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Is a fact retrieval deficit the main characteristic of children with mathematical learning disabilities?

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ABSTRACT

Although a fact retrieval deficit is widely considered to be the hallmark of children with mathematical learning disabilities (MLD), recent studies suggest that even adults use procedural strategies to solve small additions, except for ties that are unanimously considered to be solved by retrieval. Our study, based on how MLD children process ties and non-ties compared to typically developing (TD) children, sheds new light on their retrieval and procedural difficulties. Our results show that, by the end of the second grade, MLD children do not differ in their ability to solve the tie problems that are certainly solved by retrieval, but they do struggle with both small and large non-ties. These findings emphasize the extend of the difficulties that MLD children exhibit in procedural strategies relatively to retrieval ones.

1. Introduction

A mastery of mathematics and, in particular, proficiency in arithmetic play key roles in predicting individual achievement and later socioeconomic integration (Ritchie & Bates, 2013; Rivera-Batiz, 1992). Conversely, poor achievement in mathematics has serious consequences for daily functioning and for career advancement, especially in our technology-oriented culture (Hanich, Jordan, Kaplan, & Dick, 2001; Jordan & Levine, 2009). Mathematical learning disabilities (MLD), defined as an impairment in mathematic skills that is unrelated to low intelligence or inadequate schooling, is therefore of crucial interest. In particular, a better understanding of the core difficulties that differentiate children with mathematical learning disabilities (MLD) from their peers is essential for understanding and addressing problems in mathematical cognition (Ostad, 2015). However, although the amount of research regarding MLD has increased considerably over the past two decades, it still remains less studied than other disorders (Bishop, 2010).

It is commonly considered that typical arithmetic acquisition follows a gradual shift from procedural strategies towards memory-based solving processes and that MLD children – corresponding to those facing specific difficulties in mastering calculations despite adequate instruction and in the absence of mental retardation – show a deficit in the ability to use retrieval-based processes (Andersson, 2008; Geary, Hoard, Nugent, & Bailey, 2012; Jordan, Hanich, & Kaplan, 2003). Indeed, typically developing (TD) children generally begin by counting both addends and then move towards more sophisticated counting strategies (counting from the largest operand). Progressively, through the repeated use of counting strategies, children are thought to develop a representation of basic arithmetic facts, defined as a declarative knowledge network that contains the results of simple arithmetic problems (e.g., additions up to 20 or multiplication tables) and considered to be stored through processes of association of the problems with their answers (Siegler & Shrager, 1984). Comparatively, MLD children show impaired procedural strategy skills (e.g., Geary, 2004, 2015), marked by a developmental delay in the shift from immature counting strategies to more advanced procedural strategies. Above all, their deficit in retrieving arithmetic facts is considered as the "most consistent finding" (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007), the "cardinal characteristic" (Andersson, 2008) or even the "hallmark" (De Visscher & Noël, 2014a; Vanbinst, Ghesquière, & De Smedt, 2014) of children with MLD.

Nevertheless, recent studies question the conception of a retrieval stage in arithmetic acquisition, even at an adult age. For example, Fayol and Thevenot (2012), using a priming effect paradigm, showed that adult subtractions and additions (even very small ones such as 3 + 2) are facilitated by the presentation of the arithmetical sign 150 ms before the operands, but that this is not the case for multiplications. These authors inferred from these results that for additions and subtractions, "something" is activated as soon as the sign is presented. Among

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children, the findings of Thevenot, Barrouillet, Castel, and Uittenhove (2016) on solution times and their slopes also concur that 10-year-old children still use counting procedures in order to solve problems involving operands from 2 to 4. These researchers explain the fact that adults consistently report retrieval for small problems such as 3 + 2 or 4 + 3 (LeFevre, Sadesky, & Bisanz, 1996) by suggesting that these procedures have been automatized and are no longer under conscious control, which incidentally raises the issue of the validity of self-verbal reports.

If, as suggested by Fayol and Thevenot (2012), TD children evolve in terms of procedural automation rather than in the nature of the arithmetic strategies used, the assertion that MLD children differ overall from their peers in their ability to retrieve basic arithmetical facts may be challenged. Conversely, their consistently reported procedural difficulties might be and remain predominant. As an example, Vanbinst et al. (2014) found that nine-year-old children with persistent MLD used retrieval – on the basis of self-verbal reports – less frequently than TD children and that they were systematically slower and less accurate when using procedural strategies. Interestingly, post-hoc *t*-tests demonstrated that group differences were larger for procedural strategies than for fact retrieval. Furthermore, Thevenot et al. (2016) showed that faster and slower children only differed in speed but not in the distribution of solution times, suggesting that the strategies used by these two groups of children were the same. Thus, instead of a fact retrieval deficit among MLD children, it could be that TD children move on towards more and more automatized procedural strategies, which would not be the case for MLD children (Thevenot, 2017).

Actually, the only arithmetical problems that are universally considered as being solved by retrieval are ties (i.e., problems with repeated operands, such as 4 + 4, 6 × 6). Indeed, ties give rise to accuracy and response time advantages relative to non-ties, the so-called "tie effect" (e.g., Campbell, 1999; Campbell & Graham, 1985). This is the case from the early stages of acquisition since it has been shown that tie additions are already being solved by retrieval among four- and five-year-old children (Siegler & Robinson, 1982). Globally, tie problems present a much smaller problem-size effect than non-tie problems (Ashcraft & Battaglia, 1978; LeFevre et al., 1996) or no size effect at all (Butterworth, Zorzi, Girelli, & Jonckheere, 2001; Groen & Parkman, 1972). According to Fayol and Thevenot (2012), the only addition or subtraction problems that did not show any priming effect were ties, leading the authors to the conclusion that they have a special status. The tie effect is generally explained either by an encoding advantage (Blankenberger, 2001; Gallistel & Gelman, 1992) and/or by an access-based account (Ashcraft & Battaglia, 1978; Campbell & Gunter, 2002; Graham & Campbell, 1992). On the one hand, according to the encoding-based account, the tie advantage occurs because repetition of the same physical stimulus results in faster encoding of tie than of non-tie problems. Blankenberger (2001) provided evidence that mixing the format of operands with digits and words (4 × four, instead of 4 × 4 or four × four) completely cancels the tie effect. Nevertheless, methodological issues with Blankenberger's study (Campbell & Gunter, 2002; LeFevre, Shanahan, & DeStefano, 2004) as well as additional observations have challenged the exclusive encoding-based account and suggest that the tie effect is mainly due to memory-access facilitation (the access-based account, Campbell & Gunter, 2002; LeFevre et al., 2004; Campbell & Xue, 2001). For example, tie advantages were also found in subtraction and division, which could not be explained by the repetition of the same physical stimulus.

Thus, given the above-reported results, differences between TD and MLD children's ability to use retrieval-based strategies merit continued study. As the validity of the self-verbal reports has been questioned (Kirk & Ashcraft, 2001; Lucidi & Thevenot, 2014) a fortiori for struggling participants (Smith-Chant & LeFevre, 2003), an additional and interesting way to compare their ability to use retrieval and procedural strategies is to observe whether MLD children differ from their peers in their ability to process tie as compared to non-tie problems. Interestingly, many studies have excluded ties from their tasks (Carpenter & Moser, 1984; Geary, 1990; Geary et al., 2007; Ostad, 1997; Vanbinst et al., 2014) or from their analyses (Barrouillet & Lépine, 2005; Svenson & Sjöberg, 1983), rightly so as they are considered as being solved by retrieval. Moreover, additions are particularly suitable for studying how MLD and TD children process problems that are solved by retrieval as compared to procedural strategies, whereas multiplications are predominantly solved by retrieval (De Visscher & Noël, 2014b; Imbo & Vandierendonck, 2008).

In order to study MLD children's fact retrieval ability through their performance in tie problems, the tie effect should first be further examined among typically developing children performing additions. Indeed, most of the research on the tie effect has been collected on adults (Blankenberger, 2001; Butterworth et al., 2001; Campbell & Gunter, 2002; Charras, Molina, & Lupianez, 2014; LeFevre et al., 2004) or on children solving multiplications (De Brauwer, Verguts, & Fias, 2006; De Visscher & Noël, 2014b). More specifically, in order to test whether all single-digit ties belong to the same, unique category and have a "special status" (Fayol & Thevenot, 2012), the interaction between type and size should be addressed. Indeed, Groen and Parkman's (1972) pioneering study is often mentioned when reporting a flat size effect on ties among young children. Nevertheless, these authors used additions with sums up to nine, meaning that the biggest tie used was 4 + 4. Interestingly, Campbell and Gunter (2002) studied response times and reported strategies among adults when solving ties and non-ties in the four arithmetic operations. They divided their tie problems into small ties (operands from two to five) and large ties (operands from six to nine) and found that there was no tie effect for small problems, thus demonstrating that the overall tie effect was entirely related to the large problems. Furthermore, for additions, participants reported more procedural strategies for large ties than for small ones. Even for multiplications, slightly longer response times were found for large ties than for small ties among adults (De Brauwer et al., 2006; LeFevre et al., 2004). Therefore, it should first be checked whether all single-digit additions ties are similarly solved in childhood.

1.1. The current study

Thus, our study aims firstly at testing the tie effect further on children performing additions, in order to study whether all single-digit ties are retrieved by typically developing children. Secondly, it aims to compare TD and MLD children's performance in problems solved by retrieval with regard to performance in problems solved by procedural strategies. MLD children, in addition to their consistently-identified dysfluent calculation (Locuniak & Jordan, 2008; Reigosa-Crespo et al., 2012), are also known for their number-sense deficit (Piazza et al., 2010). Their inability to quickly assess magnitude from a symbolic code is particularly relevant (Rousselle & Noël, 2007) insofar as it is not due to a lower general-processing speed (Bull & Johnston, 1997). The end of the second grade is a very opportune time to compare both groups' performance in retrieval versus procedural strategies, as it ensures that a considerable amount of non-tie additions is still solved through overt counting strategies (Jordan, Kaplan, Ramineni, & Locuniak, 2008) while children already have some considerable experience in single-digit additions.

Given the fact that, even among adults, large ties give rise to slightly longer response times than small ties and to more procedural strategies, we expect that, among children, large ties would not show the same tie advantage as small ones compared to size-matched non-ties. Secondly, regarding both groups of children's performance according to the type of problems, we expect that MLD children differ at least in their ability to execute procedural strategies. Indeed, most of the studies on children with MLD show that they use more immature or less accurate counting strategies up to the end of the primary school (Geary, Hoard, Byrd-Craven, & Desoto, 2004; Ostad, 1997). Moreover, if the fact retrieval deficit is the main characteristic of MLD children, then they should