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Explaining numeracy development in weak performing kindergartners

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ABSTRACT

Gaining better insight into precursors of early numeracy in young children is important, especially in those with inadequate numeracy skills. Therefore, in the current study, visual and verbal working memory, non-symbolic and symbolic comparison skills, and specific math-related language were used to explain early numeracy performance and development of weak performing children throughout kindergarten. The early numeracy ability of both weak performers and typical performers was measured at four time points during 2 years of kindergarten to compare growth rates. Results show a significant faster development of early numeracy in the weak performers. The development of weak performers' numeracy was influenced by verbal working memory, symbolic comparison skills, and math language, whereas only math language was positively related to the slope of typical performers' numeracy. In the weak performers, visual working memory, non-symbolic comparison skills, and math language showed an effect on the initial early numeracy level of these children. The intercept of the typical performers was predicted by five covariates, all except non-symbolic comparison.

Introduction

Starting to learn basic mathematical calculations in first grade requires particular prerequisite skills (e.g., Jordan, Kaplan, Ramineni, & Locuniak, 2009) such as (verbal) counting, knowing the

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number symbols, recognizing quantities, discerning number patterns, comparing numerical magnitudes, and estimating quantities (Desoete, Ceulemans, De Weerdt, & Pieters, 2012; Fuchs et al., 2010; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Moeller, Pixner, Zuber, Kaufmann, & Nuerk, 2011). This general understanding of numbers is defined as ''early numeracy skills'' (Passolunghi & Lanfranchi, 2012), not to be confused with number sense, which is preverbal and innate and is often indicated as an approximate number system (Dehaene, Bossini, & Giraux, 1993). This system refers to the representation of non-symbolic quantities specifically, whereas early numeracy in the current study serves as an umbrella term under which several conditional early math skills can be categorized (Gersten, Jordan, & Flojo, 2005).

For most children, learning to master these early numeracy skills is a natural process that is guided by (in)formal learning that occurs in the home and preschool environment (e.g., Ginsburg, Lee, & Boyd, 2008). Not all children, however, develop this knowledge spontaneously. Research shows a reciprocal relationship between math interest and math development in preschool (Fisher, Dobbs-Oates, Doctoroff, & Arnold, 2012). As a result, by 5 years of age, some children already trail behind in their early numeracy knowledge and are not able to catch up with their typically developing peers during primary school when it comes to mathematical knowledge (Stock, Desoete, & Roeyers, 2010; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011).

Longitudinal research on typically achieving children has documented that early numeracy in kindergarten and math skills at the beginning of primary school can be identified by several precursors, often divided into domain-specific and domain-general precursors (Passolunghi & Lanfranchi, 2012; Welsh, Nix, Blair, Bierman, & Nelson, 2010). However, this type of research focusing on children with insufficient skills specifically is rather scarce. Therefore, in the current study, three different precursors (working memory, comparison skills, and math-related language) are used to explain early numeracy performance and development throughout kindergarten, before the point at which children start formal mathematical education in first grade. Identifying precursors for weak early numeracy ability can help to assist in the identification of which children belong to an at-risk group of kindergartners. Moreover, this study builds on the current idea that early precursors in math learning difficulties can be addressed as key components in remedial programs and interventions, preventing children from falling further behind (e.g., DiPerna, Lei, & Reid, 2007).

Working memory

As one of the most important domain-general precursors of early numeracy (Passolunghi & Lanfranchi, 2012; Passolunghi, Vercelloni, & Schadee, 2007), working memory is considered as important for early mathematical performance because incoming information must be stored and manipulated during the dissolving of mathematical tasks (e.g., De Smedt et al., 2009; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). Studies examining the relationship between working memory and early numeracy skills in kindergarten (e.g., Espy et al., 2004; Kroesbergen, Van de Rijt, & Van Luit, 2007) specifically show the importance of working memory characteristics in the early development of mathematical cognition (Klein & Bisanz, 2000).

In research on working memory, the model proposed by Baddeley and Hitch (1974) has proven to be useful. In this model, the term *working memory* is defined as the ability to store and manipulate information simultaneously (e.g., Baddeley, 1986; Baddeley & Hitch, 1974). Within working memory, a distinction can be made between verbal and visual working memory (Alloway, Gathercole, & Pickering, 2006). This basic modular structure of working memory has proven to be stable and assessable by 4 years of age (Alloway, Gathercole, Kirkwood, & Elliott, 2008; Alloway, Gathercole, Willis, & Adams, 2004).

Both visual and verbal working memory types were repeatedly related to math achievement and development in typically developing children (e.g., Andersson & Lyxell, 2007; De Smedt et al., 2009). However, according to a review by Raghubar, Barnes, and Hecht (2010), no consensus has been reached about which component contributes most to math development. Whereas some studies show verbal working memory (i.e., the phonological loop) correlated with children's performance in prerequisites for mathematics (Noël, 2009), other studies verify that visual–spatial working memory is important (e.g., Barnes et al., 2014). Yet, findings from studies on typically developing children of