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The development of numerical magnitude processing and its association with working memory in children with mild intellectual disabilities

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ABSTRACT

The present research examined numerical magnitude processing and its association with working memory in children with mild intellectual disabilities (MID). We investigated the performance of 8-year-old children with MID on a symbolic (Arabic digits) and non-symbolic (dot patterns) magnitude comparison task by means of a chronological-age/ability-level-match design. We also examined whether the predicted problems with numerical magnitude comparison could be explained by working memory by using three working memory tasks. Findings revealed that children with MID performed more poorly than their chronological age-matched peers on both the symbolic and non-symbolic magnitude comparison tasks, suggesting impairments in these children's ability to represent numerical magnitudes. They also performed more poorly on working memory compared to their typically developing age- and ability-matched peers, but when these differences in working memory performance were additionally controlled for, the group differences on the numerical magnitude comparison tasks remained. Both symbolic numerical magnitude processing and central executive functioning predicted addition performance in children with MID.

1. Introduction

In our modern Western societies, numbers and mathematical abilities play a crucial role, for example when getting change in a shop or when reading timetables to catch a bus. Despite the fact that mathematics is interwoven with modern life, 5% to 7% of the population experiences serious difficulties with the development of these mathematical skills (Butterworth, Varma, & Laurillard, 2011). One particular group of individuals that is expected to have mathematical difficulties are children with below-average intellectual abilities (e.g., Hoard, Geary, & Hamson, 1999; Janssen, De Boeck, Viaene, & Vallaeys, 1999). Of particular interest for research are the cognitive processes underlying these difficulties, because this knowledge provides a scientifically sound basis for appropriate remedial teaching and mathematics education. In this respect, it has been suggested that the ability to understand and process numerical magnitudes plays a crucial role in the development of mathematical skills (e.g., Butterworth et al., 2011; Gersten, Jordan, & Flojo, 2005). Therefore, a first goal of the present study was to investigate numerical magnitude processing and its development in children with mild intellectual disabilities (MID). Because several studies also pointed to the importance of working memory, a more domain-general factor,

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for the development of mathematics (e.g., De Smedt et al., 2009a; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Swanson & Kim, 2007) and mathematical difficulties (e.g., Swanson & Jerman, 2006), a second goal of the present study was to additionally examine the role of working memory in numerical magnitude processing.

1.1. Numerical magnitude processing

The ability to understand and process numerical magnitude information emerges very early in development, as infants (Xu & Arriaga, 2007) and kindergarteners (Barth, Beckmann, & Spelke, 2008) are able to compare and add sets of non-symbolic objects or dots. Further, it has been suggested that over the course of development, children learn to link these non-symbolic magnitude representations with number words and Arabic digits (Griffin, 2003). Various studies have highlighted the importance of numerical magnitude representations for successful mathematical development (e.g., Butterworth et al., 2011, for a review). The ability to understand and represent numerical magnitudes seems to be related to and even predictive of mathematics achievement in typically developing children (Bugden & Ansari, 2011; De Smedt, Verschaffel, & Ghesquière, 2009b; Halberda, Mazzocco, & Feigenson, 2008; Holloway & Ansari, 2009; Reigosa-Crespo et al., 2012). Furthermore, several studies have shown that children with mathematical difficulties experience problems with numerical magnitude processing (De Smedt & Gilmore, 2011; Landerl, Bevan, & Butterworth, 2004; Mussolin, Mejias, & Noël, 2010).

Two explanations for these problems with numerical magnitude processing have been put forward. These problems might arise from a specific deficit in the innate ability to represent numerical magnitudes, as proposed by the *defective number module hypothesis* (Butterworth, 2005). Another possibility is that these problems originate from impairments in accessing numerical meaning from symbols, as suggested by the *access deficit hypothesis* (Rousselle & Noël, 2007). To disentangle between both hypotheses, one needs to compare children's performance on a symbolic (Arabic digits) and non-symbolic (dot patterns) numerical magnitude comparison task (Sekuler & Mierkiewicz, 1977), in which children have to indicate the numerically larger of two presented quantities. If children with mathematical difficulties perform more poorly than typically developing children on both tasks, this favors the defective number module hypothesis. If, by contrast, children with mathematical difficulties perform more poorly than typically developing children on the symbolic, but not on the non-symbolic magnitude comparison task, this supports the access deficit hypothesis. Although most of the existing body of data indicates that children with mathematical difficulties show deficits in their ability to compare Arabic digits, data on non-symbolic magnitude comparison tasks have been inconclusive so far (see De Smedt, Noël, Gilmore, & Ansari, in press; Noël & Rousselle, 2011 for an overview).

It is important to point out that this existing body of data only deals with children with mathematical disabilities and that these findings may therefore not be readily generalized to children with MID. Only but a few attempts have been made to examine numerical magnitude comparison in children with a below-average intelligence or MID. Hoard et al. (1999) revealed that these children ($M_{IQ} = 78$) were less accurate in comparing Arabic digits than their typically developing peers. However, only a symbolic magnitude comparison task was included in this study, which makes it impossible to determine whether the children also had problems with non-symbolic magnitude comparison. More recently, Brankaer, Ghesquière, and De Smedt (2011) investigated numerical magnitude processing in 10–11-year-old children with MID ($M_{IQ} = 62$) more systematically by comparing the performance of these children on both a symbolic and non-symbolic magnitude comparison task with the performance of two control groups of typically developing children: One control group matched on chronological age to the children with MID and one control group matched on arithmetic achievement level to the children with MID. Findings of this study demonstrated that children with MID performed more poorly than their chronological age-matched peers on both the symbolic and non-symbolic magnitude comparison tasks, although their difficulties on the symbolic task were more pronounced.

It should be noted that the children in the study of Brankaer et al. (2011) were relatively old and already received some years of (adapted) mathematics education. As Soltész, Szűcs and Szűcs (2010) mentioned, the development of numerical magnitude representation is supported and largely influenced by formal education and numerical enculturation. Therefore, it might be interesting to examine whether the results of Brankaer et al. (2011) can be replicated in younger children with MID, which was the aim of the present study.

1.2. Working memory

The present study also focused on working memory as a determinant of children with MID's mathematical difficulties, because various studies in typically developing children and children with mathematical difficulties have shown that this domain-general factor also plays an important role in, and even predicts, mathematics performance (Bull, Espy, & Wiebe, 2008; De Smedt et al., 2009a; Passolunghi & Siegel, 2004; Passolunghi, Vercelloni, & Schadee, 2007; Swanson & Kim, 2007). More specifically, because recent data pointed to an association between working memory and numerical magnitude processing (Gullick, Sprute, & Temple, 2011; Passolunghi & Lanfranchi, 2012) and several studies indicated working memory impairments in children with MID (e.g., Henry & MacLean, 2002; Schuchardt, Gebhardt, & Mäehler, 2010; Van der Molen, Van Luit, Jongmans, & Van der Molen, 2009), we aimed to examine whether the predicted difficulties with numerical magnitude comparison in children with MID could be explained by working memory.