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Visuo-spatial abilities are key for young children's verbal number skills

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ABSTRACT

Children's development of verbal number skills (i.e., counting abilities and knowledge of the number names) presents a milestone in mathematical development. Different factors such as visuo-spatial and verbal abilities have been discussed as contributing to the development of these foundational skills. To understand the cognitive nature of verbal number skills in young children, the current study assessed the relation of preschoolers' verbal and visuo-spatial abilities to their verbal number skills. In total, 141 children aged 5 or 6 years participated in the current study. Verbal number skills were regressed on vocabulary, phonological awareness and visuo-spatial abilities, and verbal and visuo-spatial working memory in a structural equation model. Only visuo-spatial abilities emerged as a significant predictor of verbal number skills in the estimated model. Our results suggest that visuo-spatial abilities contribute to a larger extent to children's verbal number skills than verbal abilities. From a theoretical point of view, these results suggest a visuo-spatial, rather than a verbal, grounding of verbal number skills. These results are potentially informative for the conception of early mathematics assessments and interventions.

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Introduction

Poor mathematical skills are associated with adverse life outcomes, such as lower qualification and socioeconomic attainment, highlighting the importance of mathematical abilities in numerate societies (Duncan et al., 2007; Ritchie & Bates, 2013). The development of mathematical abilities sets off during infant years and continues along a learning trajectory (Clements & Sarama, 2010). Development along a learning trajectory implies that more complex skills build on more basic skills. In other words, basic skills lay the foundation for later achievement in mathematics and are crucially important for scholastic achievement (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009).

Development of mathematical abilities

The development of mathematical abilities occurs in a quasi-hierarchical manner (Von Aster & Shalev, 2007). A first grasp of mathematical understanding is already present during infancy, allowing infants, for example, to discriminate the numerosity of two sets (Hyde, 2011; Izard, Sann, Spelke, & Streri, 2009; Starr, Libertus, & Brannon, 2013; Xu, Spelke, & Goddard, 2005). This inherited core representation of magnitude is preverbal and nonsymbolic. The first step toward a symbolic notion of numbers is the acquisition of verbal number knowledge. The development of symbolic knowledge starts during the preschool years by learning the number words. During these preschool years, children learn more than simply reciting the number chain. They learn to use these number words in a meaningful way and map them onto the corresponding representations of quantity and Arabic numerals (Benoit, Lehalle, Molina, Tijus, & Jouen, 2013; Gunderson, Spaepen, & Levine, 2015; Mundy & Gilmore, 2009). The knowledge of Arabic numerals marks the second milestone in the development of symbolic number knowledge (Von Aster & Shalev, 2007). In the current study, we use the term *verbal number skills* to refer to the knowledge about number words and their meaningful use (e.g., ascribing the correct number word to a number of items or an Arabic numeral). Hence, verbal number skills critically influence the processes of (verbal and Arabic) number symbolization (see quasi-hierarchical structure of the developmental model of numerical cognition; Von Aster & Shalev, 2007). The current study aimed at investigating the cognitive basis of these verbal number skills. It asked whether verbal number skills are relying primarily on verbal or nonverbal (i.e., visuo-spatial) processes. The first assumption may appear obvious. However, considering that children's earliest mathematical knowledge is nonsymbolic and preverbal, it is also possible that verbal number skills have a visuo-spatial basis. Before tackling the above question, we provide a brief overview of the literature on the respective contributions of verbal and visuo-spatial abilities (VSAs) for mathematical development.

Role of verbal abilities in mathematical development

Verbal abilities have been related to math development and achievement in multiple studies (Kleemans, Peeters, Segers, & Verhoeven, 2012; LeFevre et al., 2010; Purpura & Ganley, 2014; Purpura, Hume, Sims, & Lonigan, 2011; Toll & Van Luit, 2014; Vukovic & Lesaux, 2013b). Various types of verbal and linguistic abilities have been investigated in this context such as vocabulary (Purpura & Ganley, 2014), phonological awareness (Kleemans, Segers, & Verhoeven, 2011; Krajewski & Schneider, 2009; Simmons, Singleton, & Horne, 2008), and verbal working memory (Bull, Espy, & Wiebe, 2008; De Smedt et al., 2009; Hornung, Schiltz, Brunner, & Martin, 2014; Noël, 2009; Passolunghi, Mammarella, & Altoè, 2008). Among the many facets of mathematical abilities, the focus of the current research lies on young children's verbal number skills. The verbal nature of these skills makes them particularly susceptible to relying on verbal abilities. LeFevre et al. (2010) reported, for instance, that children's general vocabulary is tied to their ability to acquire number-specific vocabulary (see also Vukovic & Lesaux, 2013a). Other researchers emphasize the role of phonological awareness (i.e., the awareness of sounds in spoken language; see, e.g., Stahl & Murray, 1994, for a more precise definition) for mathematics (De Smedt, Taylor, Archibald, & Ansari, 2010; Hecht, Torgesen, Wagner, & Rashotte, 2001; Krajewski & Schneider, 2009; Lopes-Silva, Moura, Júlio-Costa, Haase, & Wood, 2014; Simmons et al.,