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Numerical magnitude processing in children with mild intellectual disabilities

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ABSTRACT

The present study investigated numerical magnitude processing in children with mild intellectual disabilities (MID) and examined whether these children have difficulties in the ability to represent numerical magnitudes and/or difficulties in the ability to access numerical magnitudes from formal symbols. We compared the performance of 26 children with MID on a symbolic (digits) and a non-symbolic (dot-arrays) comparison task with the performance of two control groups of typically developing children: one group matched on chronological age and one group matched on mathematical ability level. Findings revealed that children with MID performed more poorly than their typically developing chronological age-matched peers on both the symbolic and non-symbolic comparison tasks, while their performance did not substantially differ from the ability-matched control group. These findings suggest that the development of numerical magnitude representation in children with MID is marked by a delay. This performance pattern was observed for both symbolic and non-symbolic comparison tasks, although difficulties on the former task were more prominent. Interventions in children with MID should therefore foster both the development of magnitude representations and the connections between symbols and the magnitudes they represent.

1. Introduction

Mathematical abilities are crucial in modern Western societies, for example when taking medical and social decisions (Reyna & Brainerd, 2007), and they are associated with greater labour market success (Chiswick, Lee, & Miller, 2003). Children with below-average intellectual abilities (IQ < 85) are known to have difficulties with the development of mathematical skills (Hoard, Geary, & Hamson, 1999), but little is known about the cognitive deficits that underlie their poor achievement in mathematics. Such information is important in order to devise appropriate interventions for these children. It has been suggested that the ability to represent numerical magnitudes plays a crucial role in the development of mathematical skills (e.g., Butterworth, 2005a; Gersten, Jordan, & Flojo, 2005). The present study therefore aims to investigate numerical magnitude processing skills in children with mild intellectual disabilities (MID).

Infants (Xu & Spelke, 2000) and kindergarteners (Barth, Beckmann, & Spelke, 2008) are able to understand and process numerical magnitude information by means of non-symbolic representations: they are able to compare and add sets of dots or objects. It is assumed that this ability is innate and independent of language and education (Dehaene, 1997) as uneducated adults (Pica, Lemer, Izard, & Dehaene, 2004) and even non-human animals (Brannon, 2006; Brannon & Terrace, 1998) are able to make such comparisons. Over the course of development, children learn to link these non-symbolic representations

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with symbols or numbers (Griffin, 2003). Both cross-sectional (Holloway & Ansari, 2009) and longitudinal studies (De Smedt, Verschaffel, & Ghesquière, 2009; Halberda, Mazzocco, & Feigenson, 2008) with typically developing children showed that the ability to represent numerical magnitudes is related to mathematics achievement.

A classic task to measure numerical magnitude representation is the numerical magnitude comparison task (Sekuler & Mierkiewicz, 1977). In this task, children have to indicate the numerically larger of two presented numerical magnitudes. These magnitudes can be presented both in a symbolic and a non-symbolic format (e.g., De Smedt et al., 2009; De Smedt & Gilmore, 2011; Halberda et al., 2008; Holloway & Ansari, 2009). When people are comparing two numerical magnitudes, the distance effect occurs (Moyer & Landauer, 1967): people are faster and more accurate at making responses when the numerical distance between the two magnitudes is relatively large (e.g., 2 vs. 9) than when it is small (e.g., 7 vs. 9). This effect is assumed to arise from overlapping internal representations of numerical magnitudes: magnitudes that are closer to each other have more representational overlap and are more difficult to discriminate than magnitudes that are further apart (for a review, see Noël, Rousselle, & Mussolin, 2005). This distance effect decreases with increasing age (Sekuler & Mierkiewicz, 1977), indicating that these magnitude representations become more precise and show less overlap throughout development. Moreover, the size of the distance effect predicts later individual differences in mathematics achievement. For example, De Smedt et al. (2009) showed that children with a smaller distance effect at the start of formal schooling had higher mathematics achievement levels in second grade.

Several studies have demonstrated that children with mathematical difficulties have difficulties with magnitude comparison (De Smedt & Gilmore, 2011; Landerl, Bevan, & Butterworth, 2004; Landerl, Fussenegger, Moll, & Willburger, 2009; Mussolin et al., 2010; Rousselle & Noël, 2007). Two explanations for difficulties in magnitude comparison have been put forward. According to the *defective number module hypothesis* (Butterworth, 2005b), these difficulties originate from a specific deficit in the innate ability to understand and represent numerical magnitudes. In contrast, the *access deficit hypothesis* (Rousselle & Noël, 2007) proposes that these difficulties originate from impairments in accessing numerical meaning from symbols, rather than from difficulties in processing magnitude per se. To disentangle between both hypotheses, one needs to compare performance on a symbolic and a non-symbolic task. If children with mathematical difficulties perform more poorly on both types of tasks, this supports the defective number module hypothesis. If children with mathematical difficulties perform more poorly on the symbolic, but not on the non-symbolic task, this favours the access deficit hypothesis.

Because children with MID are expected to have difficulties in acquiring mathematical skills, it is important to find out whether they mainly have problems with the representation of magnitude per se (defective number module) or with accessing numerical information from symbols (access deficit). To the best of our knowledge, only one study examined numerical magnitude comparison in children with below-average intellectual abilities (Hoard et al., 1999). This study revealed that children with a below-average IQ ($M = 78$) were less accurate in comparing digits than their typically developing peers. However, it remains unclear whether children with MID participated in this study. Furthermore, these authors only examined accuracy but not the speed with which the digits were compared, and it has been argued in research on numerical magnitude processing in children that reaction time might reveal subtle yet important differences that cannot be uncovered by looking at accuracy alone (Berch, 2005). The comparison of non-symbolic magnitudes was also not included in the study of Hoard et al. (1999), which makes it impossible to determine whether the children in this study had difficulties with representing numerosity per se (number module) or whether they had only difficulties in accessing numerical information from symbolic digits (access deficit).

The present study tried to address these issues by systematically investigating numerical magnitude comparison in children with MID. In order to contrast the defective number module hypothesis and the access deficit hypothesis, we focused both on symbolic and non-symbolic magnitude comparison tasks. If children with MID have problems with the representation of numerical magnitudes per se, they should perform more poorly on both the symbolic and the non-symbolic comparison tasks. If children with MID have mainly difficulties in accessing magnitude information from symbols, they should perform more poorly on the symbolic but not on the non-symbolic comparison task.

We also wanted to examine whether the difficulties with magnitude representation in children with MID are marked by a delay or a deficit. According to the *delay* model, children with MID follow the same overall pattern of development as typically developing individuals, but they progress at a slower rate and ultimately attain a lower asymptote of cognitive functioning. In contrast, the *deficit* model states that the difficulties of children with MID are the result of deficits in specific cognitive processes, which makes the general principles of development not applicable (Bennett-Gates & Zigler, 1998). This research question was addressed by using a chronological-age/ability-level-match design. This design involves the selection of two control groups of typically developing children: one control group matched on chronological age to the group of children with MID and one control group matched on arithmetic achievement level to the children with MID. If the performance of children with MID differs from the performance of their chronological age matched peers, but not from the performance of younger children with the same arithmetic achievement level, then the development of children with MID is marked by a delay. If, by contrast, the performance of children with MID differs from the performance of both control groups, then their development can be characterized by a deficit.

It should be noted that children's performance on the symbolic magnitude comparison task might be influenced by their knowledge of the digits that are used in this task. In order to control for this factor, we administered a digit identification task to find out whether group differences are due to differences in symbolic knowledge rather than to differences in accessing magnitude information from symbols.