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Non-symbolic approximate arithmetic training improves math performance in preschoolers

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ABSTRACT

Math proficiency at early school age is an important predictor of later academic achievement. Thus, an important goal for society should be to improve math readiness in preschool-age children, especially in low-income children who typically arrive in kindergarten with less mathematical competency than their higher income peers. The majority of existing research-based math intervention programs target symbolic verbal number concepts in young children. However, very little attention has been paid to the preverbal intuitive ability to approximately represent numerical quantity, which is hypothesized to be an important foundation for full-fledged mathematical thinking. Here, we tested the hypothesis that repeated engagement of non-symbolic approximate addition and subtraction of large arrays of items results in improved math skills in very young children, an idea that stems from our previous studies in adults. In the current study, 3- to 5-year-olds showed selective improvements in math skills after multiple days of playing a tablet-based non-symbolic approximate arithmetic game compared with children who played a memory game. These findings, collectively with our previous reports, suggest that mental manipulation of approximate numerosities

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provides an important tool for improving math readiness, even in preschoolers who have yet to master the meaning of number words.

Introduction

Mathematical competence during early school years is a powerful predictor of later academic success not only in math but also in other domains such as reading (Aubrey, Godfrey, & Dahl, 2006; Duncan et al., 2007; Geary, Hoard, Nugent, & Bailey, 2013; Jordan, Glutting, & Ramineni, 2010; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Martin, Cirino, Sharp, & Barnes, 2014). Unfortunately, many children, especially from low-income families, start kindergarten with minimal competencies in math (Jordan, Kaplan, Nabors Oláh, & Locuniak, 2006; Jordan et al., 2007; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Starkey, Klein, & Wakeley, 2004). Thus, enhancing mathematical competence during preschool years is an important societal challenge.

The traditional approach to enhancing mathematical achievement in young children is to target skills foundational to mathematics, including domain-specific abilities such as counting skills and domain-general abilities such as working memory (Baroody, Eiland, & Thompson, 2009; Bryant et al., 2011; Chard et al., 2008; Clements & Sarama, 2007; Dyson, Jordan, & Glutting, 2013; Fuchs et al., 2005; Ramani & Siegler, 2008; Siegler & Ramani, 2009; Starkey et al., 2004). Many of these programs are curriculum based and focus on enhancing specific foundational mathematical knowledge in everyday activities to improve children's mathematical competence. In particular, nearly all of these programs focus on symbolic number concepts such as counting and number facts as well as arithmetic operations with numerical symbols. These intervention programs have started to show great successes in increasing children's mathematical knowledge at young ages (Clements & Sarama, 2011). Nonetheless, there are some limitations to the approaches that currently dominate the landscape. First, many of these programs require a large investment of teacher training and must be implemented over a full academic year. Relatedly, because the teachers are given a great deal of additional training to implement the intervention curricula, it is often difficult to find a fair control group. Another limitation from the standpoint of cognitive science is that most interventions are very heterogeneous, often consisting of multiple different tasks or skills. Although such large-scale interventions may be a very effective strategy for improving mathematical ability, it is difficult to pinpoint which aspects of the curriculum are most effective.

Here we take an alternative approach and ask whether training aimed at children's preverbal number sense could be an effective way to improve math readiness. Children come into the world with a preverbal number sense that allows an approximate sense of quantity (Dehaene, 1999; Gallistel & Gelman, 1992). This system has been termed the approximate number system (ANS) and has been shown to be present in newborn infants (Izard, Sann, Spelke, & Streri, 2009; Xu & Spelke, 2000), to operate in adults from cultures without symbolic counting systems (Gordon, 2004; Pica, Lemer, Izard, & Dehaene, 2004), and to be present in a wide range of nonhuman animals (Agrillo, Cohen Kadosh, & Dowker, 2014; Beran, Perdue, & Evans, 2015). Furthermore, the system increases in precision with age and is found across the lifespan (Halberda & Feigenson, 2008; Halberda, Ly, Wilmer, Naiman, & Germine, 2012).

Despite the profound differences between a symbolic representation of number, which allows the representation of number with extreme precision, and approximate non-symbolic representations, which are noisy and follow Weber's law, recent studies have uncovered a correlation between individual ANS acuity and symbolic math ability (e.g., Gilmore, McCarthy, & Spelke, 2010; Halberda, Mazzocco, & Feigenson, 2008; Libertus, Feigenson, & Halberda, 2011; Mazzocco, Feigenson, & Halberda, 2011; but see Fuhs & McNeil, 2013; Gobel, Watson, Lervag, & Hulme, 2014; Inglis,