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Cognitive factors affecting children's nonsymbolic and symbolic magnitude judgment abilities: A latent profile analysis

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ABSTRACT

Early math abilities are claimed to be linked to magnitude representation ability. Some claim that nonsymbolic magnitude abilities scaffold the acquisition of symbolic (Arabic number) magnitude abilities and influence math ability. Others claim that symbolic magnitude abilities, and ipso facto math abilities, are independent of nonsymbolic abilities and instead depend on the ability to process number symbols (e.g., 2, 7). Currently, the issue of whether symbolic abilities are or are not related to nonsymbolic abilities, and the cognitive factors associated with nonsymbolic–symbolic relationships, remains unresolved. We suggest that different nonsymbolic–symbolic relationships reside within the general magnitude ability distribution and that different cognitive abilities are likely associated with these different relationships. We further suggest that the different nonsymbolic–symbolic relationships and cognitive abilities in combination differentially predict math abilities. To test these claims, we used latent profile analysis to identify nonsymbolic–symbolic judgment patterns of 124, 5- to 7-year-olds. We also assessed four cognitive factors (visuospatial working memory [VSWM], naming numbers, nonverbal IQ, and basic reaction time [RT]) and two math abilities (number transcoding and single-digit addition abilities). Four nonsymbolic–symbolic ability profiles were identified. Naming numbers, VSWM, and basic RT abilities were differentially associated with the different ability profiles and in combination differentially predicted math abilities. Findings show that different patterns of nonsymbolic–symbolic magnitude abilities can be identified and suggest that an adequate account of math development should specify the inter-relationship

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between cognitive factors and nonsymbolic–symbolic ability patterns.

Introduction

It is claimed that magnitude representation abilities support emerging math abilities. This claim is predicated in part on the proposition that early developing nonsymbolic magnitude abilities support the acquisition of later acquired symbolic magnitude abilities (Dehaene, 2007; Piazza, 2010). Nonsymbolic and symbolic magnitude representations are typically assessed by the ability to compare quantities (e.g., •• vs. •••••) and Arabic digits (e.g., 3 vs. 5) that differ in magnitude, respectively. Similar error and reaction time (RT) response signatures for nonsymbolic and symbolic magnitude judgments support the claim that they share a common representation system (Gebuis, Cohen Kadosh, de Haan, & Henik, 2009; Halberda, Mazzocco, & Feigenson, 2008; Moyer & Landauer, 1967). However, nonsymbolic and symbolic magnitude abilities are not always related to each other, nor is nonsymbolic ability always related to math abilities (Holloway & Ansari, 2009; Sasanguie, De Smedt, Defever, & Reynvoet, 2012; Vanbinst, Ghesquière, & De Smedt, 2012). Indeed, some claim that symbolic magnitude ability is independent of nonsymbolic ability and that symbolic judgments reflect an ability to connect number symbols to the magnitude information (De Smedt, Verschaffel, & Ghesquière, 2009; Rousselle & Noël, 2007). It is evident that the circumstances under which symbolic magnitude abilities are or are not related to nonsymbolic abilities are currently underspecified. We suggest that one way to resolve this impasse would be to determine whether different patterns of nonsymbolic–symbolic magnitude abilities reside within a general nonsymbolic–symbolic magnitude ability distribution and to identify the cognitive markers linked to these different patterns to better understand individual differences in children's math abilities.

Nonsymbolic–symbolic magnitude abilities and math abilities

Some researchers have found an association between nonsymbolic and symbolic magnitude abilities and math abilities in typically developing children (Bonny & Lourenco, 2013; Gilmore, Attridge, De Smedt, & Inglis, 2014; Mussolin, Nys, Leybaert, & Content, 2012) as well as in children with math learning difficulties (Landerl & Kölle, 2009; Mazzocco, Feigenson, & Halberda, 2011a; Mussolin, Mejias, & Noël, 2010; Piazza et al., 2010). This pattern of findings is interpreted as showing that nonsymbolic abilities affect symbolic abilities, which in turn affect math abilities.

In contrast, others have found only an association between symbolic magnitude abilities and math abilities (De Smedt & Gilmore, 2011; De Smedt et al., 2009; Holloway & Ansari, 2009; Iuculano, Tang, Hall, & Butterworth, 2008; Landerl & Kölle, 2009). The lack of a relationship between nonsymbolic and symbolic magnitude abilities has led some to suggest that they are independent abilities (Le Corre & Carey, 2007; Lyons, Ansari, & Beilock, 2012; Noël & Rousselle, 2011) and exert independent effects on math abilities (Fazio, Bailey, Thompson, & Siegler, 2014). Still others have suggested that nonsymbolic magnitude abilities play a noncrucial role in math development (De Smedt, Noël, Gilmore, & Ansari, 2013). Children may possess adequate nonsymbolic magnitude abilities but poor symbolic abilities. This position is often characterized as a symbolic access deficit, which argues that children's symbolic magnitude judgment and math difficulties stem from difficulties connecting number symbols with their corresponding nonsymbolic quantities (Rousselle & Noël, 2007).

Can different nonsymbolic–symbolic ability relationship findings be reconciled?

Although findings suggest that nonsymbolic–symbolic magnitude relationships may be affected by factors such as age (Inglis, Attridge, Batchelor, & Gilmore, 2011; Rousselle & Noël, 2008), magnitude