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Mathematical skills in children with dyslexia ☆

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ABSTRACT

The mathematical performance of 17 children with developmental dyslexia (DD) was assessed and compared to a control group to examine whether difficulties related to reading and phonological processing affect the development of mathematical skills. The DD group performed worse than the controls on number fact retrieval, multi-step arithmetic problem solving, and multi-digit calculation, whereas their scores on tasks tapping approximate arithmetic and conceptual understanding (i.e., place value, calculation principles) were equal to the controls. In view of the Triple-code model, the findings demonstrate that children with DD have problems with tasks depending on verbal–phonological number codes but have no problems with tasks depending on analogue magnitude representations or visual-Arabic number codes.

1. Introduction

Developmental dyslexia (DD) is a common learning disability in the Western World affecting approximately 5–7% of the school-age population (Badian, 1999; Lewis, Hitch, & Walker, 1994; Vellutino, Fletcher, Snowling, & Scanlon, 2004). DD is a specific learning disorder characterized by a persistent deficit in the accurate and/or fluent word recognition and by poor spelling (International Dyslexia Association, 2002). A large amount of evidence demonstrates that the core deficit underlying DD is impaired phonological representations affecting not only reading performance but also performance on tasks tapping phonological awareness, rapid automatic naming, and verbal short-term memory (Fletcher et al., 1994; Ramus, 2004; Stanovich & Siegel, 1994). There are also indications that individuals with DD have weaknesses in executive functions and processing speed (Helland & Asbjørnsen, 2000; Menghinia et al., 2010; Reiter, Reiter, Tucha, & Lange, 2005; Stein & Walsh, 1997).

In contrast to the bulk of research that have focused on mapping the cognitive profiles of individuals with DD, the present study focused on mathematical skills. The main question is whether difficulties related to reading and phonological processing affects the development of mathematical skills?

Theoretical models such as the Triple code model (Dehaene, 1992) and the developmental model of numerical cognition (von Aster & Shalev, 2007) postulate that language and phonological skills underlie the development of early number and arithmetic skills. The Triple-code model (Dehaene, 1992) states that humans have three number codes; a verbal–phonological code used for counting, and establishing and retrieving number facts, a visual-Arabic number code used during multi-digit calculation, and an analogue magnitude representation used for number comparison, number estimation and approximate arithmetic. Research also demonstrates that language, especially reading, and phonological processing, contribute to early mathematical development (Hecht, Torgesen, Wagner, & Rashotte, 2001; Krajewski & Schneider, 2009; Simmons, Singleton, & Horne, 2008). Furthermore, De Smedt, Taylor, Archibald, and Ansari (2010) found that phonological awareness predict arithmetic problems with a small problems size but not large problem size. The former problems were solved via direct retrieval from long-term memory whereas the latter problems were solved via procedural strategies. Based on these findings, De Smedt et al. (2010) proposed that "the quality of children's long-term phonological representations mediates individual differences in single-digit arithmetic, suggesting that more distinct long-term phonological representations are related to more efficient arithmetic fact retrieval" (p. 508). This conclusion is consistent with neuroimaging findings showing that phonological processing and arithmetic fact retrieval recruit the same cortical regions in the left temporo-parietal areas, especially the left angular gyrus (Gelfand & Bookheimer, 2003; Grabner et al., 2007, 2009; Shaywitz et al., 1998). Thus, there are both theoretical and empirical reasons to assume that children with DD can be expected to have problems with early mathematics.

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Consistent with this assumption, research shows that individuals with DD have weak number fact retrieval skills (see Simmons & Singleton, 2008 for a review; De Smedt & Boets, 2010; Göbel & Snowling, 2010; Vukovic, Lesaux, & Siegel, 2010). In view of the Triple-code model, the weak phonological representations of children with DD hamper fast and accurate retrieval of number facts (De Smedt & Boets, 2010). In contrast, they should not have any problems with arithmetic tasks relying on the visual Arabic number code or the analogue magnitude representation. Research confirms this assumption, by showing that adults with dyslexia display intact symbolic and non-symbolic number processing and approximate arithmetic skills (De Smedt & Boets, 2010; Göbel & Snowling, 2010).

Theoretically, reading difficulties could have a negative impact on arithmetic word problem-solving ability, as poor language or reading skills should hamper the establishment of a correct problem representation, as it entails comprehending and translating each statement in the problem and integrating it with the other statements (Hegarty, Mayer, & Green, 1992; Hegarty, Mayer, & Monk, 1995; Kail & Hall, 1999; Kintsch & Greeno, 1985; Mayer & Hegarty, 1996).

Poor word problem solving in children with DD or with specific reading comprehension difficulty has been reported by Vukovic et al. (2010). These two groups of eight to ten-year-olds obtained lower scores than controls, despite that the problems were read to the child. The DD children also obtained lower scores on arithmetic fact retrieval and multi-digit calculation, while the group with specific reading comprehension difficulty, but intact word decoding, performed equal to the controls on both tasks (see also Göbel & Snowling, 2010). Including the fact retrieval task as a covariate did not eliminate the lower scores of the DD group on the problem solving and calculation tasks. Thus, suggesting that the children's issues are not related to word-decoding per se but possibly language related processes. Vukovic et al. (2010) also concluded that children with DD have more comprehensive mathematical difficulties related to several tasks, whereas children with specific reading comprehension difficulties only have problems with complex tasks (problems solving).

Weaknesses in mathematics have also been found in other groups with RD (Hanich, Jordan, Kaplan, & Dick, 2001; Jordan, Hanich, & Kaplan, 2003). These studies used a different and less strict operationalization of RD compared to studies on DD, as they included children having reading composite (reading comprehension and word decoding) scores at or below the 35th percentile. Similar to Vukovic et al. (2010), Jordan et al. (2003) found poor word problem solving and calculation in RD children. The RD and DD children's weak calculation ability (Jordan et al., 2003; Vukovic et al., 2010) is unexpected in relation to the Triple-code model as this task is assumed to involve a visual Arabic number code (Dehaene, 1992). Similarly unexpected, Jordan et al. (2003) found that the RD children displayed problems with place value understanding (cf. Hanich et al., 2001). However, it should be noted that studies, using similar operationalization of RD as Jordan et al. (2003), have not found any evidence of mathematical difficulties in individuals with RD (Jordan & Hanich, 2000; Jordan, Kaplan, & Hanich, 2002). For example, Jordan and Hanich (2000) found that children with RD performed equal to controls on tasks tapping word problem solving, calculation, place value understanding and even number fact retrieval. Jordan et al. (2002) replicated Jordan and Hanich's (2000) findings, as the RD children revealed intact problem solving and calculation skills. In addition, Simmons and Singleton (2009) reported unimpaired place value understanding in children with DD.

In summary, the empirical picture concerning mathematical skills in DD is still far from conclusive, but suggests an uneven profile. Individuals with DD appear to have intact approximate arithmetic skills and number processing skills, whereas the evidence of weak number fact retrieval skills is increasing. Research concerning problem solving, calculation and conceptual skills (e.g., place value) has generated mixed results.

1.1. The study

The aim was to examine mathematical skills in children with DD to extend our knowledge regarding the relationship between reading difficulties and mathematical skills. Based on the Triple code theory (Dehaene, 1992) and previous findings, the following predictions and research questions were examined:

1. It was predicted that children with DD would show impaired number fact retrieval as it involves verbal–phonological number codes.
2. It was predicted that children with DD would display problems with word problem solving, as this type of tasks is mediated by language processes.
3. The DD children were expected to display intact approximate arithmetic, because this aspect of mathematics is assumed to be founded on an analogue magnitude representation.
4. A question that needs to be examined further is whether individuals with DD have difficulties with multi-digit calculation and conceptual understanding, as they are assumed to not involve verbal–phonological codes.

A test battery including eight mathematical tasks and seven cognitive tasks was used. The cognitive tasks were included to account for possible group differences. The selection of the tasks was based on prior research demonstrating that children with DD display impaired phonological processing, processing speed, verbal short-term memory, and executive functions (Fletcher et al., 1994; Helland & Asbjørnsen, 2000; Menghinia et al., 2010; Ramus, 2004; Reiter et al., 2005; Stanovich & Siegel, 1994; Stein & Walsh, 1997). Furthermore, converging evidence demonstrates that children's mathematical performance is supported by cognitive abilities such as working memory, executive functions, semantic long-term memory and processing speed (e.g. Andersson, 2007; Berg, 2008; Bull, Espy, & Wiebe, 2008; Geary, 2004; Passolunghi, Mammarella, & Altoè, 2008; Passolunghi & Pazzaglia, 2004; Swanson, 1994; Träff, 2013).

2. Material and methods

2.1. Participants

Sixty-five third and fourth graders attending 27 schools participated in the study. The children were recruited by means of a letter of consent that the children took home to the parents from school. All children were fluent speakers of Swedish, had normal or corrected-to-normal visual acuity, and no hearing loss. Children diagnosed with neuropsychological disturbances were excluded from the study. Two criterions were used to classify children as having DD. The first criterion was that the child received special education instructions in reading and writing (i.e., Swedish) and no other school subject at the time of the study (Andersson & Östergren, 2012). Parental permission was received from 27 third graders and 23 fourth graders receiving special education instructions in reading and writing. Parental permission was obtained from 53 third graders and 59 fourth graders who never had received any special education instruction. The second criterion for being classified as having DD was that the child's word-decoding score and spelling score were at/below the 5th percentile of the 112 normal achievers (53 third and 59 fourth graders). Seventeen of the children receiving special education instructions in reading and writing met the 5th percentile criteria for inclusion in the DD group. The control group was made up of the 112 normal achievers having word-decoding and spelling scores between the 15th and the 85th percentile. Forty-eight children out of 112 met this criterion. Two reading comprehension tasks and three sets (B, C, D) of the Raven's Progressive Matrices test (Raven, 1976) were administered to obtain measures of reading comprehension and non-verbal intelligence.

Background information, results on the reading and spelling tasks, and the Raven's test are displayed in Table 1. The DD children performed