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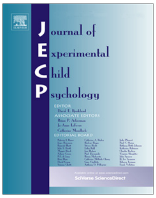

Explaining the relationship between number line estimation and mathematical achievement: The role of visuomotor integration and visuospatial skills

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ABSTRACT

Performance on number line tasks, typically used as a measure of numerical representations, are reliably related to children's mathematical achievement. However, recent debate has questioned what precisely performance on the number line estimation task measures. Specifically, there has been a suggestion that this task may measure not only numerical representations but also proportional judgment skills; if this is the case, then individual differences in visuospatial skills, not just the precision of numerical representations, may explain the relationship between number line estimation and mathematical achievement. The current study investigated the relationships among visuospatial skills, visuomotor integration, number line estimation, and mathematical achievement. In total, 77 children were assessed using a number line estimation task, a standardized measure of mathematical achievement, and tests of visuospatial skills and visuomotor integration. The majority of measures were significantly correlated. In addition, the relationship between one metric from the number line estimation task (R^2_{LIN}) and mathematical achievement was fully explained by visuomotor integration and visuospatial skill

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competency. These results have important implications for understanding what the number line task measures as well as the choice of number line metric for research purposes.

Introduction

Achievement in mathematics is important not only for general academic achievement but also for future health and life chances (Every Child a Chance Trust, 2008; Williams, Clements, Oleinikova, & Tarvin, 2003). A large body of research has identified individual differences in mathematical achievement, and researchers have begun to explore the range of factors that are important for success in mathematics. Of the cognitive factors studied, individuals' internal numerical representations have frequently been identified as a potential contributing factor to individual differences in mathematical performance (e.g., Muldoon, Towse, Simms, Perra, & Menzies, 2013; Siegler & Booth, 2004).

Representations of number are believed to be stored along a mental "number line" (Dehaene, 1997). A number of tasks have been used to provide an indication of the precision of individuals' numerical representations, of which the number line estimation task is a popular measure (Geary, Hoard, Nugent, & Byrd-Craven, 2008; Siegler & Opfer, 2003; Simms, Muldoon, & Towse, 2013; van den Bos et al., 2015). In a number line estimation task, participants are generally presented with number lines that include the values of the start and end points of the scale (e.g., 0 and 10) and are asked to position a series of numbers on the line. Because these tasks may be confounded with number knowledge, a variety of age-appropriate scales have been used (e.g., 0–10, 0–20, 0–100; Muldoon et al., 2013), with larger scales being used with older children.

Two metrics can be calculated from participants' responses on the number line task to try and capture developmental change in performance. Curve estimation, using the estimated position as the dependent variable and the actual position as the independent variable, produces R^2 values for both linear (R^2_{LIN}) and logarithmic (R^2_{LOG}) functions that fit the data points. However, it is important to note that even if a participant has an R^2_{LIN} value approaching 1, this does not necessarily mean that his or her responses are highly accurate; instead, this indicates that the participant's estimates are linearly spread across the number line. In contrast, percentage absolute error (PAE) quantifies the difference between an individual's estimate and the actual position of the number in relation to the scale of the line, thereby providing a metric of accuracy of the positioning of estimates. These two metrics are typically presented concurrently (e.g., Muldoon et al., 2013; Opfer & Siegler, 2007; Siegler & Booth, 2004; Simms et al., 2013), with many researchers acknowledging that these metrics may provide distinct information on numerical representations. However, the literature to date currently lacks an in-depth discussion as to how and why these metrics differ.

Clear developmental changes in number line task performance have been noted, with young children producing estimates that are best explained by a logarithmic function, with small numbers spread out over the lower end of the number line and larger numbers squashed together at the top of the number line. With development, children's estimates become more evenly spread across the number line and, thus, are best explained by a linear function (Siegler & Opfer, 2003). However, this change is gradual, and children have been observed to concurrently hold linear representations for some scales and logarithmic representations for other scales (Muldoon et al., 2013), consistent with an overlapping waves model of cognition (Siegler, 1996).

Performance on the number line estimation task has been related to children's mathematical achievement in a number of studies (e.g., Booth & Siegler, 2008; Muldoon et al., 2013; Siegler & Booth, 2004; van den Bos et al., 2015) in which participants with more linear and accurate performance demonstrate better mathematical achievement. Moreover, interventions that have focused on improving numerical representations through game-based tasks such as number line board games and repetitive physical movements along a large-scale number line have noted transfer to arithmetic