Journal of Experimental Child Psychology 140 (2015) 38–55

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

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

How preschool executive functioning predicts several aspects of math achievement in Grades 1 and 3: A longitudinal study

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ARTICLE INFO

Article history:
Received 22 October 2014
Revised 30 June 2015
Available online 26 July 2015

Keywords:
Executive function
Preschool
Mathematics
School readiness
Working memory
Inhibition

ABSTRACT

This longitudinal study analyzes whether selected components of executive function (EF) measured during the preschool period predict several indices of math achievement in primary school. Six EF measures were assessed in a sample of 5-year-old children ($N = 175$). The math achievement of the same children was then tested in Grades 1 and 3 using both a composite math score and three single indices of written calculation, arithmetical facts, and problem solving. Using previous results obtained from the same sample of children, a confirmatory factor analysis examining the latent EF structure in kindergarten indicated that a two-factor model provided the best fit for the data. In this model, inhibition and working memory (WM)–flexibility were separate dimensions. A full structural equation model was then used to test the hypothesis that math achievement (the composite math score and single math scores) in Grades 1 and 3 could be explained by the two EF components comprising the kindergarten model. The results indicate that the WM–flexibility component measured during the preschool period substantially predicts mathematical achievement, especially in Grade 3. The math composite scores were predicted by the WM–flexibility factor at both grade levels. In Grade 3, both problem solving and arithmetical facts were predicted by the WM–flexibility component. The results empirically support interventions that target EF as an important component of early childhood mathematics education.

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http://dx.doi.org/10.1016/j.jecp.2015.06.014
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Introduction

During recent decades, substantial gains have been made in identifying the preschool precursors of later math achievement, and among the various cognitive processes found to be associated with or predictive of math skills, executive function (EF) appears to be particularly important. In adults (Miyake et al., 2000) and older children (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003), EF has been conceptualized as a multicomponent construct comprising several functions, primarily working memory, set shifting, and inhibition.

A number of studies have shown a developmental link between EF and math performance, especially in school-aged children (see, e.g., Agostino, Johnson, & Pascual-Leone, 2010; Mazzocco & Kover, 2007; Van der Ven, Kroesbergen, Boom, & Leseman, 2012). Fewer studies have been conducted on preschoolers, although increasing evidence indicates that emerging math skills are significantly correlated with concurrent measures of EF in younger children (Best, Miller, & Naglieri, 2011; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Espy et al., 2004; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Lan, Legare, Ponitz, Li, & Morrison, 2011; Miller, Müller, Giesbrecht, Carpendale, & Kerns, 2013). Furthermore, longitudinal studies suggest that EF fosters the acquisition of emerging math skills (Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; McClelland et al., 2007; Passolunghi & Lanfranchi, 2012; Röthlisberger, Neuenschwander, Cimeli, & Roebers, 2013; Welsh, Nix, Blair, Bierman, & Nelson, 2010). These longitudinal studies are particularly relevant because they facilitate the identification of the cognitive precursors of math achievement before school entry and contribute to the development of interventions that may enhance the skills necessary for children's learning of early math concepts.

EF and math achievement: Critical issues

Although it is generally agreed that EF plays a role in early math achievement, it is not clear whether all EF processes are equally involved in math learning or how EF affects different aspects of math performance. The majority of studies have found that working memory (WM) is a significant predictor of math achievement (Bull et al., 2008; Miller et al., 2013; Passolunghi & Lanfranchi, 2012; Passolunghi, Mammarella, & Altoè, 2008; see Raghubar, Barnes, & Hecht, 2010, for a review), and several studies have found that early math performance is associated with inhibition (Blair & Razza, 2007; Clark et al., 2010; Espy et al., 2004) or with both WM and inhibition (Bull et al., 2008). However, many of these studies examined only one aspect of EF and its effect on a single task, rendering them unable to identify the net contribution of each EF component while controlling for others. Similarly, the studies that used a composite or a single complex EF measure (Best et al., 2011; McClelland et al., 2007; Röthlisberger et al., 2013; Welsh et al., 2010) could not identify the specific contributions of the various EF processes, for example, inhibition and WM.

These problems are closely associated with the difficulty of separating the different EF processes. Several studies conducted during the last decade showed that the latent structure of EF might undergo change between early childhood and adulthood, suggesting that the organization of EF may change over the course of development and that EF might be a relatively undifferentiated construct in young children and becomes more modular only with age (Zelazo & Müller, 2002). Using a confirmatory statistical approach, early studies found that a single undifferentiated executive control factor best described the latent EF structure during early childhood and in preschoolers (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011). Diverging from these results, Miller, Giesbrecht, Müller, McInerney, and Kerns (2012) reported that a two-factor model consisting of WM and inhibition showed a better fit to the data in a sample of preschoolers between 3 and 5 years of age than did a single-factor model or a three-factor model composed of WM, inhibition, and shifting. Similarly, Usai, Viterbori, Traverso, and De Franchis (2014) found that a two-factor model in which inhibition and WM–flexibility were separate dimensions provided the best fit to the data at both 5 and 6 years of age. These two studies suggest that the differentiation of EF processes is already apparent during early childhood and that inhibitory processes emerge as a separate dimension as early as preschool. A two-factor structure was also described by Lee, Bull, and Ho (2013) for children

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