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Children's mathematical performance: Five cognitive tasks across five grades

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ABSTRACT

Children in elementary school, along with college adults, were tested on a battery of basic mathematical tasks, including digit naming, number comparison, dot enumeration, and simple addition or subtraction. Beyond cataloguing performance to these standard tasks in Grades 1 to 5, we also examined relationships among the tasks, including previously reported results on a number line estimation task. Accuracy and latency improved across grades for all tasks, and classic interaction patterns were found, for example, a speed-up of subitizing and counting, increasingly shallow slopes in number comparison, and progressive speeding of responses especially to larger addition and subtraction problems. Surprisingly, digit naming was faster than subitizing at all ages, arguing against a pre-attentive processing explanation for subitizing. Estimation accuracy and speed were strong predictors of children's addition and subtraction performance. Children who gave exponential responses on the number line estimation task were slower at counting in the dot enumeration task and had longer latencies on addition and subtraction problems. The results provided further support for the importance of estimation as an indicator of children's current and future mathematical expertise.

Introduction

The development of numerical abilities and math-related skills has become a heavily researched topic, with a growing body of evidence demonstrating that early competence in math skills is

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predictive of later math achievement (Ashcraft & Moore, 2012; Booth & Siegler, 2006; De Smedt, Verschaffel, & Ghesquière, 2009; Geary, 2011; Holloway & Ansari, 2009; Hornung, Schiltz, Brunner, & Martin, 2014; Landerl, Bevan, & Butterworth, 2004; LeFevre et al., 2010; Lyons, Price, Vaessen, Blomert, & Ansari, 2014; Reeve, Reynolds, Humberstone, & Butterworth, 2012; Siegler & Booth, 2004). These relationships carry strong implications, recently being the basis for successful math skill interventions early in primary school (Siegler & Ramani, 2009). Despite the growth of this type of research, however, the literature still lacks a thorough examination of how performance on various math tasks might be interrelated. The typical study generally examines only a small number of tasks and tests only a limited number of age groups, whether longitudinally or cross-sectionally, leading to an "inchoate patchwork of results" in the description of one team of investigators (Lyons et al., 2014, p. 715). Because of this, integrative questions about development across multiple tasks often cannot be addressed. For example, counting, one of the earlier numerical skills that children acquire, is considered to be a foundational skill or a marker of "core number competence" (Reeve et al., 2012) and is, of course, a nontrivial accomplishment (e.g., Fuson, 1988; Gelman & Gallistel, 1978). Is counting limited, early in primary school, by difficulties in recognition or naming of numbers? What other tasks that assess important math skills are related to counting performance? Does performance on all of these tasks approach adult-like patterns at the same age or rate?

The overarching goal for this project was to investigate the interrelationships between foundational mathematical competencies throughout primary school to gain insight on such integrative questions. To this end, we administered a battery of standard cognitive math tasks to children in Grades 1 through 5; all tasks were also given to a group of college adults to establish the developmental endpoint of performance. The specific tasks were chosen because theoretical and empirical understanding of math skill development, normal or otherwise, often relies on the results obtained from these laboratory tasks. That is, there appears to be widespread agreement that "core numerical competence" (Reeve et al., 2012) consists of identifying, ordering, and comparing numerical quantities. Three of our tasks have been identified as relevant to these abilities.

Number comparison tests how rapidly and accurately one can select the larger of two digits, so it relies on ordering and comparison abilities as well as access to the ordered mental representation of magnitude (see Landerl, 2013; Lyons et al., 2014, and Reeve et al., 2012, for reports with this task). Typically, the time needed for the decision is a decreasing function of the numerical distance between the two values in the pair. That is, as the numerical distance or difference between the digits increases, latencies (and errors) decrease, an effect referred to as the numerical distance effect (NDE). This effect is generally thought to index the precision with which the individual represents numerical magnitudes on an internal number line; each magnitude is thought to be associated with some degree of variability, such that near values overlap to some extent. When two nearby digits are compared, their overlapping representations make discrimination more difficult, that is, slower and more prone to error. Conversely, two digits separated by a large numerical distance should overlap very little, yielding faster and more accurate decisions (e.g., Moyer & Landauer, 1967).

The NDE has been shown to decrease developmentally (Duncan & McFarland, 1980; Sekuler & Mierkiewicz, 1977), either because children's number representations become more precise across age or, perhaps equivalently, because subjective distance between magnitudes grows as numerical experience and education increase, resulting in less overlap between representations (Sekuler & Mierkiewicz, 1977). Importantly, the effect is related to children's math proficiency (De Smedt et al., 2009; Holloway & Ansari, 2009) and is considered by Reeve and colleagues (2012) as measuring a core numerical competency. Because of the prevailing belief that the NDE reflects the use of an internal mental number line, we wanted to see whether performance on this task predicted performance on other tasks that rely on the mental number line as well.

Dot enumeration tests the ability to rapidly apprehend or count the number of dots in a display and is considered to be a test of core competence in that it clearly involves identifying quantities and also involves matching a magnitude representation to a word symbol (Reeve et al., 2012). The task itself presents a number of dots, usually from 1 to 8, for rapid enumeration. The results typically show only a shallow slope ($\sim$50 ms) for displays up to 3 or 4 dots, the "subitizing" range, but then a much steeper function for larger sets, the latter interpreted to reflect deliberate counting. The subitizing process is conventionally thought to be automatic or even preattentive (Kaufman, Lord, Reese, & Volkmann,