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Limited knowledge of fraction representations differentiates middle school students with mathematics learning disability (dyscalculia) versus low mathematics achievement

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ABSTRACT

Fractions pose significant challenges for many children, but for some children those challenges persist into high school. Here we administered a fractions magnitude comparison test to 122 children, from Grades 4 to 8, to test whether their knowledge of fractions typically learned early in the sequence of formal math instruction (e.g., fractions equivalent to one-half, fraction pairs with common denominators) differentiates those with mathematics learning disability (MLD) versus low achievement (LA) or typical achievement (TA) in mathematics and whether long-term learning trajectories of this knowledge also differentiate these groups. We confirmed that although fourth graders with TA ($n = 93$) were more accurate in evaluating "one-half" fractions than in evaluating "non-half" fractions (until they reached ceiling performance levels on both types of fractions), children with MLD ($n = 11$) did not show a one-half advantage until Grade 7 and did not reach ceiling performance even by Grade 8. Both the MLD and LA groups had early difficulties with fractions, but by Grade 5 the LA group approached performance levels of the TA group and deviated from the MLD group. All groups showed a visual model advantage over Arabic number representation of fractions,

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but this advantage was short-lived for the TA group (because ceiling level was achieved across formats), whereas it was slightly more persistent for the LA group and persisted through Grade 8 for children with MLD. Thus, difficulties with fractions persist through Grade 8 for many students, but the nature and trajectories of those difficulties vary across children with math difficulties (MLD or LA).

Introduction

Fractions pose significant challenges for many children (Hecht, Vagi, & Torgesen, 2007; Mazzocco & Devlin, 2008) and adults (Stafylidou & Vosniadou, 2004). This is concerning because reliance on fractions is pervasive throughout daily life during activities as varied as recipe conversion, calculating a tip, and determining appropriate medicinal doses based on, for instance, a person's body weight. That lifelong difficulties with fractions persist is intriguing given that fractions are introduced by third grade and continue to be a focus of instruction throughout elementary and middle school (Common Core State Standards Initiative; CCSSI, 2010). Early difficulties in learning fractions is of significant concern because elementary school students' knowledge of fractions is a stronger predictor of their overall later high school mathematics achievement than their elementary whole number arithmetic knowledge (Siegler et al., 2012). Thus, it is not surprising that the National Mathematics Advisory Panel (NMAP, 2008) described the teaching of fractions as critically important, and in need of improvement, if gains in student achievement in the United States are to be realized.

Efforts to improve children's knowledge of fractions include improving instruction, instructional materials, and mathematics curriculum (NMAP, 2008; Siegler et al., 2010). Here we propose that efforts should also focus on identifying individual differences in cognitive skills relevant to learning fractions—such as differences in the strength with which children's whole number knowledge interferes with learning fractions—and on identifying the children who are at greatest risk for lifelong struggles. For instance, although the "whole number bias" that interferes with learning fractions (Ni & Zhou, 2005) is a well-described source of early misconceptions (e.g., that ¼ is larger than ½ because 4 is greater than 2; Behr, Harel, Post, & Lesh, 1992; Hartnett & Gelman, 1998), its persistence over time may vary across children. Typically developing children gradually abandon this whole number bias sometime between Grades 5 and 6 when they understand that quantities can be represented by a single numerical ratio (Stafylidou & Vosniadou, 2004) and that, therefore, fractions represent one quantity rather than two quantities (the numerator and the denominator). It is possible that some children do not experience this shift or that children with a weak concept of whole numbers will lack this bias but face different obstacles to learning fractions.

Knowledge of the sources of errors in fractions knowledge informs instructional practices, as does information concerning the likelihood that obstacles to learning fractions will persist. In this study, we evaluate whether subgroups of children can be characterized by distinct and measurable variation in their learning trajectories for rational number knowledge. Specifically, we test the notion that learning and performance trajectories from Grades 4 to 8, measured with magnitude comparisons involving fractions, vary as a function of whether children meet criteria for mathematics learning disability (MLD) versus low mathematics achievement not otherwise specified (LA) despite the fact that both of these groups of children have difficulty in learning mathematics in general (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Murphy, Mazzocco, Hanich, & Early, 2007) and fractions specifically (Mazzocco & Devlin, 2008). In the absence of a "gold standard" definition of MLD, we use cutoff scores as a proxy classification, and in doing so we attempt to reduce false positives in our MLD sample by adopting a cutoff score closer to the MLD reported prevalence ratings of approximately 6% to 11% across many studies (Shalev, 2007).

We differentiate between these two low-performing groups—MLD and LA—because of the growing evidence base that not all children with mathematics difficulties have MLD and that children with