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Prediction of English and Spanish kindergarten mathematics from English and Spanish cognitive and linguistic abilities in Hispanic dual language learners

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ABSTRACT

This study with dual language learners builds on research within monolingual samples that explore important cross- domain links between mathematics and cognitive and linguistic skills. We use a series of univariate multiple regression models to examine the prediction of end-of-year kindergarten numeracy and applied problem solving from autoregressive numeracy and cognitive and linguistic abilities measured at the beginning of kindergarten (Wave 1). Participants included 270 Hispanic dual language learners. In addition to nonverbal IQ, pretest abilities were assessed at the beginning of kindergarten in English and Spanish, including numeracy, vocabulary, phonological short-term memory (STM), rapid autonomized naming, and phonological awareness. Results provided evidence of strong within language relations; however, English and Spanish Wave 1abilities were similarly predictive of English numeracy and applied problems solving at the end of kindergarten. From among Wave 1 abilities, autoregressive numeracy, nonverbal IQ, phonological STM, and vocabulary were the most consistent and strongest predictors of mathematics at the end of kindergarten.

1. Introduction

A recent report indicated that fourth and eighth grade mathematics scores of Hispanic students' in the U.S. have declined (National Center for Education Statistics, 2015). The same report also indicated that 74% or more of Hispanic students in fourth and eighth grade did not demonstrate competency over challenging subject matter (i.e., they were not proficient) in mathematics relative to 60% or more for all fourth and eighth grade students in the U.S. (National Center for Education Statistics, 2015). Added to the seriousness of this report is that Hispanic children are the fastest growing segment of the U.S. population (Passel, Cohn, & Lopez, 2011), comprising 29% of students in the nation's K-12 public school system (Kena et al., 2016). Therefore, an exploration of cross-domain predictive relations between mathematics and cognitive and linguistics skills is important, informing the understanding of how these skills develop simultaneously. Such an exploration may also provide understanding of the cognitive and linguistic mechanisms that support the learning of mathematics in Hispanic kindergartners, especially those learning Spanish and English (i.e., dual language learners [DLLs]), which is not well understood. Greater understanding of these relations could inform the development of mathematics programs tailored to the needs of Spanish–English speaking DLLs. Therefore, gaining a better understanding of cross-domain relations in Spanish–English speaking DLLs, is timely.

1.1. Background on early mathematics

One of the strongest predictors of later school achievement is early knowledge of mathematics (Duncan et al., 2007), predicting children's reading achievement better than early literacy skills (Duncan & Magnuson, 2011; Duncan et al., 2007; Koponen, Salmi, Eklund, & Aro, 2013). Research also demonstrates that children who

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enter school with the lowest achievement levels show the lowest growth in mathematical skills through the elementary school grades (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Bodovski & Farkas, 2007). Finally, in yet another study, Morgan, Farkas, and Wu (2009) demonstrated that children who scored below the 10th percentile at the beginning and end of kindergarten on the mathematics test from the Early Childhood Longitudinal Study (ECLS) had a 70% chance of remaining below the 10th percentile five years later. Thus, early mathematics achievement is critical for placing children on a positive educational trajectory (Foster, Anthony, Clements, & Sarama, 2015).

Of particular importance, kindergartners are developing a variety of mathematics skills, with *numeracy* (e.g., understanding of cardinality, ordinality, counting words, magnitude comparison, basic arithmetic calculation) being a critical element across several aspects of mathematics knowledge (e.g., Clements, Sarama, & Liu, 2008; Clements, Sarama, Spitler, Lange, & Wolfe, 2011). Numeracy is thought to lay the foundation from which formal school-based mathematics instruction builds (Jordan, Kaplan, Locuniak, & Ramineni, 2007). Further, because of the interrelated nature of mathematical development, numeracy skills are necessary for solving more complex mathematics problems (Baroody, 2003; Duncan et al., 2007; Ferrari & Sternberg, 1998). For example, early difficulties with the recall of basic arithmetic facts interfere with the learning of fractions, which subsequently impedes algebraic learning (National Mathematics Advisory Panel, 2008). Thus, without numeracy concepts, children cannot be expected to build increasingly complex understandings of mathematics, including applied problem solving (e.g., the application of numerical knowledge to solve verbally presented word problems; Foster, Anthony, Clements, Sarama, & Williams, 2016; Woodcock, McGrew, & Mather, 2007) and problem solving within the areas of geometry (i.e., the study of shapes and space), measurement (e.g., determining the size of shapes, objects, regions, or quantifying other attributes), and data analysis (e.g., classifying information into categories and describing or comparing the categories; National Research Council, 2009).

1.2. Cognitive and linguistic abilities involved in early mathematics

Research confirms that the strongest predictor of later mathematics performance is prior mathematical knowledge (Bodovski & Youn, 2011; Duncan et al., 2007; Foster et al., 2015; Watts, Duncan, Siegler, & Davis-Kean, 2014). However, cross-domain cognitive and linguistic abilities also influence the learning of mathematics (e.g., Bryant, MacLean, Bradley, & Crossland, 1990; Bull & Johnston, 1997; Foster et al., 2015; LeFevre et al., 2010; Purpura & Ganley, 2014). Cognitive abilities commonly attributed to influencing mathematics performance include intelligence (IQ), phonological processing, and working memory (WM). Linguistic abilities attributed to influencing mathematics performance include various oral language skills such as vocabulary and verbal comprehension. Despite growing consensus that cognitive and linguistic abilities are involved in early mathematics (e.g., Bryant et al., 1990; Bull & Johnston, 1997; Foster et al., 2015; LeFevre et al., 2010; Purpura & Ganley, 2014), the overwhelming majority of extant studies have focused on monolingual English speaking children. Few studies have examined the prediction of mathematics from cognitive and linguistic abilities in Spanish–English speaking DLLs in the U.S. These students are learning two languages simultaneously and have diverse language abilities in each language based on their personal language histories. Therefore, the cognitive and linguistic abilities that influence the learning of mathematics in DLLs may differ from those evidenced in monolingual speaking peers, which we review below.

1.2.1. Intelligence

IQ is known to be related to the development of cognitive, linguistic, and mathematics skills (Geary, 1993; Noël, 2009; Primi, Ferrão, & Almeida, 2010). For example, Stock, Desoete, and Roeyers (2010) identified IQ in a sample of Dutch kindergartners as uniquely predictive of arithmetic reasoning at the end of first and second grade. More recently, in a sample of Italian first grade students, Passolunghi, Cargnelutti, and Pastore (2007) identified significant relations between IQ and concurrently measured mathematics tasks (i.e., approximate number and numeracy) and cognitive abilities (i.e., short-term memory [STM] and WM). IQ was directly related to numeracy as well as indirectly related to numeracy through WM, STM and approximate number, all of which were predictive of concurrent numeracy ability. Because IQ influences early mathematics directly and through its influence on other variables, it is an important variable to consider when examining the prediction of mathematics from other cognitive and linguistic abilities.

1.2.2. Phonological processing

The weak phonological representation hypothesis posits that poorly specified phonological representations can result in poor performance on mathematics tasks that involve the retention, retrieval or manipulation of phonological codes (e.g., retrieving number words and solving arithmetic problems such as "3 + 4 = 5"; Hecht, Torgesen, Wagner, & Rashotte, 2001; Robinson, Menchetti, & Torgesen, 2002). Phonological processing, including phonological awareness (PA), phonological STM, and rapid autonomized naming (RAN) have been linked to the development of mathematics skills (e.g., Bryant et al., 1990; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). The metalinguistic component of PA may help children manipulate individual words in the number sequence (Krajewski & Schneider, 2009) and encode verbal information (i.e., phonological representations for mathematical terms and operators) when solving arithmetic problems (Hecht et al., 2001; Robinson et al., 2002; Simmons & Singleton, 2008). RAN may be important for solving arithmetic problems through an influence on children's ability to quickly retrieve arithmetic facts and when linking appropriate facts to a particular problem (Geary, 1993; Hecht et al., 2001). For instance, when children retrieve phonological name codes for numbers from long-term memory to solve arithmetic problems, naming speed is thought to be involved (Dehaene, 1992; Geary, 1993). As naming speed improves, cognitive resources are freed and one can attend to other aspects of complex problem solving (Bull & Johnston, 1997; Geary, 1993; Hecht et al., 2001). Finally, phonological STM, the non-executive component of WM, is a limited capacity processing resource that helps children actively maintain a mathematics task in mind as he or she decides on a course of action for solving it (Foster et al., 2015). Limited processing resources such as short-term storage for phonological information could interfere with learning arithmetic facts and could limit one's ability to solve mathematics problems.

Of phonological processing abilities, findings from Hecht et al. (2001) support the link between PA and arithmetic, suggesting that PA tends to be the strongest and most consistent predictor, among phonological abilities, of arithmetic in elementary grades. In particular, Hecht et al. (2001) accounted for the influences of vocabulary and prior mathematics ability when investigating the predictive relations of PA, phonological STM, and RAN with arithmetic achievement. Vocabulary and prior mathematics ability significantly predicted arithmetic achievement at each time period under study (i.e., second to fifth grade, second to third grade, third to fourth grade, and fourth to fifth grade). Hecht et al. (2001) also showed that RAN and phonological STM significantly predicted arithmetic achievement from second to third grade after accounting for prior mathematics ability. However, of the three phonological processing abilities, only PA significantly predicted

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