance on arithmetic fact retrieval. Importantly, these longitudinal associations were not explained by children's intellectual ability, children's general mathematical knowledge at the start of primary school, working memory or processing speed. Importantly, these associations remained when children's non-symbolic numerical magnitude processing skills were controlled for. These longitudinal findings demonstrate that proficient symbolic numerical magnitude processing skills provide an important and unique scaffold for developing arithmetical facts.

Does symbolic numerical magnitude processing still play a role in more advanced stages of learning single-digit arithmetic? To answer this question, Vanbinst, Ceulemans, et al. (2015) ran a three-year longitudinal study, starting in third grade of primary school. By means of a model-based clustering approach (Banfield & Raftery, 1993) they identified three profiles of arithmetic fact development who were labelled as *slow and variable*, *average*, and *efficient* and whose performance was marked by differences in arithmetic fact mastery from third to fifth grade. Crucially, these three profiles differed in their symbolic numerical magnitude processing skills at each time point. These differences were very persistent and were not accounted for by other confounds such as age, sex, socioeconomic status, intellectual ability, general mathematics achievement, or reading ability.

Do children with dyscalculia also show deficits in symbolic numerical magnitude processing? It is important to emphasize that one of the major characteristics of these children comprises difficulties in learning arithmetic facts as well as performing accurate or fluent calculations, and, crucially, these difficulties do not substantially improve throughout primary school (e.g., Berch & Mazzocco, 2007; Geary, 2010; Geary et al., 2012), and even persist intensive instructional interventions (e.g., Howell, Sidorenko, & Jurica, 1987). Various studies have shown that children with dyscalculia show consistent deficits in symbolic numerical magnitude processing, although deficits in nonsymbolic numerical magnitude processing have not always been observed (Andersson & Ostergren, 2012; De Smedt & Gilmore, 2011; Iuculano et al., 2008; Landerl et al., 2004; Landerl &

Kölle, 2009; Mazzocco et al., 2011; Piazza et al., 2010; Rousselle & Noël, 2007; De Smedt et al., 2013, for a review). One limitation of these studies is that they investigated numerical magnitude processing at only one time point. Also, most of these studies considered only low achievement to define dyscalculia and did not consider into detail the persistence of the mathematical difficulties. To address these issues, Vanbinst, Ghesquière and De Smedt (2014) conducted a two-year longitudinal study (three time points) in which they compared a group of children with persistent dyscalculia with a typically developing group of children, matched on IQ, age, reading ability, sex and socioeconomic status. The children with dyscalculia showed persistent deficits in arithmetic (i.e., less frequent fact retrieval, slower performance in addition and subtraction) at all time points. Crucially, these arithmetic difficulties coincided with persistent impairments in symbolic numerical magnitude processing over time; no differences in nonsymbolic numerical magnitude processing were observed.

From the studies reviewed above, it appears that the ability to process symbolic numerical magnitudes plays an especially important role in subject variability in children's ability to acquire and retrieve arithmetic facts, potentially over the entire primary school period. In 1999, Gersten and Chard already theoretically suggested that children's ability to understand the meaning of Arabic digits (i.e., that they represent quantity), might be "an analog as important to mathematics learning as phonemic awareness has been to the reading research field" (p. 18). Indeed, in the fare more extensive reading literature, it is established that phonological awareness, or the conscious sensitivity to the sound structure of language, underlies individual differences in learning to read (see Melby-Lervåg, Lyster, & Hulme, 2012 and Swanson, Trainin, Necoechea, & Hammill, 2003, for a meta-analysis). Is the association between symbolic numerical magnitude processing and arithmetic of a similar nature? Vanbinst et al. (submitted) empirically tested this prediction by contrasting the strength of the association between symbolic numerical magnitude processing and arithmetic with the well-established phonological awareness-reading association. A direct comparison of these associations revealed that they were not significantly different from each other, both crosssectionally and longitudinally. These data indicate that symbolic numerical magnitude processing is as important to arithmetic development as phonological awareness is to the acquisition of reading.

The consistent association between symbolic numerical magnitude processing and arithmetic leads to the suggestion that screening symbolic numerical magnitude processing (early in children's academic career) might be helpful to identify at-risk children. Interestingly, measures that allow one to quickly and easily assess symbolic numerical magnitude processing in classroom settings have been developed and validated (Nosworthy et al., 2013). On a related note, remedial interventions should focus on these symbolic skills, for example by providing a variety of opportunities in which children are stimulated to connect Arabic symbols and their meaning (e.g., Brankaer et al., 2015; Dyson et al., 2011; Ramani & Siegler, 2008; Obersteiner et al., 2013; Wilson et al., 2006). From a scientific point of view, intervention studies will allow us to establish whether the association between symbolic numerical magnitude processing and arithmetic is causal or not. Indeed, the studies reviewed above are all correlational in nature and do not allow us to draw causal conclusions. This would require carefully controlled interventions in which only symbolic numerical magnitude processing is trained and in which the transfer to arithmetic performance is investigated, and this clearly represents an agenda for future research.

At the theoretical level, it remains an open question why symbolic numerical magnitude processing skills are so important for children's arithmetic (fact) development. One reason might be that understanding symbolic magnitudes provides an important scaffold to develop advanced counting strategies. For example, children gradually progress in their arithmetic development from counting-all to counting-on-from-larger, as in 5, 6, 7 to solve 2 + 5 (Geary et al., 1992). This latter advanced strategy requires children to select the larger of two Arabic symbols, which in turn might speed on the memorization of arithmetic facts. Furthermore, it is possible that arithmetic facts are stored in long-term memory in a meaningful way, i.e., according to their magnitude (e.g., Butterworth, Zorzi, Girelli, & Jonckheere, 2001; Robinson, Menchetti, & Torgesen, 2002). It also might be the case that this association reflects a common mapping process between numerical symbols and their semantic referents, i.e. Arabic digits and their quantity or arithmetic expressions and their solution. Finally, it is not unlikely that symbolic numerical magnitude processing in itself is affected by children's arithmetic development. Indeed, there might be a bi-directional association between children's symbolic numerical magnitude processing skills and their arithmetic abilities, and future studies should consider this possibility.

Working memory

While research on the role of numerical magnitude processing in individual differences in arithmetic is a fairly recent endeavor, studies on the influence of working memory on mathematical performance have a much more long-standing tradition (e.g., Bull & Scerif, 2001; DeStefano & LeFevre, 2004; Mazzocco & Kover, 2007; Raghubar et al., 2010, for reviews; Friso-van den Bos et al., 2013; Peng et al., 2015; Swanson & Jerman, 2006 for meta-analyses). The majority of this research adopted Baddeley's multi-component model of working memory (Baddeley, 1986, 2003) as their theoretical framework. At the core of this model is the central executive, which is responsible for the attention-driven control, regulation, and monitoring of complex cognitive processes. This central executive is sometimes fractionated into related executive functions, including updating, inhibition and shifting (Baddeley, 1986; see also Friso-van den Bos et al., 2013). The model additionally encompasses two slave systems of limited capacity, which are used for the temporary storage of visual and spatial information, the visuo-spatial sketchpad, as well as verbal information, the phonological loop. The flow of information in these slave systems is further orchestrated by the central executive.

Many studies have investigated the predictive value of working memory, specifically for learning arithmetic (e.g., Andersson, 2008; Andersson & Lyxell, 2007; Bull et al., 2008; De Smedt et al., 2009; Geary et al., 2007; Geary et al., 2012; Jarvis & Gathercole, 2003; Krajewski & Schneider, 2009; Mazzocco & Kover, 2007; Szücs et al., 2013; Rasmussen & Bisanz, 2005; St Clair-Thompson & Gathercole, 2006; Vukovic & Siegel, 2010), but the existing evidence remains to be mixed as to which of the components of Baddeley's working memory model explains individual differences in arithmetic fact retrieval.

The most consistent findings have been observed for the central executive, which is typically measured by means of complex span tasks during which individuals have to simultaneously store and process information, as is the case in the backward digit span. For example, associations have been reported between measures of the central executive and children's development of arithmetic facts (e.g., Bailey et al., 2012; Hitch & McAuley, 1991). It also has been shown that children with poor central executive capacities rely longer on immature calculation strategies, such as finger counting, and commit more counting errors (Geary et al., 2004) as well as that they rely less frequently on arithmetic fact retrieval compared with their peers with high central executive capacities (Barrouillet & Lépine, 2005).

The involvement of both slave systems, i.e. the visuo-spatial sketchpad and the phonological loop, remains, however, much less clear and it has been suggested that both have a time-limited role in predicting arithmetic, depending on children's dominant strategy to solve these problems (e.g., De Smedt et al., 2009; McKenzie et al., 2003). Specifically, the visuo-spatial sketchpad may be a particularly important correlate in young children during the early stages of learning single-digit arithmetic, during which children rely heavily on finger counting, which may be visuospatial in nature (e.g., McKenzie et al., 2003; Raghubar et al., 2010; Rasmussen & Bisanz, 2005). With increasing age, children develop a reliance on fact retrieval, during which the phonological loop plays a more prominent role and the impact of the visuospatial sketchpad decreases (e.g., Barrouillet & Lépine, 2005; Geary et al., 2007; Geary et al., 2012; Noël et al., 2004; Raghubar et al., 2010; see also the next section on phonological processing). This is in line with earlier accounts of the phonological loop being involved in the process of accurately memorizing arithmetic facts (Bull & Johnston, 1997) and related suggestions that an impaired phonological loop might prevent children from changing towards arithmetic fact retrieval (Noël et al., 2004). While these studies suggest a role of working memory slave systems, depending on children's development of arithmetic strategies, others have not been able to replicate this (e.g., Andersson & Lyxell, 2007; Bull et al., 2008; Szücs et al., 2013; Vanbinst, Ghesquière et al., 2015; Wu et al., 2008).

In order to make headway in understanding the association between working memory and arithmetic, a meta-analysis that statistically summarizes the existing findings and investigates potential moderators of the working memory – arithmetic association is needed. Such analysis was recently provided by Peng et al. (2015), who summarized the data of 110 studies (829 effect sizes), yet only focused on tasks that involved the simultaneous processing and storage of information, hence only involved the central executive. Their analysis revealed a significant medium association between working memory and mathematics (r = .35, 95%CI = [0.32, 0.37]) and it is interesting to note that these confidence intervals overlap with the confidence intervals of the association between symbolic numerical magnitude processing and mathematics, but not with non-symbolic numerical magnitude processing and mathematics, whose association is much smaller (Schneider et al., 2015). As is the case for the numerical magnitude processing – mathematics association, the association between working memory and mathematics was significantly moderated by the mathematical skill under investigation, with the highest associations observed for word-problem solving and whole number arithmetic.

Peng et al. (2015) observed that the association between working memory and whole number arithmetic was significantly moderated by age, such that the association was significantly stronger in younger than in older children. It is, however, important to emphasize that the load placed on working memory resources depends on the complexity and novelty of the task to be performed (Ackerman, 1988; Raghubar et al., 2010) and in the context of whole number arithmetic, working memory might be specifically important in the early learning stages, when new skills are acquired. Such effect would be independent of age, and the observed age effects might simply reflect artefacts due to experience or familiarity with a particular concept or arithmetic procedure (Raghubar et al., 2010). In arithmetic, the association between single-digit arithmetic and working memory might decrease quickly over time, but such association might continue to exist longer for multi-digit arithmetic. If then, more studies are focusing on single-digit arithmetic compared to multi-digit arithmetic, this might appear that the association with working memory is stronger in younger children (as observed by Peng et al., 2015), but this might simply be driven to the type of arithmetic skill (and its novelty) under investigation.

Another important moderator of the working memory – arithmetic association are the stimuli that are used to measure working memory (Peng et al., 2015). Indeed, various numerical tasks have been used, such as the backward digit span task (in which children are presented with a sequence of numbers and are asked to reproduce the sequence in the reversed order), the counting span task (in which children have to count sets of dots and to remember the totals in the order as presented), or the operation span task (during which children have to perform series of calculations and remember the totals in the order as presented). It is not unlikely that variability numerical, counting, and arithmetic performance contributes to span performances observed in the backward digit recall, counting span and operation span tasks, which makes an association between these tasks and arithmetic difficult to interpret, given their overlap in mathematical processes. In order to more precisely estimate the association between working memory and arithmetic, some researchers have therefore restricted their investigations to working memory tasks without numerical processing requirements (e.g., Vanbinst et al., 2015).

At a theoretical level, this issue touches on the debate of the domain-specificity of working memory. In Baddeley's model (1986), working memory is conceptualized as a domain-general construct and associations with other cognitive skills, such as arithmetic, are not expected to be affected by the way working memory is measured. On the other hand, there are domain-specific models of working memory (e.g. Ericsson & Kintsch, 1995), which posit that working memory is not a general purpose mechanism, but a workspace for integrating domain-specific skills, procedures and knowledge that are needed to meet the cognitive demands of a task in a particular domain. Such domain-specific models predict that the associations between mathematics and working memory would be higher for numerical measures of working memory. Peng et al. (2015) investigated the effect of working memory measures on the working memory – mathematics association, but observed no moderating effect of working memory measure, supporting the domain-general influence of working memory in mathematical performance.

An association between working memory and mathematical performance has also been observed in the context of atypical development, as many studies have shown that working memory difficulties occur in children with dyscalculia (Swanson & Jerman, 2006, for a meta-analysis), but not all studies have been consistent with this (e.g., Landerl et al., 2004; Szucs et al, 2013; Vanbinst et al. 2014). Raghubar et al. (2010) argued that this might have been explained by the working memory under investigation, and that difficulties in working memory are only observed in these children when numerical but not non-numerical working memory tasks are used (see for example, Passolunghi & Cornoldi, 2008; Passolunghi & Siegel, 2001, 2004; Siegel & Ryan, 1989; van der Sluis, van der Leij, & de Jong, 2005). On the other hand, it needs to be emphasized that studies on children with dyscalculia (sometimes) include children with and without comorbid difficulties (e.g., reading disorders, ADHD, genetic disorders, prematurity), the latter of which also are all associated with deficits in working memory (Peng et al., 2015). To better understand this issue, one needs to carefully compare children with dyscalculia without any other cognitive disorders to those that have dyscalculia and other cognitive deficits. In their meta-analysis, Peng et al. (2015) compared typically developing children, children with only dyscalculia, and children with dyscalculia and other cognitive disorders. Their data revealed that the association between working memory and mathematics was similar in typically developing children and children with dyscalculia. However, significantly stronger associations were observed in the sample with dyscalculia and other cognitive disorders.

It is important to emphasize that working memory has also been related to individual differences in children's numerical magnitude processing, but again the evidence appears to be mixed (Peng et al., 2015). For example, Simmons, Willis and Adams observed that the visuo-spatial sketchpad predicted unique variance in children's performance on a symbolic magnitude judgment test, in which children had to choose the largest symbolic number from a choice of three. Xenidou-

Dervou et al. (2013) observed significant associations between working memory and measures of symbolic and non-symbolic numerical magnitude processing, even though these were small and were not observed for all numerical measures. Others have failed to observe such association in typically developing children (e.g. Andersson & Ostergren, 2012). These differences might again, as highlighted above, be explained by children's expertise with numbers. On the other hand, the above mentioned association between symbolic numerical magnitude processing and arithmetic remains to be significant when measures of working memory have been taken into account (e.g., Vanbinst et al., 2015; Vanbinst, Ceulemans et al., 2015). Chen and Li (2014) revealed in their meta-analysis that the association between non-symbolic numerical magnitude processing and mathematics significantly dropped when domain-general cognitive factors, potentially including working memory, were taken into account, although they did not specify which domain-general cognitive factors were considered. Against this background, it remains to be determined to which extend working memory affects the association between numerical magnitude processing and mathematics, whether this might differ between non-symbolic and symbolic numerical magnitude processing, and this should be considered in future meta-analyses.

While above-reviewed studies indicate that the association between working memory and arithmetic is highly complex, it must be noted that the majority of these studies used a correlational approach to study the role of working memory in arithmetic. On the other hand, there are experimental approaches, such as dual-task studies, during which individuals have to simultaneously perform a criterion task (e.g. arithmetic) and a secondary task that taps into one component of working memory, to more directly investigate this connection (DeStefano & Lefevre, 2004; Raghubar et al., 2010, for reviews). These approaches are particularly fruitful, because they allow to investigate the online effect of working memory during arithmetic processing itself. Dual-task studies in arithmetic have a long-standing tradition (Hitch, 1978) but the majority of them have been conducted with adults. Only but a few studies have been executed in children (McKenzie et al., 2003; Imbo & Vandierendonck, 2008), showing the direct effects of different working memory components on arithmetic performance. These studies clearly show the influence of working memory on arithmetic performance, yet, this does not necessarily imply that variation in working memory abilities contributes to variability in arithmetic performance.

Taken together, the abovementioned review suggests that working memory clearly plays a role in learning arithmetic, but that the precise associations between these two abilities are very complex, even when one narrows down mathematical performance to the study of one particular type of skill, such as arithmetic. It is evident that these associations are dependent on the type of working memory task, but even more crucially, on the skill level (early vs. advanced) and strategies (procedural vs. retrieval) children apply. This necessitates the use of developmental designs in order to understand the working memory – arithmetic associations in which the skill level and strategies of children need to be specified.

Phonological processing

The most influential neurocognitive model of number processing, the triple code model (Dehaene, 1992; Dehaene & Cohen, 1995) already postulated, against the background of neuropsychological case study data, an association between phonological processing and arithmetic. Specifically, the model stated that numbers can be represented in a verbal-phonological code and that this code is activated during the (rote) retrieval of arithmetic facts from semantic memory, particularly in multiplication. Phonological processing has been highlighted as a key factor in reading ability and reading impairments or dyslexia (Melby-Lervåg et al., 2012; Snowling, 2000; Vellutino et al., 2004). On the other hand, consistent associations between reading ability and arithmetic have been reported (e.g., Fuchs et al., 2005; Fuchs et al., 2006; Hecht et al., 2001; Jordan et al., 2003) and disorders of learning to read (dyslexia) and learning to calculate (dyslexia) often co-occur (Landerl & Moll, 2010). Cognitive neuroimaging studies have pointed to shared neural correlates for reading and arithmetic in the left temporo-parietal cortex (see De Smedt et al., 2010, for a discussion). Specifically, developmental studies of reading have revealed that the temporoparietal cortex is consistently activated during phonological processing tasks and phonological reading strategies, which require children to convert letters into sounds, as is the case during the initial stages of reading and the reading of nonwords (e.g. Eden et al., 2015; Schlaggar & McCandliss, 2007). At the same time, studies in arithmetic have shown that the left temporo-parietal cortex is particularly active during fact retrieval (Grabner et al., 2007). Furthermore, recent connectivity data acquired by means of diffusion tensor imaging (Van Beek et al., 2014) have revealed that individual differences in the arcuate fasciculus – a white matter pathway that connects the frontal and parietal lobes, the quality of which has been related to individual differences in language and reading ability (Vandermosten et al., 2012) – were also related to individual differences in fact retrieval in 12-year-old children (Van Beek et al., 2014). This neural overlap between reading and arithmetic might therefore predict an association between phonological processing and arithmetic fact retrieval, due to their potential common reliance on phonological codes (see also Simmons and Singleton, 2008, for a similar discussion).

Studies on phonological processing have typically distinguished three types of phonological processing skills (e.g., Hecht et al., 2001; Wagner & Torgesen, 1987): (1) phonological awareness, which refers to the conscious sensitivity to the phonological structure of oral language (2) children's rate of access to phonological information in long-term memory and (3) phonological working memory (analogous to the phonological loop of Baddeley's working memory model), referring to the short-term storage of phonological information. Each of these phonological processing skills has been related to individual differences in calculation (e.g., Hecht et al., 2001; Koponen et al., 2007; Lefevre et al., 2010; Vukovic & Lesaux, 2013), but not all studies have focused specifically on the association with arithmetic fact retrieval.

De Smedt et al. (2010) tested this association in typically developing 9-11-year-olds. Specifically, they administered a phoneme deletion task, a classic measure of phonological awareness in which children are asked to indicate what a word would be if a specified phoneme in the word were to be deleted (e.g., saying cup without the phoneme /k/) and different types of single-digit arithmetic problems, i.e. those that are likely to be solved by means of fact retrieval (i.e. small additions and subtractions as well as multiplications) and those that are typically solved with procedural strategies (i.e. large additions and subtractions). They observed that phonological awareness was uniquely, i.e. independent of reading ability, related to performance on the "retrieval" problems, but not to performance on the "procedural problems". Other studies have observed associations between the rate of access to phonologically coded information in long-term memory and individual differences in efficient (i.e. fast and accurate) retrieval of arithmetic facts (e.g., Bull & Johnston, 1997; Hecht et al., 2001; Koponen, Aunola, Ahonen, & Nurmi, 2007). As reviewed above, the evidence for associations between phonological working memory and arithmetic remains to be mixed (see section working memory).

In their study of different profiles of arithmetic fact development, Vanbinst et al. (2015) also investigated whether these profiles differed in their phonological processing abilities. While the *efficient* and *average* groups did not differ in their phonological abilities, the *slow and variable* group, who relied less frequently on fact retrieval, showed poorer performance in phonological processing. These differences, however, disappeared when individual differences in reading ability were taken into account, although it needs to be emphasized that the children in the *slow and variable* group did not reflect a subgroup of children with reading learning difficulties or dyslexia. It is also important to note that this study only focused on addition and subtraction, and that an association with phonological processing might be particularly observed in other operations, such as multiplication.

Studies in children with dyscalculia have indicated that these children show poorer performance in all areas of phonological processing compared to typically developing children (Chong & Siegel, 2013; Murphy et al., 2007; Vukovic & Siegel, 2010). In view of the comorbidity between dyscalculia and dyslexia (Landerl & Moll, 2010), the co-occurrence of reading difficulties might explain the phonological processing difficulties in these samples with dyscalculia, although others have argued that these difficulties in phonological processing are independent of co-morbid dyslexia (Simmons & Singleton, 2008; Vukovic & Lesaux, 2013). To further understand this issue, Vanbinst et al. (2014) selected a sample of children with dyscalculia who had persistent impairments in mathematical performance and arithmetic fact retrieval but without difficulties in reading ability. The performance of these children was compared to a group of typically developing children, matched on IQ and reading ability. This specific group of children with persistent dyscalculia performed significantly more poorly than controls on all domains of phonological processing. On the other hand, data in children (Boets & De Smedt, 2010) as well as adults (De Smedt & Boets, 2010) with dyslexia who showed no difficulties in mathematical performance showed that they had specific impairments in retrieving arithmetic facts, particularly multiplication. De Smedt and Boets (2010) further showed that in healthy adults as well as adults with dyslexia, fact retrieval ability was related to their phonological skills, in particular phonological awareness. Interestingly, Evans et al. (2014) investigated this issue at the neural level by studying the brain activity during arithmetic in children with dyslexia. Their data revealed less activity in the left perisylvian language regions, including the supramarginal gyrus, in children with dyslexia during fact retrieval, confirming the link between language deficits and poor arithmetic fact retrieval in dyslexia.

The above reviewed studies focused specifically on phonological processing but did not examine its unique role when an important domain-specific factor, i.e. symbolic numerical magnitude processing, was also taken into account to predict arithmetic ability. Vanbinst et al. (submitted) tested this issue in typically developing children. This data revealed cross-sectional but not longitudinal associations between phonological awareness and arithmetic. Follow-up regression analyses and analyses of Bayes factors revealed a far less prominent role of phonological awareness in children's arithmetic development compared to simultaneously considered symbolic numerical magnitude processing skills.

From the literature reviewed above, it appears that weak phonological processing might constitute a risk factor for poor arithmetic fact retrieval, although such association might not always be consistently observed in the typical population, particularly not when domain-specific factors, such as symbolic numerical magnitude processing, are considered. It also needs to be emphasized that much of the available evidence is cross-sectional and not all studies have considered all factors of phonological processing. It remains to be determined at which point in the developmental trajectory of arithmetic fact learning, phonological processing plays the most prominent role. This requires longitudinal research to determine whether phonological processing plays a role in the transition from procedural to retrieval strategies or whether it affects the subsequent consolidation of arithmetic facts, or both.

Conclusions and future directions

Well-developed mathematical skills are crucial to life success in modern Western society and the ability to acquire and retrieve arithmetic facts is a major building block for the successful development of mathematical skills (Kilpatrick et al., 2001). The goal of this chapter was to review the available evidence on the domain-specific and domain-general neurocognitive determinants of individual differences in children's arithmetic development, other than the factor non-symbolic numerical magnitude processing, which might have been overemphasized as the primary determinant of individual differences in mathematics and of dyscalculia. We focused on the contributions of symbolic numerical magnitude processing, working memory and phonological processing, as these cognitive determinants have received the most attention so far and their roles in arithmetic can be predicted against the background of existing brain imaging data.

It is evident from the studies reviewed above that symbolic numerical magnitude processing is a major determinant of individual differences in arithmetic, even across primary school. Working memory, particularly the central executive, plays a role in learning arithmetic, but its influence appears to be dependent on the learning stage and the experience of children, which need to be taken into account in future research on the associations between working memory and mathematics. The available evidence on phonological processing, although more limited in nature, suggests that it plays a more subtle role in children's acquisition of arithmetic facts.

The above reviewed studies also highlight that it is crucial to investigate the roles of domain-specific and domain-general cognitive factors in concert. This requires longitudinal studies in which each of these factors is investigated, in order to understand its relative contribution as well as the mediating and moderating roles of these cognitive factors in children's arithmetic development. It is highly likely that different pathways contribute to individual differences in children arithmetic (see LeFevre et al., 2010, for a similar rationale), which are to be determined in future work. Importantly, such research should carefully characterize the dependent variable, i.e. the arithmetic strategies, skill level and expertise. The same accounts for the independent variables under investigation. Such characterization is needed in order to determine potential pathways as well as time points during which a particular cognitive factor may exert its largest effects. On a related note, impairments in the above reviewed cognitive factors all constitute risk factors for developing deficits in arithmetic, and consequently dyscalculia. As has been argued by Pennington (2006) on the origins of developmental disorders, it is unlikely that one single deficit accounts for the emergence of such a disorder. This requires future studies on dyscalculia to consider the relative contribution of these risk factors.

We would like to emphasize that in addition to the determinants reviewed in this chapter, other cognitive factors have been related to individual differences, which were not discussed into detail. One such factor, that has received some recent interest, is inhibitory control (Cragg & Gilmore, 2014, for a review). For example, it has been suggested that difficulties in arithmetic fact development might be related to difficulties in suppressing irrelevant information during the fact retrieval process (e.g., Barrioullet & Lépine, 2005; Geary et al., 2012; Verguts & Fias, 2005), although not all studies have found consistent associations between inhibitory control and arithmetic fact retrieval (e.g., Censabella & Noël, 2007). Another factor, recently proposed by De Visscher and Noël (2014), is an individual's (hyper)sensitivity to interference in memory. Specifically, these authors argued that during the arithmetic fact learning process, the storage of problem-answer associations in long-term memory might be hindered through interference, provoked by feature overlap of the to be learned problem-answer associations or arithmetic facts. These authors showed that individual differences in the sensitivity to this interference is related to individual differences in arithmetic fact retrieval in children and adults (De Visscher & Noël, 2014a, 2014b). Future studies should investigate the relative importance of these domain-general cognitive factors by also including domain-specific factors, such as symbolic numerical magnitude processing in their designs.

Another area in need of exploration is how non-cognitive factors interact with the cognitive factors reviewed above in their prediction of individual differences in arithmetic. These factors include mathematics anxiety (e.g., Ma, 1999; Maloney & Beilock, 2012; Ramirez et al., 2013), parental involvement (Fan, & Chen, 2001, for a meta-analysis) or attitudes towards mathematics (Ma & Kishor, 1997, for a meta-analysis). Mathematics anxiety is particularly relevant in this context, as it might affect children's strategic behavior in arithmetic: children with high math anxiety might feel not confident enough to retrieve arithmetic facts from memory and as a consequence, rely more on procedural strategies (i.e. counting and decomposition), which are slower and more error prone and put a high demand on working memory resources (e.g., Ashcraft & Krause, 2007).

It is also important to point out that the development of arithmetic does not occur in isolation but is dependent on the educational environment in general and the degree to which a mathematics curriculum emphasizes the acquisition of this skill and the use of specific strategies in particular. For example, cross-cultural studies have highlighted substantial differences between Chinese and U.S. children (Campbell & Xue, 2001; Geary et al., 1996), which might be explained by the extent to which curricular programs place an emphasis on fact retrieval. It therefore would be interesting to explore how determinants of individual differences in arithmetic vary as a function of the type of mathematics education.

Acknowledgements

This work was supported by grant G.0359.10 and G.0946.12 of the Research Foundation Flanders (FWO), Belgium, and by a postdoctoral fellowship (PDM) of the KULeuven awarded to Kiran Vanbinst.

References

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117,* 288–318.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (5th ed.).* Washington, DC: Author.

Andersson, U. (2008). Working memory as a predictor of written arithmetic skills in children: The importance of executive functions. *British Journal of Educational Psychology, 78*, 181–203.

Andersson, U., & Lyxell, B. (2007). Working memory deficit in children with mathematical problems: A general or specific deficit? *Journal of Experimental Child Psychology, 96*, 197–228.

Andersson, U., & Ostergren, R. (2012). Number magnitude processing and basic cognitive functions in children with mathematical learning disabilities. *Learning and Individual Differences, 22*, 701-714.

Ansari, D. (2010). Neurocognitive approaches to developmental disorders of numerical and mathematical cognition: The perils of neglecting the role of development. Learning and Individual Differences, 20, 123-129.

Ansari, D. (2016). Number symbols in the brain. In D. Berch, D. Geary and K. Mann-Koepke (Eds.) Development of Mathematical Cognition. Neural substrates and genetic influences(pp. 27-50). London, UK: Elsevier.

Ansari, D. (2008). Effects of development and enculturation on number representation in the brain. *Nature Reviews Neuroscience, 9*, 278-291

Arsalidou, M., & Taylor, M.J. (2011). Is 2 + 2 = 4? Meta-analyses of brain areas needed for numbers and calculations. Neuroimage, 54, 2382-2393.

Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance and math anxiety. *Psychonomic Bulletin & Review, 14*, 243-248.

Baddeley, A. D. (1986). *Working memory*. New York: Clarendon.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*, 829-839.

Bailey, D. H., Littlefield, A., & Geary, D. C. (2012). The co-development of skill at and preference for use of retrieval-based processes for solving addition problems: Individual and sex differences from first to sixth grades. *Journal of Experimental Child Psychology, 113*, 78-92.

Banfield, J. D., & Raftery, A. E. (1993). Model-based Gaussian and non-Gaussian clustering. *Biometrics, 49,* 803–821.

Barrouillet, P., & Lépine, R. (2005). Working memory and children's use of retrieval to solve addition problems. *Journal of Experimental Child Psychology, 91*, 183-204.

Berch, D. B., Geary, D. C., & Mann Koepke, K. (2016). Introduction: How the study of neurobiological and genetic factors can enhance our understanding of mathematical cognitive development. In D. Berch, D. Geary and K. Mann-Koepke (Eds.) *Development of Mathematical Cognition. Neural substrates and genetic influences* (pp. 1-26). London, UK: Elsevier.

Berch, D. B., & Mazzocco, M. M. M. (2007). *Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities*. Baltimore: Paul H. Brookes Publishing.

Boets, B., & De Smedt, B. (2010). Single-digit arithmetic in children with dyslexia. *Dyslexia, 16*, 183-191.

Bull, R., & Johnston, R. S. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology, 65*, 1-24.

Bull, R., & Scerif, G. (2001). Executive function as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*, 273-293.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at 7 years. *Developmental Neuropsychology, 33*, 205–228.

Bulthé, J., De Smedt, B., Op de Beeck, H. (2014). Format-dependent representations of symbolic and non-symbolic numbers in the human cortex as revealed by multi-voxel pattern analyses. *NeuroImage, 87*, 311-322.

Butterworth, B., Zorzi, M, Girelli, L., & Jonckheere, A. R. (2001). Storage and retrieval of addition facts: the role of number comparison. *The quarterly Journal of Experimental Psychology, 54*, 1005-1029.

Campbell, J. I. D., & Xue, Q. L. (2001). Cognitive arithmetic across cultures. *Journal of Experimental Psychology, 130*, 299–315.

Censabella, S. & Noël, M. (2008). The inhibition capacities of children with mathematical disabilities. *Child Neuropsychology, 14*, 1-20.

Chen, Q. & Li, J. (2014). Association between individual differences in non-symbolic number acuity and math performance: A meta-analysis. *Acta Psychologica, 148*, 163–172.

Cho, S., Metcalfe, A.W.S., Young, C.B., Ryali, S., Geary, D.C., & Menon, V. (2012). Hippocampal-prefrontal engagement and dynamic causal interactions in the maturation of children's fact retrieval. Journal of Cognitive Neuroscience, 24, 1849-1866.

Chong, S. L., & Siegel, L. S. (2008). Stability of computational deficits in math learning disability from second through fifth grades. *Developmental Neuropsychology, 33*, 300-317.

Corbetta, M., & Shulman, G. L., (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3,* 201-215.

De Smedt, B., & Boets, B. (2010). Phonological processing and arithmetic fact retrieval: Evidence from developmental dyslexia. *Neuropsychologia, 48*, 3973-3981.

De Smedt, B., & Gilmore, C. K. (2011). Defective number module or impaired access? Numerical magnitude processing in first graders with mathematical difficulties. *Journal of Experimental Child Psychology, 108*, 278–292.

De Smedt, B., & Grabner, R. (2015). Applications of neuroscience to mathematics education. In. A. Dowker and R. Cohen-Kadosh (Eds.) Oxford handbook of mathematical cognition (pp. 613-636). Oxford, UK: Oxford University Press.

De Smedt, B., Holloway, I. D., & Ansari, D. (2011). Effects of problem size and arithmetic operation on brain activation during calculation in children with varying levels of arithmetical fluency. *Neuroimage , 57*, 771-781.

De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology, 103*, 186-201.

De Smedt, B., Noël, M., Gilmore, C., & Ansari, D. (2013). How do symbolic and non-symbolic numerical magnitude processing skills relate to individual differences in children's mathematical skills? A review of evidence from brain and behavior. *Trends in Neuroscience and Education, 2*, 48-55.

De Smedt, B., Taylor, J., Archibald, L., & Ansari, D. (2010). How is phonological processing related to individual differences in children's arithmetic skills. *Developmental Science, 13*, 508-520.

De Visscher, A., & Noël, M. (2014a). Arithmetic facts storage deficit: the hypersensitivity-to-interference in memory hypothesis. *Developmental Science, 17*, 434–442.

De Visscher, A., & Noël, M. (2014b). The detrimental effect of interference in multiplication facts storing: typical development and individual differences. *Journal of Experimental Psychology: General, 143,* 2380-2400.

Dehaene, S. & Cohen, L. (1995). Towards an anatomical and functional model of number processing. *Mathematical Cognition, 1,* 83-120.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44*, 1–42.

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology, 20*, 487-506.

DeStefano, D., & LeFevre, J. (2004). The role of working memory in mental arithmetic. *European Journal of Cognitive Psychology, 16*, 353-386.

Dowker, A. (2005). *Individual differences in arithmetic. Implications for psychology, neuroscience and education*. Hove, UK: Psychology Press.

Dumontheil, I., & Klingberg, T. (2012). Brain activity during visuospatial working memory predicts arithmetical performance 2 years later. *Cerebral Cortex, 22,* 1087-1085.

Eden, G.F., Olulade, O.A., Evans, T.M., Krafnick, A.J., & Alkire, D.A. (2016). Developmental dyslexia. In G. Hickok and S. Small (Eds.), *Neurobiology of Language* (pp. 815-826) . Elsevier: Oxford, UK.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102,* 211–245.

Evans, T.M., Flowers, D.L., Napoliello, E.M., Olulade, O.A., Eden, G.F. (2014). The functional anatomy of single-digit arithmetic in children with developmental dyslexia. *Neuroimage, 101,* 644-652.

Fan, X., & Chen, M. (2001). Parental involvement and students' academic achievement: a meta-analysis. *Educational psychology review, 13*, 1-22.

Fazio, L. K., Bailey, D. H., Thompson, C. A., & Siegler, R. S. (2014). Relations of different types of numerical magnitude representations to each other and to mathematics achievement. *Journal of Experimental Child Psychology, 123*, 53-72.

Feigenson, L., Libertus, M.E., Halberda, J. (2013). Links between the intuitive sense of number and formal mathematics ability. *Child Development Perspectives, 7*, 74–79.

Fias, W. (2016). Neurocognitive components of mathematical skills and dyscalculia. In D. Berch, D. Geary and K. Mann-Koepke (Eds.) *Development of Mathematical Cognition. Neural substrates and genetic influences* (pp. 27-50). London, UK: Elsevier.

Friso-van den Bos, I., van der Ven, S. H. G., Kroesbergen, E. H., & van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review, 10*, 29-44.

Fuchs, L. S., Compton, D. L., Fuchs, D., Paulsen, K., Bryant, J. D., & Hamlett, C. L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology, 97*, 493-513.

Fuchs, L. S., Fuchs, D., Compton, D. L., Powell, S. R., Seethaler, P. M., Capizzi, A. M., Schatschneider, C., & Fletcher, J. M. (2006). The cognitive correlates of third-grade skill in arithmetic, algorithmic computation, and arithmetic word problems. *Journal of Educational Psychology, 98*, 29-43.

Geary, D. C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities, 37,* 4-15.

Geary, D. C. (2010). Mathematical Disabilities: Reflections on Cognitive, Neuropsychological, and Genetic Components. *Learning and Individual Differences, 20*, 130-133.

Geary, D. C., Bow-Thomas, C. C., & Yao, Y. (1992). Counting knowledge and skill in cognitive addition: A comparison of normal and mathematically disabled children. *Journal of Experimental Child Psychology, 54*, 372-391.

Geary, D. C., Hamson, C. O., & Hoard, M. K. (2000). Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology, 77*, 236-263.

Geary, D. C., Hoard, M. K., & Bailey, D. H. (2012). Fact retrieval deficits in low achieving children and children with mathematical learning disability. *Journal of Learning Disabilities, 45*, 291-307.

Geary, D. C., Hoard, M. K., & Nugent, L. (2012). Independent contributions of the central executive, intelligence, and in-class attentive behavior to developmental change in the strategies used to solve addition problems. *Journal of Experimental Child Psychology, 113,* 49-65.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions to working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology, 88*, 121-151.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child development, 78*, 1343-1359.

Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2012). Mathematical cognition deficits in children with learning disabilities and persistent low achievement: A five year prospective study. *Journal of Educational Psychology, 104*, 206–223.

Gersten, R., & Chard, D. (1999). Number sense: Rethinking arithmetic instruction for students with mathematical disabilities. *The Journal of Special Education, 33*, 18-28.

Grabner, R.H., Ansari, D., Koschutnig, K., Reishofer, G., Ebner, F., & Neuper, C. (2009). To retrieve or to calculate? Left angular gyrus mediates the retrieval of arithmetic facts during problem solving. *Neuropsychologia, 47,* 604-608.

Grabner, R.H., Ansari, D., Reishofer, G., Stern, E., Ebner, F., & Neuper, C. (2007). Individual differences in mathematical competence predict parietal brain activation during mental calculation. *Neuroimage, 38,* 346-356.

Hecht, S. A., Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (2001). The relations between phonological processing abilities and emerging individual differences in mathematical computation skills: A longitudinal study from second to fifth grades. *Journal of Experimental Child Psychology, 79*, 192-227.

Hitch, G., & McAuley, E. (1991). Working memory in children with specific arithmetical learning difficulties. *British Journal of Psychology, 82*, 375-386.

Hitch, G.J. (1978). The role of short-term working memory in mental arithmetic. *Cognitive Psychology, 10,* 302-323.

Holloway, I.D., Price, G.R., & Ansari, D. (2010). Common and segregated neural pathways for the processing of symbolic and nonsymbolic numerical magnitude: an fMRI study. *Neuroimage, 49,* 1006-1017.

Howell, R., Sidorenko, E., & Jurica, J. (1987). The effects of computer use on the acquisition of multiplication facts by a student with learning disabilities. *Journal of Learning Disabilities, 20*, 336-341.

Imbo, I., & Vandierendonck, A. (2008). Effects of problem size, operation, and working-memory span on simple-arithmetic strategies: differences between children and adults? *Psychological Research-Psychologische Forschung, 72*, 331-346.

Iuculano, T., Tang, J., Hall, C. W. B., & Butterworth, B. (2008). Core information processing deficits in developmental dyscalculia and low numeracy. *Developmental Science, 11*, 669-680.

Jarvis, H. E., & Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on National Curriculum tests at 11 and 14 years of age. *Educational and Child Psychology, 20*, 123–140.

Jordan, N. C., Hanich, L. B., & Kaplan, D. (2003). Arithmetic fact mastery in young children: A longitudinal investigation. *Journal of Experimental Child Psychology, 85*, 103-119.

Kaufmann, L., Wood, G., Rubinsten, O., & Henik, A. (2011). Meta-analyses of developmental fMRI studies investigating typical and atypical trajectories of number processing and calculation. Developmental Neuropsychology, 36, 763-787.

Kilpatrick, J., Swafford, J., & Findell, B. (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: National Academy Press.

Koponen, T., Aunola., K., Ahonen, T., & Nurmi., J. E. (2007). Cognitive predictors of single-digit and procedural calculation and their covariation with reading skill. *Journal of Experimental Child Psychology, 97,* 220–241.

Kosc, L. (1974). Developmental dyscalculia. Journal of Learning Disabilities, 7, 164-177.

Krajewski, K., & Schneider, W. (2009). Exploring the impact of phonological awareness, visual–spatial working memory, and preschool quantity–number competencies on mathematics achievement in elementary school: Findings from a 3-year longitudinal study. *Journal of Experimental Child Psychology, 103*, 516–531.

Kucian, K. (2016). Developmental dyscalculia and the brain. In D. Berch, D. Geary and K. Mann-Koepke (Eds.) *Development of Mathematical Cognition. Neural substrates and genetic influences* (pp. 165-194). London, UK: Elsevier.

Landerl, K. & Moll, K. (2010). Comorbidity of learning disorder: prevalence and familial transmission. *Journal of Child Psychology and Psychiatry, 51*, 287-94.

Landerl, K., & Kölle, C. (2009). Typical and atypical development of basic numerical skills in elementary school. *Journal of Experimental Child Psychology, 103*, 546-565.

Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8-9-year-old students. *Cognition, 93*, 99-125.

Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: an investigation of the conceptual sources of the verbal counting principles. *Cognition, 105,* 395-438.

Lefevre, J. A., Fast, L., Skwarchuk, S. L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., & Penner-Wilger, M. (2010). Pathways to mathematics: longitudinal predictors of performance. *Child Development, 81,* 1753-1767.

Lyons, I.M., Ansari, D., & Beilock, S. (2015). Qualitatively different coding of symbolic and nonsymbolic numbers in the human brain. *Human Brain Mapping, 36,* 475-488.

Ma, X. (1999). A meta-analysis of the relationship between anxiety towards mathematics and achievement in mathematics. *Journal of Research in mathematics education, 30*, 520-540.

Ma, X., & Kishor, N. (1997). Assessing the relationship between attitude toward mathematics and achievement in mathematics: a meta-analysis. *Journal for Research in Mathematics Education, 28*, 26-47.

Maloney, E.A., & Beilock, S.L. (2012). Math anxiety: who has it, why it develops, and how to guard against it. *Trends in Cognitive Sciences, 16*, 404-406.

Marshuetz, C. (2005). Order information in working memory: an integrative review of evidence from brain and behaviour. *Psychological Bulletin, 131,* 323-339.

Matejko, A., & Ansari, D. (2015). Drawing connections between white matter and numerical and mathematical cognition: A literature review. *Neuroscience & Biobehavioral Reviews, 48,* 35-52.

Mazzocco, M. M. M., & Kover, S. T. (2007). A longitudinal assessment of executive functioning skills and their association with math performance. *Child Neuropsychology, 13*, 18-45.

Mazzocco, M. M. M., Feigenson, L, & Halberda, J. (2011a). Impaired acuity of the approximate number system underlies mathematical learning disability (dyscalculia). *Child Development, 82*, 1224-1237.

McKenzie, B., Bull, R., & Gray, C. (2003). The effects of phonological and visual-spatial interference on children's arithmetical performance. *Educational and Child Psychology, 20*, 93-108.

Melby-Lervåg, M., Lyster, S. H., & Hulme, C. (2012). Phonological skills and their role in learning to read: A Meta-Analytic Review. *Psychological Bulletin, 138*, 322–352.

Menon, V. (2015). Arithmetic in the child and adult brain. In R. Cohen-Kadosh & A. Dowker (Eds.), *The Oxford Handbook of Mathematical Cognition*. Oxford: Oxford University Press.

Monette, S., Bigras, M., & Guay M. C. (2011). The role of executive functions in school achievement at the end of Grade 1. *Journal of Experimental Child Psychology, 109*, 158-173.

Murphy, M. M., Mazzocco, M. M. M., Hanich, L. B., & Early, M. C. (2007). Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD. *Journal of Learning Disabilities, 40*, 458-478.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: US Department of Education.

Nieder, A., & Dehaene, S. (2009). Representation of number in the brain. *Annual Review of Neuroscience, 32*, 185-208.

Noël, M., Seron, X., & Trovarelli, F. (2004). Working memory as a predictor of addition skills and addition strategies in children. *Current Psychology of Cognition, 22*, 3-25.

Nosworthy, N., Bugden, S., Archibald, L., Evans, B., & Ansari, D. (2013). A two-minute paper-and-pencil test of symbolic and nonsymbolic numerical magnitude processing explains variability in primary school children's arithmetic competence. *PLoS ONE 8,* e67918.

Passolunghi, M. C., & Siegel, L. S. (2004). Working memory and access to numerical information in children with disability in mathematics. *Journal of Experimental Child Psychology, 88*, 348-367.

Passolunghi, M.C., & Cornoldi, C. (2008). Working memory failures in children with arithmetical difficulties. *Child Neuropsychology, 14*, 387-400.

Peng, P., Namkung, J., Barnes, M., Sun, C. (2015). A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. *Journal of Educational Psychology.*

Piazza, M. (2010). Neurocognitive start-up tools for symbolic number representations. *Trends in Cognitive Sciences, 14*, 542–551.

Piazza, M., Facoetti, A., Trussardi, A.N., Berteletti, I., Conte, S., Lucangeli, D., Dehaene, S., & Zorzi, M. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition, 116*, 33-41.

Price, G.R., & Ansari, D. (2011). Symbol processing in the left angular gyrus: evidence from passive perception of digits. *Neuroimage, 57,* 1205-1211.

Qin, S., Cho, S., Chen, T., Rosenberg-Lee, M., Geary, D.C., & Menon, V. (2014). Hippocampal-neocortical functional reorganization underlies children's cognitive development. *Nature Neuroscience, 17,* 1263-1269.

Raghabur, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences, 20*, 110-122.

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-Income children's numerical knowledge through playing number board games. *Child Development, 79*, 375-394.

Ramirez, G., Gunderson, E.A., Levine, S.C., & Beilock, S.L. (2013). Math anxiety, working memory, and math achievement in early elementary school. *Journal of Cognition and Development, 14*, 187-202.

Rasmussen, C., & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology, 91*, 137–157.

Rivera, S.M., Reiss, A.L., Eckert, M.A., & Menon, V. (2005). Developmental changes in mental arithmetic: Evidence for increased functional specialization in the left inferior parietal cortex. *Cerebral Cortex, 15,* 1779-1790.

Robinson, C. S., Menchetti, B. M., & Torgesen, J. K. (2002). Toward a two-factor theory of one type of mathematics disabilities. *Learning Disabilities and Practice, 17*, 81-89.

Rousselle, L., & Noël, M. (2007). Basic numerical skills in children with mathematics learning disabilities: A comparison of symbolic vs. non-symbolic number magnitude. *Cognition, 102*, 361-395.

Schlaggar, B. L., & McCandliss, B. D. (2007). Development of neural systems for reading. *Annual Review of Neuroscience, 30*, 475-503.

Schneider, M., Beeres, K., Coban, L., Merzl, S., Schmidt, S., Stricker, J., & De Smedt, B. (2015). Associations of Non-Symbolic and Symbolic Numerical Magnitude Processing with Mathematical Competence: A Meta-analysis. *Developmental Science.*

Siegel, L. S., & Ryan, E. B. (1989). The Development of Working Memory in Normally Achieving and Subtypes of Learning Disabled Children. *Child Development, 60,* 973-980.

Siegler, R. S. (1996). *Emerging minds: The process of change in children's thinking*. New York, NY: Oxford University Press.

Siegler, R. S., & Shrager, J. (1984). Strategy choice in addition and subtraction: How do children know what to do? In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 229-293). Hillsdale, NJ: Erlbaum.

Simmons, F. R., & Singleton, C. (2008). Do weak phonological representations impact on arithmetic development? A review of research into arithmetic and dyslexia. *Dyslexia, 14*, 77-94.

Simmons, F. R., Willis, C., & Adams, A. (2012). Different components of working memory have different relationships with different mathematical skills. *Journal of Experimental Child Psychology, 111*, 139-155.

Skwarchuk, S., Sowinski, C., & LeFevre, J. (2014). Formal and informal home learning activities in relation to children's early numeracy and literacy skills: The development of a home numeracy model. *Journal of Experimental Child Psychology, 121*, 63–84.

Smith, C.N., & Squire, L.R. (2009). Medial temporal lobe activity during retrieval of semantic memory is related to the age of the memory. *Journal of Neuroscience, 29,* 930-938.

Snowling, M.J. (2000). *Dyslexia* (2nd ed.). Malden, MA: Blackwell Publishers.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology,* 59, 745–759.

Swanson, H. L., & Jerman, O. (2006). Math disabilities: A selective meta-analysis of the literature. *Review of Educational Research, 76*, 249-274.

Swanson, H.L., Trainin, G., Necoechea, D.M., & Hammill, D.D. (2003). Rapid naming, phonological awareness, and reading: A meta-analysis of the correlation evidence. *Review of Educational Research, 73*, 407-440.

Szücs, D., Devine, A., Soltesz, F., Nobes, A., & Gabriel, F. (2013). Developmental dyscalculia is related to visuo-spatial memory and inhibition impairment. *Cortex, 49*, 2674-2688.

Todd, J. J., & Marois, R. (2005). Posterior parietal cortex activity predicts individual differences in visual short-term memory capacity. *Cognitive, Affective & Behavioral Neuroscience, 5,* 144–155.

Torbeyns, J., Verschaffel, L., & Ghesquière, P. (2004). Strategic aspects of simple addition and subtraction: The influence of mathematical ability. *Learning and Instruction, 14*, 177-195.

Van Beek, L., Ghesquière, P., Lagae, L., & De Smedt, B. (2014). Left fronto-parietal white matter correlates with individual differences in children's ability to solve additions and multiplications: A tractography study. *Neuroimage, 90,* 117-127.

van der Sluis, S., van der Leij, A., & de Jong, P.F. (2005). Working memory in Dutch children with reading- and arithmetic-related LD. *Journal of Learning Disabilities, 38,* 207-221.

Vanbinst, K., Ansari, D., Ghesquière, P., & De Smedt, B. (submitted). Symbolic magnitude processing is as important to arithmetic development as phonological awareness is to reading.

Vanbinst, K., Ceulemans, E., Ghesquière, P., & De Smedt, B. (2015). Profiles of children's arithmetic fact development: A model-based clustering approach. *Journal of Experimental Child Psychology, 133*, 29-46.

Vanbinst, K., Ghesquière, P., & De Smedt, B. (2012). Numerical magnitude representations and individual differences in children's arithmetic strategy use. *Mind, Brain and Education, 6*, 129-136.

Vanbinst, K., Ghesquière, P., & De Smedt, B. (2014). Arithmetic strategy development and its domain-specific and domain-general cognitive correlates: A longitudinal study in children with persistent mathematical learning difficulties. *Research in Developmental Disabilities, 35*, 3001-3013.

Vanbinst, K., Ghesquière, P., & De Smedt, B. (2015). Does numerical processing uniquely predict first graders' future development of single-digit arithmetic?. *Learning & Individual Differences, 37*, 153–160.

Vandermosten, M., Boets, B., Wouters, J., Ghesquière, P. (2012). A qualitative and quantitative review of diffusion tensor imaging studies in reading and dyslexia. *Neuroscience and Biobehavioral Reviews, 36*, 1532-1552.

Vellutino, F.R., Fletcher, J.M., Snowling, M.J., & Scanlon, D.M. (2004). Specific reading disability (dyslexia): what have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45,* 2–40.

Verguts, T., & Fias, W. (2005). Interacting neighbors: A connectionist model of retrieval in single-digit multiplication. *Memory & Cognition, 33*, 1-16.

Verschaffel, L., Luwel, K., Torbeyns, J., & Van Dooren, W. (2009). Conceptualizing, investigating, and enhancing adaptive expertise in elementary mathematics education. *European Journal of Psychology of Education, 24*, 335-359.

Vukovic, R. K., & Lesaux, N. K. (2013). The language of mathematics: Investigating the ways language counts for children's mathematical development. *Journal of Experimental Child Psychology, 115*, 227-244.

Vukovic, R. K., & Siegel, L. S. (2010). Academic and cognitive characteristics of persistent mathematics difficulty from first through fourth grade. *Learning Disabilities Research & Practice, 25*, 25-38.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192-212.

Wilson, A., Dehaene, S., Dubois, O., & Fayol, M. (2009). Effects of an adaptive game intervention on accessing number sense in low-socioeconomic-status kindergarten children. *Mind, Brain, and Education, 3*, 224–234.

Wu, S. S., Meyer, M. L., Maeda, U., Salimpoor, V., Tomiyama, S., Geary, D. C., & Menon, V. (2008). Standardized assessment of strategy use and working memory in early mental arithmetic performance. *Developmental Neuropsychology, 33*, 365-393.

Xenidou-Dervou, I., van Lieshout, E. C. D. M., & van der Schoot, M. (2013). Working memory in nonsymbolic approximate arithmetic processing: A dual-task study with preschoolers. *Cognitive Science, 38*, 101–127.

Zamarian, L., & Delazer, M. (2015). Arithmetic learning in adults: Evidence from brain imaging. In R. Cohen-Kadosh & A. Dowker (Eds.), *The Oxford Handbook of Mathematical cognition.* Oxford: Oxford University Press.