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The development of product parity sensitivity in children with mathematics learning disability and in typical achievers

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ABSTRACT

Parity helps us determine whether an arithmetic equation is true or false. The current research examines the development of sensitivity to parity cues in multiplication in typically achieving (TA) children (grades 2, 3, 4 and 6) and in children with mathematics learning disabilities (MLD, grades 6 and 8), via a verification task. In TA children the onset of parity sensitivity was observed at the beginning of 3rd grade, whereas in children with MLD it was documented only in 8th grade. These results suggest that children with MLD develop parity aspects of number sense, though later than TA children. To check the plausibility of equations, children used mainly the multiplication parity rule rather than familiarity with even products. Similar to observations in adults, parity sensitivity was largest for problems with two even operands, moderate for problems with one even and one odd operand, and smallest for problems with two odd operands.

1. Introduction

About 6% of the population is deficient in mathematics due to a mathematics learning disability (MLD; Shalev & Gross-Tsur, 2001), which is a risk factor for their life quality. Developing a number sense is especially important for children with MLD (Gersten & Chard, 1999). Sensitivity to features of numbers such as parity is a part of a number sense (Berch, 2005). We tested sensitivity to product parity in children with MLD and typical achievers (TA).

1.1. *Development of multiplication facts*

In most Western countries, children begin to learn simple multiplication in 2nd grade. With age and schooling, children form an associative network of problems and results to problems, and their performance becomes accurate and fast (Cho, Ryali, Geary, & Menon, 2011; Jordan, Kaplan, Ramineni, & Locuniak, 2008; Lemaire & Siegler, 1995; Sherin & Fuson, 2005). By 6th grade, their multiplication network is similar to an adult's network (De Brauwer, Verguts, & Fias, 2006).

Mathematics learning disability is a cognitive disorder impairing the typical acquisition of arithmetic skills despite normal intelligence and adequate schooling (American Psychiatric Association, 1994). Children with MLD have an arithmetic facts deficiency, which persists to middle and high school ages (Bryant & Bryant, 2008; Calhoon, Emerson, Flores, & Houchins, 2007; Cawley, Parmar, Foley, Salmon, & Roy, 2001; Mabbott & Bisanz, 2008; Mazzocco, Devlin, & McKenny, 2008; Mussolin & Noel, 2008; Ostad, 1997, 1999; Rotem & Henik, in preparation). Despite this deficiency, with age and schooling children with

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MLD acquire some basic numerical concepts and skills (Geary & Brown, 1991; Mabbott & Bisanz, 2008; Mazzocco et al., 2008; Shalev, 2004). Yet, little research has been devoted to the arithmetic development of older children with MLD, which is the first focus of the current work.

1.2. Development of product parity sensitivity

When forming the arithmetic network, children develop a ''number sense'', that is, sensitivity to reasonableness of calculations, to effects that operations have on numbers, and to various numerical features in the network—one of which is parity (Berch, 2005; U.S. Department of Education, 2008). Current curricula emphasize the importance of developing a number sense (Israeli Ministry of Education, 2006; National Council of Teachers of Mathematics, 2000), especially for children with MLD (Gersten & Chard, 1999). It is not clear whether they develop sensitivity to parity in multiplication despite their fact retrieval deficiency.

The concept of parity is taught from kindergarten onward (Israel Ministry of Education, 2008; National Council of Teachers of Mathematics, 2000). Second graders can indicate whether a number is even or odd (Berch, Foley, Hill, & Ryan, 1999). Third graders are sensitive to parity cues even when they are not explicitly directed to look for the parity of numbers in verification tasks (i.e., when they are presented with arithmetic equations such as $3 \times 4 = 16$ and are asked whether they are true or false; Lemaire & Fayol, 1995). Thus, they are slower and less accurate with equations in which the parity of the proposed result matches the parity of the true result (e.g., $6 \times 4 = 26$) than when it mismatches it (e.g., $6 \times 4 = 23$).

Zbrodoff and Logan (1990) suggested that in order to decide whether results in verification tasks are true or false, participants check their plausibility. Parity is one of the features used for plausibility checking (Krueger, 1986). The question of how people specifically use parity cues is still under debate.

One suggestion is that participants use the parity rule (Krueger, 1986; Lemaire & Reder, 1999; Vandorpe, De Rammelaere, & Vandierendonck, 2004). The multiplication parity rule says that if any multiplier is even, the product must be even; otherwise, it must be odd. Thus, participants easily reject odd results on even $\times$ even and mixed (even $\times$ odd; odd $\times$ even) problems, and they easily reject even results on odd $\times$ odd problems. In contrast, Lochy, Seron, Delazer, and Butterworth (2000) found that it was easier for participants to reject odd proposed results on all problem types. Accordingly, they suggested that people do not use the parity rule but rather use familiarity checking; because participants are familiar with the fact that most products are even, they judge even results as plausible and odd results as implausible. The difference between rule-based and familiarity-based strategies can be observed only on odd $\times$ odd problems: while the rule-based hypothesis predicts fast rejection of even results, the familiarity-based hypothesis predicts fast rejection of odd results. Importantly, speed differences between rejecting even and odd results were too small to reach significance in all but one study (i.e., Lochy et al., 2000), leaving the strategy question unresolved. Consequently, advocates of both strategies suggested that people use some kind of a combination of these two strategies.

Lochy et al. (2000) also suggested that the expertise of participants should be taken into account, as experts may rely more heavily than non-experts on a rule-based strategy. According to this hypothesis, children, who are non-experts, might rely more heavily on familiarity with even products than on the parity rule. Alternatively, because children might not be experienced enough with the fact that most products are even, they might not rely on a familiarity-based strategy, but rather rely mainly on the parity rule that they explicitly learn in school.

Interestingly, the parity effect (i.e., speed difference between rejecting even and odd false results) was the smallest on odd $\times$ odd problems, moderate on mixed problems and largest on even $\times$ even problems. Neither rule-based nor familiarity-based hypotheses can fully account for these differences.

Krueger (1986) and Vandorpe et al. (2004) suggested that the different effect sizes reflect different processes executed with different problem types. People easily detect an even multiplier when there are two even multipliers; therefore the effect is large on even $\times$ even problems. People know that detection of one even multiplier is enough to reject an odd result on mixed problems; therefore the effect is moderate on mixed problems. People use only the first part of the rule, which says that when any multiplier is even the product must be even. This part does not relate to odd $\times$ odd problems, therefore the effect is small on odd $\times$ odd problems. It is not clear yet whether the effect sizes in children are similar to those seen in adults. If so, it might indicate that children execute processes that are similar to those executed by adults.

1.3. The current study

The current study focused on the multiplication development of TA children and children with MLD, and in particular on the development of sensitivity to product parity. Specifically, we examined whether children with MLD develop product parity sensitivity despite their arithmetic fact deficiency, what strategy children use when using parity cues in a verification task, and whether they process the various multiplication problem types similarly to adults.

Examining parity sensitivity is informative only in problems with false results. However, because performance on false results is affected by the properties of these results, only true results are informative for examining arithmetic proficiency (Campbell, 1987). Accordingly, we will examine multiplication development via data obtained by true proposed results, and parity sensitivity will be examined via data obtained by false proposed results.