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Early numerical abilities and cognitive skills in kindergarten children



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ABSTRACT

In this study, a unitary path analysis model was developed to investigate the relationship between cognitive variables (derived from published studies) and early numerical abilities in children attending the last year of kindergarten. We tested 100 children starting their last year of kindergarten on the following cognitive abilities: intelligence, phonological abilities, counting, verbal and visuospatial short-term memory and working memory, processing speed, and early numerical abilities. The same children were tested again on early numerical abilities at the end of the same year. The children's early numerical abilities at the beginning of the final year of kindergarten were found to be directly related to their verbal intelligence, phonological abilities, processing speed, and working memory and to be indirectly related to their nonverbal intelligence. Early numerical abilities at the end of the same year are directly related not only to early numerical abilities assessed at the beginning of the year but also to working memory and phonological abilities as well as have an indirect relationship with verbal and nonverbal intelligence. Overall, our results showed that both general and specific abilities are related to early mathematic learning in kindergarten-age children.

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Introduction

Achieving a good level of mathematical ability is important to success at school and attainment in the activities of everyday life. Investigating the abilities linked to math learning, therefore, is important both from a theoretical standpoint, to clarify the cognitive abilities related to successful math learning, and from a social and educational point of view, with a view to the early identification of individuals at risk for mathematical learning disability and to the development of appropriate enhancement training for them.

Although a shared definition is still lacking, the core skills that predict children's performance in mathematics have been referred to using the general term *early numeracy abilities*. They include skills such as counting ability, one-to-one correspondence, quantity comparison, and representing numerical magnitudes in the form of a mental number line (Gersten, Jordan, & Flojo, 2005; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Van de Rijdt & Van Luit, 1999). A number of studies on kindergarten children found a relationship between early numerical abilities and later mathematical skills (e.g., Aunio & Niemivirta, 2010; Jordan, Kaplan, Oláh, & Locuniak, 2006; Jordan et al., 2009). For example, Mazzocco and Thompson (2005) found that mathematical learning disability in third grade could be accurately predicted from difficulty with certain mathematics tasks in kindergarten, including reading numerals, applying counting principles, number line concepts, and mental additions. Koponen, Aunola, Ahonen, and Nurmi (2007) showed that procedural calculation skills in fourth grade were predicted by individual differences in children's early numerical abilities assessed in kindergarten. Investigating the impact of early numerical abilities on mathematical achievement in the first grade of primary school, Jordan, Kaplan, Locuniak, and Ramineni (2007) found that the former accounted for 66% of the variance in the latter.

Only a few studies have considered the role of both general cognitive skills and more specific abilities, such as early numerical abilities, in predicting later mathematical achievement in primary school. Geary (2011) found that early numerical abilities, processing speed, and visuospatial working memory predicted mathematical achievement from first grade to fifth grade. Hassinger-Das, Jordan, Glutting, Irwin, and Dyson (2014) found that attention problems and executive functioning were unique predictors of mathematical achievement in first-grade children with weak early numerical abilities at the end of kindergarten. Östergren and Träff (2013) found that both early number knowledge and verbal working memory affected kindergarten and first-grade arithmetical ability. Locuniak and Jordan (2008) reported that early numerical abilities in kindergarten contributed a significant amount of the variance in calculation fluency in second-graders over and above the influence of more general predictors (age, reading, memory, and verbal and spatial cognition).

However, no studies have been conducted to date to develop a comprehensive model that includes general cognitive variables such as working memory, processing speed, phonological ability, intelligence, and early numerical abilities in children attending their last year of kindergarten. In the current study, therefore, we aimed to produce a unitary path analysis model capable of identifying the relationship between these variables. We also aimed to analyze the autoregressive effects of the numerical abilities identified at the beginning of the school year on the numerical abilities measured at the end of the same year. Thus, our model concerns both the concurrent and predictive roles of cognitive variables in influencing early numerical abilities. The following sections briefly explain the rationale underlying the variables considered in the study and our specific study hypotheses.

Working memory and short-term memory

Working memory can be seen as a short-term "working space" for temporarily retaining information while the individual is involved in other tasks. Baddeley and Hitch (1974) described working memory as a three-way system comprising a central executive and two slave systems. The central executive can be seen as a limited-capacity processor responsible for attentional control over actions and for processing and coordinating the two slave systems called the phonological loop (for retaining linguistic information) and the visuospatial sketchpad (for retaining visuospatial information). The distinctions between the central executive system and specific memory storage systems (i.e., the

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