Journal of Experimental Child Psychology 108 (2011) 278–292

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Defective number module or impaired access? Numerical magnitude processing in first graders with mathematical difficulties

Bert De Smedt [a,*], Camilla K. Gilmore [b]

[a] *Centre for Parenting, Child Welfare & Disabilities, Katholieke Universiteit, Leuven, 3000 Leuven, Belgium*
[b] *Learning Sciences Research Institute, University of Nottingham, Nottingham NG8 1BB, UK*

ARTICLE INFO

Article history:
Received 18 September 2009
Revised 23 August 2010
Available online 25 October 2010

Keywords:
Mathematical difficulties
First grade
Magnitude representation
Comparison
Approximate addition
Dyscalculia
Low math achievement

ABSTRACT

This study examined numerical magnitude processing in first graders with severe and mild forms of mathematical difficulties, children with mathematics learning disabilities (MLD) and children with low achievement (LA) in mathematics, respectively. In total, 20 children with MLD, 21 children with LA, and 41 regular achievers completed a numerical magnitude comparison task and an approximate addition task, which were presented in a symbolic and a nonsymbolic (dot arrays) format. Children with MLD and LA were impaired on tasks that involved the access of numerical magnitude information from symbolic representations, with the LA children showing a less severe performance pattern than children with MLD. They showed no deficits in accessing magnitude from underlying nonsymbolic magnitude representations. Our findings indicate that this performance pattern occurs in children from first grade onward and generalizes beyond numerical magnitude comparison tasks. These findings shed light on the types of intervention that may help children who struggle with learning mathematics.

Introduction

Mathematics learning represents a stumbling block for many children in primary school. To devise appropriate interventions, and in view of the fact that mathematical abilities are crucial to life success

* Corresponding author. Fax: +32 16 32 59 33.
E-mail address: bert.desmedt@ped.kuleuven.be (B. De Smedt).

0022-0965/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.jecp.2010.09.003

in modern Western societies (Ancker & Kaufman, 2007; Finnie & Meng, 2001), we need to have a good understanding of the cognitive deficits underlying children's poor achievement in mathematics. One source of these deficits may be in the types of numerical representations that underlie mathematics learning (Ansari & Karmiloff-Smith, 2002; Butterworth, 1999; Dehaene, 1997; Wilson & Dehaene, 2007). Indeed, studies have demonstrated that children with mathematical difficulties have particular impairments in understanding and processing numerical magnitudes (De Smedt, Reynvoet, et al., 2009; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Geary, Hoard, Nugent, & Byrd-Craven, 2008; Landerl, Bevan, & Butterworth, 2004; Landerl, Fussenegger, Moll, & Willburger, 2009; Passolunghi & Siegel, 2004; Rousselle & Noël, 2007). Two accounts for these impairments have been put forward (Rousselle & Noël, 2007; see also Wilson & Dehaene, 2007). The *defective number module hypothesis* (Butterworth, 2005) proposes that a highly specific deficit of an innate capacity to understand and represent quantities leads to difficulties in learning number and arithmetic. The *access deficit hypothesis* (Rousselle & Noël, 2007) states that mathematical difficulties originate from impairments in accessing numerical meaning (i.e., their quantity) from symbols rather than from difficulties in processing numerosity per se. To disentangle between both hypotheses, performance should be compared on numerical tasks with and without a symbolic processing requirement. If children with mathematical difficulties perform more poorly on both types of task, this favors the defective number module hypothesis; if they perform more poorly on the symbolic task but not on the nonsymbolic task, this supports the access deficit hypothesis. Specifying the locus of this impairment provides a crucial building block for developing appropriate intervention, which should then focus either on the representation of quantity or on the mapping between symbols and the quantities they represent.

To date, findings remain inconclusive and studies supporting both the defective number module hypothesis (Landerl et al., 2009) and the access deficit hypothesis (Iuculano, Tang, Hall, & Butterworth, 2008; Rousselle & Noël, 2007) have been reported. The current study aimed to contrast both hypotheses and to extend previous findings in two important ways. First, the aforementioned studies focused on children in second to fourth grades. Difficulties in processing nonsymbolic representations of quantity might have occurred in early life but may be compensated during the early years of schooling. In other words, it might not be possible to detect difficulties in nonsymbolic quantity processing at older ages such as in the reported studies; therefore, we investigated younger children with mathematical difficulties. Second, the available studies investigated the understanding and processing of quantities only by one type of task, namely, numerical magnitude comparison. Although this task is considered to be a classic indicator of children's understanding of numerical magnitudes, performance patterns should also generalize to other symbolic and nonsymbolic tasks that measure the understanding of numerical magnitudes, such as approximate addition (e.g., Barth, Beckmann, & Spelke, 2008; Gilmore, McCarthy, & Spelke, 2007). To the best of our knowledge, there are no studies that have compared performance on symbolic and nonsymbolic approximate addition tasks in children with mathematical difficulties. In the remainder of the Introduction, we first review the available evidence that the ability to understand and manipulate numerical magnitudes is related to individual differences in mathematics. Next, we evaluate the studies that have examined the defective number module hypothesis and the access deficit hypothesis. Finally, we present the specific aims of our study.

Understanding numerical magnitudes and mathematics development

There exists consistent evidence that infants and young children are able to understand and manipulate numerical magnitude information by means of nonsymbolic representations. For example, 6-month-olds are able to discriminate between large sets of dots on the basis of numerosity (Xu & Spelke, 2000; for a review, see Feigenson, Dehaene, & Spelke, 2004) and 5-year-olds who had not yet been taught formal arithmetic can compare, add, and subtract nonsymbolic numerosities (i.e., dot arrays or sequences of sounds) (Barth et al., 2008). These nonsymbolic representations are characterized by an effect of ratio or distance: When the numerical difference or distance between the two sets that need to be compared, added, or subtracted is small or the ratio between them approaches 1, performance on these tasks is slower and less accurate than when the distance is large or the ratio is small. This effect is assumed to arise from overlapping internal representations of