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Research report

A case study of arithmetic facts dyscalculia caused by a hypersensitivity-to-interference in memory

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ABSTRACT

While the heterogeneity of developmental dyscalculia is increasingly recognized, the different profiles have not yet been clearly established. Among the features underpinning types of developmental dyscalculia suggested in the literature, an impairment in arithmetic fact retrieval is particularly prominent. In this paper, we present a case study of an adult woman (DB) with very good cognitive capacities suffering from a specific and developmental arithmetic fact retrieval deficit. We test the main hypotheses about developmental dyscalculia derived from literature. We first explore the influential hypothesis of an approximate number system deficit, through estimation tasks, comparison tasks and a priming comparison task. Secondly, we evaluate whether DB's mathematical deficiencies are caused by a rote verbal memory deficit, using tasks involving completion of expressions, and reciting automatic series such as the alphabet and the months of the year. Alternatively, taking into account the extreme similarity of the arithmetic facts, we propose that a heightened sensitivity to interference could have prevented DB from memorizing the arithmetic facts. The pattern of DB's results on different tasks supports this hypothesis. Our findings identify a new etiology of a specific impairment of arithmetic facts storage, namely a hypersensitivity-to-interference.

1. Introduction

Developmental dyscalculia (DD) is a severe and persistent learning disability that concerns mathematical skills. According to the DSM IV (Diagnostic and Statistical Manual of Mental Disorders), the diagnostic criterion for mathematical disorder is a deficit in standardized tests assessing mathematical ability, which interferes with academic achievement or daily living, and which cannot be explained by a sensory deficit or by educational deprivation (American Psychiatric Association, 2000). Based on these criteria and depending on the study, the prevalence of children with mathematical disabilities is between 3 and 6% (Badian, 1983; Gross-Tsur et al., 1996; Kosc, 1974; Lewis et al., 1994). Two main characteristics of dyscalculia are generally agreed: a difficulty in learning and remembering arithmetic facts, and a difficulty in executing calculation procedures (Landerl et al., 2004).

There are two distinct perspectives on the etiology of DD. One is to regard DD as due to a specific impairment of the approximate number system (Piazza et al., 2010; Wilson and Dehaene, 2007). This approximate number system is conceptualized as a logarithmically-compressed mental number line

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which represents numerical quantities as Gaussian curves (Dehaene, 1992). Accordingly, large numbers/numerosities are represented less precisely than small ones. These characteristics lead to the distance effect (Moyer and Landauer, 1967) [the fact that it is easier to compare two numerically distant numbers (e.g., 1 and 9) than two close ones (e.g., 8 and 9)].

In line with this approach, Mussolin et al. (2010) have found a larger comparison distance effect (CDE) for both symbolic and non-symbolic numbers in DD children, compared to control children. Similarly, Piazza et al. (2010) have shown lower non-symbolic number acuity (i.e., lower precision of the number line) in DD children than in typically developing children. Using a priming paradigm in which two successive numbers have to be compared to the standard 5, Reynvoet et al. (2009) showed that response to the second number was faster if it was primed by a close number rather than by a distant number. Moreover a smaller priming distance effect (PDE) was associated with poorer math performance in children (Defever et al., 2011). Finally, using number estimation tasks, Mejias et al. (2012) observed that DD participants were less precise than controls in estimating the number of dots in a set by producing an Arabic number, in producing a set of dots to match a given Arabic number, and in producing the same number of identically-sized dots as seen in a previous collection of dots of various sizes.

However, other studies found that the performance of DD children was only impaired when they had to process the magnitude of symbolic numbers; sets of items were not affected (De Smedt and Gilmore, 2011; Iuculano et al., 2008; Rousselle and Noël, 2007). Accordingly, Rousselle and Noël proposed that the deficit lies in the link between symbolic numbers and their magnitude representation.

The other way of tackling the origin of DD is to focus on deficits in diverse general cognitive processing which potentially prevent the development of mathematical skills. Among these general cognitive processes, the capacity of the working memory has been the subject of several studies. For instance, McLean and Hitch (1999), Passolunghi and Siegel (2004) and Swanson and Jerman (2006, for a meta-analysis) have shown that the central executive component of the working memory in children with DD has a smaller capacity than that of typically developing children. Nevertheless, the findings for this second approach have also been controversial. For instance, Landerl et al. (2004) and Schuchardt et al. (2008) did not find any evidence for a deficit of the central executive function in their sample of DD children.

All these studies tested groups of DD children without taking into account the heterogeneity of their profiles. This could substantially influence the findings and could lead to inconsistent outcomes. Single case studies (Butterworth, 1999; Kaufmann, 2002; Ta'ir et al., 1997; Temple, 1992), group studies (Geary et al., 1999) and literature reviews (Rubinsten and Henik, 2009; von Aster and Shalev, 2007; Wilson and Dehaene, 2007) all indicate distinct profiles of mathematical disabilities. The frequent combination of dyscalculia with dyslexia or with attention deficit and hyperactivity disorder (ADHD), has led researchers to suspect multiple etiologies for this problem. Models of adult numerical cognition have also suggested that different neural networks could sustain different number processing that could be selectively impaired (see, for instance, Dehaene et al., 2003).

Despite this heterogeneity, difficulty in quickly retrieving arithmetical facts (over-learned single-digit problems) appears to be a general hallmark of DD. This has been noticed since the early 1970s (Slade and Russel, 1971), is consistently reported in the literature (Geary et al., 1999), and seems to be a persistent trouble (Jordan and Montani, 1997). Arithmetic facts refer to problems for which we retrieve the correct answer from memory. In adults, single-digit multiplications are known to be mainly retrieved from memory. Solving additions can involve both direct retrieval (mainly for sums up to ten) or counting-based procedural strategies (e.g., Roussel et al., 2002). Concerning subtraction, Thevenot et al. (2010) have shown that subjects highly skilled in arithmetic mainly retrieve the answer for subtractions with minuend up to 17, while lower-skilled subjects retrieve the answer only for problems with a minuend up to 10. Finally, for divisions, subjects usually use related multiplication facts while direct retrieval strategy is rare (Robinson et al., 2006).

While typical children show a transition from a procedural strategy to a memory-based resolution by developing arithmetic facts network, this does not seem to be the case for many DD children (Garnett and Fleischner, 1983; Geary et al., 1991; Jordan and Montani, 1997). Because DD children have to solve problems by computing the answer which is absent from their long-term memory, they are slower and produce more errors than typically developing children.

This paper consists of a case study of an individual with a very specific deficit of arithmetic facts, particularly multiplication facts. Focusing on this specific profile, we investigated the explanatory power of three main theories: (1) the possibility of a defective approximate number system, (2) the verbal memory deficit hypothesis and (3) the hypersensitivity-to-interference in memory hypothesis.

The hypothesis of a defective approximate number system has been described above and corresponds to the current dominant explanation for DD. The second hypothesis has been suggested by Wilson and Dehaene (2007). Among several profiles of DD, they proposed the existence of a verbal memory dyscalculia that is characterized by a selective impairment of arithmetic facts (especially multiplication facts) and a possible difficulty in learning the counting sequence. This proposition was based on the hypothesis that multiplication facts are learned as rote verbal memory. This was supported by the fact that brain-damaged patients with selective multiplication impairment, also suffered from larger deficits in rote verbal memory, as witnessed by their difficulties in reciting verbal sequences such as the alphabet or the months of the year (Dehaene and Cohen, 1997, patient BOO). Some patients have a reading deficit (Cohen and Dehaene, 2000) or a language impairment (Lemer et al., 2003, patient BRI) in addition to the selective multiplication impairment. In normal populations, performance in multiplication correlates with other language skills, in particular, phonological awareness. This is true for adult students (De Smedt and Boets, 2010) as well as for children in Grades 4 and 5 (De Smedt et al., 2009). Accordingly, a selective impairment in multiplication might result from a rote verbal memory deficit (which would be evident in difficulties in reciting verbal sequences, or other