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Memory abilities in children with mathematical difficulties: Comorbid language difficulties matter

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ABSTRACT

The present study investigated cognitive abilities in children with difficulties in mathematics only ($n=48$, $M=8$ years and 5 months), combined mathematical and language difficulty ($n=27$, $M=8$ years and 1 month) and controls ($n=783$, $M=7$ years and 11 months). Cognitive abilities were measured with seven subtests, tapping visual perception, selective attention, memory, and reasoning, as well as full-scale-IQ. Children with difficulties in mathematics only differed in their cognitive abilities, not only from controls, but also from children with comorbid language difficulties. Children with mathematical difficulties only performed worse than controls in a selective attention measure, but not in any working memory measure, meanwhile children with difficulties in mathematics and language performed worse than controls in verbal working memory components, but not selective attention. Theoretical and practical implications are discussed.

1. Introduction

Mathematical deficits are usually persistent over the first school years (Andersson, 2010; Aunio & Niemivirta, 2010; Passolunghi & Siegel, 2004), and may be even associated with earlier school dropout and unemployment (Parsons & Bynner, 2005). Most literature points to working memory (Baddeley, 2000; Baddeley & Hitch, 1974) as a possible explanation for mathematical learning difficulties (e.g., Alloway, Gathercole, Kirkwood, & Elliott, 2009). The *phonological loop* is supposed to be of importance when performing calculations, as the instructions have to be remembered and subresults stored (Schuchardt, Kunze, Grube, & Hasselhorn, 2006; Swanson & Jerman, 2006). The *visual–spatial sketchpad* can serve as a mental blackboard that supports number representation (Alloway, 2006) and representation of some forms of conceptual knowledge (Geary, 2004). The *central executive* represents the controlling component of working memory and is assumed to manage the different processing steps of calculation and to enable children to use more elaborated, memory-based strategies in lieu of simpler visually-based strategies (Andersson & Lyxell, 2007).

However, research evidence with respect to group differences between children with and without difficulties in mathematics is mixed. There is evidence for underperformance of mathematically impaired children in every single memory subcomponent, i.e., the phonological loop (Andersson & Lyxell, 2007; D'Amico & Guarnera, 2005; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Schuchardt et al., 2006; Swanson & Beebe-Frankenberger, 2004), the visual–spatial sketchpad (D'Amico & Guarnera, 2005; Geary et al., 2007; McLean & Hitch, 1999), and the central executive (Andersson, 2010; Andersson & Lyxell, 2007; D'Amico & Guarnera, 2005; Geary et al., 2004, 2007; Kyttälä, Aunio, & Hautamäki, 2010; Mabott & Bisanz, 2008; McLean & Hitch, 1999; Passolunghi & Cornoldi, 2008; Passolunghi & Siegel, 2001; Passolunghi & Siegel, 2004; Swanson & Beebe-Frankenberger, 2004; Swanson & Jerman, 2006). On the other hand, mathematically impaired children and controls were found to be equal with respect to the phonological loop (Geary, Hoard, & Hamson, 1999; Landerl, Bevan, & Butterworth, 2004; Landerl, Fussenegger, Moll, & Willburger, 2009; McLean & Hitch, 1999; Passolunghi & Cornoldi, 2008; Passolunghi & Siegel, 2004; van der Sluis, van der Leij, & de Jong, 2005), the visual–spatial sketchpad (Geary, Hamson, & Hoard, 2000; Passolunghi & Cornoldi, 2008; Schuchardt et al., 2006; van der Sluis et al., 2005), or the central executive (Iuculano, Moro, & Butterworth, 2011; Landerl et al., 2004; Schuchardt et al., 2006; van der Sluis et al., 2005).

We think that two factors may distinguish studies reporting lower scores on any memory subcomponent from studies that do not: Restriction of IQ and restriction of language abilities. Studies that restrict IQ and language or reading abilities of children with mathematical difficulties to be in the average range often report no group differences with respect to any memory subcomponent (e.g. Geary et al., 2000; Landerl et al., 2004; Schuchardt et al., 2006; van der Sluis et al., 2005), whereas studies that only restrict IQ (e.g., Geary et al., 2004, 2007; Swanson & Beebe-Frankenberger, 2004) or only restrict language or reading abilities (e.g., Andersson, 2010; Andersson & Lyxell, 2007; D'Amico & Guarnera, 2005; Passolunghi & Cornoldi, 2008; Passolunghi & Siegel, 2001, 2004) or neither (e.g., Kyttälä et al., 2010) are more likely

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to report lower memory scores in children with mathematical difficulty. This pattern is mostly consistent and seems worth pursuing.

Mathematical and language difficulties often co-occur, as has been shown for children with Specific Language Impairment (SLI; Donlan, Cowan, Newton, & Lloyd, 2007) as well as for children with mathematical difficulties who exhibited lower language scores (Kyttälä et al., 2010). However, the causal link of this association remains unclear. It is reasonable to assume that language skills are essential to the development of precise counting and arithmetical skills (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Kyttälä et al., 2010). Language difficulties are likely to affect phonological processing, which may reduce working memory capacity and impede verbal fact retrieval (Butterworth, 2005). There is evidence that early oral language capacities are predictive of later reading abilities (NICHD, 2005), and that children with specific reading difficulties at the beginning of grade two and no initial mathematical difficulty are at risk for developing associated mathematical difficulties by the end of third grade (Jordan, Kaplan, & Hanich, 2002). Children with combined mathematical and reading difficulty generally score lower in digit span, short-term memory for words as well as visual–spatial sketchpad, visual working-memory and long-term memory tasks when compared to controls (Andersson, 2010; Maehler & Schuchardt, 2009) and to children with mathematical disability only (Swanson & Jerman, 2006). Children with comorbid dyslexia/dyscalculia show additive cognitive deficits, that is, their profile represents a combination of the deficits shown by dyslexic only and dyscalculic only (Landerl et al., 2009; Schuchardt et al., 2006).

The empirical studies mentioned so far addressed language difficulties in terms of reading difficulties or dyslexia (e.g., Andersson, 2010; Landerl et al., 2009; Maehler & Schuchardt, 2009; Schuchardt et al., 2006; Swanson & Jerman, 2006), which represent a special form of language difficulties, excluding children with other types of language difficulties (Snowling & Hulme, 2011). Since a problematic language development represents the main risk factor for reading disorders (Snowling & Hulme, 2012), it seems warranted to adapt a more comprehensive approach by taking more general language abilities into account. However, no known studies exist investigating children with mathematical difficulties combined with general language difficulties. It could be assumed that difficulties in language processing and verbal fact retrieval lead to increased working memory load, which would in turn also affect mathematical problem solving. Therefore, it could be hypothesized that children who struggle with mathematics exhibit lower memory scores, but only if their language abilities are also deficient. Hence, the first goal of this paper is to compare mathematically impaired children with and without comorbid language difficulties, but average IQ. We expect that children with mathematical difficulty only would perform comparably to controls in all memory subcomponents, whereas children with comorbid mathematical and language difficulty are more likely to score lower on memory tasks. Extreme deficits in memory tasks were not expected, however, because IQ was defined to be in the average range. The current study goes beyond existing literature by comparing children with mathematical difficulty only to children with comorbid mathematical and language difficulties and by including children with more general language problems, that is receptive as well as expressive language difficulties.

The finding of lower memory scores in mathematically impaired children might also depend on memory task characteristics. Some research suggests impairment for span tasks including numerical information only (i.e., digit span), but not when verbal material has to be remembered (i.e., word or letter span; D'Amico & Guarnera, 2005; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989). Other studies, however, report no group differences in any phonological loop task at all (Geary et al., 1999; Landerl et al., 2009; McLean & Hitch, 1999), be it digit span or letter span (Koontz & Berch, 1996), be it forward, as a pure measure of span capacity, or backward, measuring not only span, but also executive processing (Iuculano et al., 2011), which puts the hypothesis of a specific deficit in phonological memory for numerical information into question. Hence, the second goal of the present study is to investigate whether children with mathematical difficulty would exhibit lower scores in phonological memory for numerical information compared to scores in phonological memory for verbal information. If so, their performance in a digit span task should be worse than their performance in a letter span task. The present study extends previous research by examining this question in children with mathematical difficulty only and children with comorbid mathematical and language difficulties separately. We expect children with mathematical difficulties only to score lower only with respect to digit span tasks, but not with respect to letter span. Children with comorbid mathematical and language difficulties should struggle with letter as well as digit span tasks when compared to controls.

With regard to specific cognitive abilities other than working memory, research is scarce. There is some evidence that children with mathematical difficulties exhibit impaired attention capacities (Fuchs et al., 2008; Schwenck & Schneider, 2003), fluid reasoning, comprehension knowledge (Proctor, Floyd, & Shaver, 2005), inhibition of irrelevant information (D'Amico & Passolunghi, 2009; Passolunghi & Siegel, 2001, 2004), and slower processing speed (Bull & Johnston, 1997; Fuchs et al., 2008; Geary et al., 2007) as well as activating speed (D'Amico & Passolunghi, 2009). It is argued that slow information processing as well as the lack of inhibition of irrelevant information leads to faster decay in memory and higher memory load, which impedes mathematical problem solving (D'Amico & Passolunghi, 2009; Fuchs et al., 2008). Therefore, it may not be memory per se, but underlying difficulties with processing speed, attention and inhibition that affect memory as well as mathematical problem solving. Mostly, cognitive abilities have been addressed via full-scale IQ, with mathematically impaired children attaining lower IQ scores when compared to controls (Andersson, 2010; Proctor et al., 2005). The third goal of the present study is therefore to investigate not only memory, but also specific cognitive abilities as well as general intelligence in children with mathematical difficulty. We expect mathematically impaired children to score lower than controls on tasks tapping attention, fluid reasoning, comprehension knowledge, inhibition and processing speed as well as full-scale IQ. Because of the finding that impaired attention, inhibition and processing speed were reported for children with mathematical, but no language difficulty (Fuchs et al., 2008; Passolunghi & Siegel, 2004; Schwenck & Schneider, 2003), we would expect children with mathematical difficulty only to score lower in these variables, meanwhile children with combined difficulty might not follow this pattern.

2. Method

2.1. Participants

Participants were drawn from three representative standardization samples ($N = 1330$, 668 girls and 662 boys, tested in Austria, Germany, and Switzerland) of the *Intelligence and Development Scales* for children aged 5 to 10 years (IDS, Grob, Meyer, & Hagmann-von Arx, 2009). Participants were included in the present analyses if they had a full-scale IQ of ≥ 85 and ≤ 115. All children understood and spoke German fluently enough to follow test instructions, and all children attended public schools and are part of a non-clinical sample. Group membership was defined according to the scores in the standardized mathematics and language subtests of the IDS, which do not factor into the full-scale IQ. Children were assigned to the group with mathematical difficulty (MD) if they had a standardized mathematics score below the 15th percentile compared to the age norm, but average language scores ($n = 48$, mean age = 8 years and 5 months, $SD = 1$ year and 6 months, range: 5–10 years and 10 months, 69% female). This procedure is in line with previous literature (e.g., Geary et al., 2007) and represents a rather strict cut-off compared to other studies