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Approximate number word knowledge before the cardinal principle

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ABSTRACT

Approximate number word knowledge—understanding the relation between the count words and the approximate magnitudes of sets—is a critical piece of knowledge that predicts later math achievement. However, researchers disagree about when children first show evidence of approximate number word knowledge—before, or only after, they have learned the cardinal principle. In two studies, children who had not yet learned the cardinal principle (subset-knowers) produced sets in response to number words (verbal comprehension task) and produced number words in response to set sizes (verbal production task). As evidence of approximate number word knowledge, we examined whether children's numerical responses increased with increasing numerosity of the stimulus. In Study 1, subset-knowers (ages 3.0–4.2 years) showed approximate number word knowledge above their knower-level on both tasks, but this effect did not extend to numbers above 4. In Study 2, we collected data from a broader age range of subset-knowers (ages 3.1–5.6 years). In this sample, children showed approximate number word knowledge on the verbal production task even when only examining set sizes above 4. Across studies, children's age predicted approximate number word knowledge (above 4) on the verbal production task when controlling for their knower-level, study (1 or 2), and parents' education, none of which predicted approximation ability. Thus, children *can* develop approximate knowledge of number words up to 10 before learning the cardinal principle. Furthermore, approximate

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number word knowledge increases with age and might not be closely related to the development of exact number word knowledge.

Introduction

Approximate number word knowledge—understanding the approximate numerical magnitudes represented by number words or symbols—has been increasingly recognized as an important aspect of mathematical development (e.g., Booth & Siegler, 2008; Bugden & Ansari, 2011; Davidson, Eng, & Barner, 2012). Approximate number word knowledge is thought to reflect a mapping between number words and the approximate number system (ANS), which represents numerical quantity in a noisy fashion, with increasing variability as the quantity represented increases (e.g., Cordes & Brannon, 2008). Children's performance on tasks tapping approximate number word knowledge, such as symbolic number line estimation, speeded comparison of Arabic numerals, and labeling set sizes without counting, correlates with a variety of important mathematical outcomes, including standardized math achievement tests (e.g., Booth & Siegler, 2008; Bugden & Ansari, 2011; Davidson et al., 2012; Sasanguie, Göbel, Moll, Smets, & Reynvoet, 2013).

Despite the importance of approximate number word knowledge in children's mathematical learning, relatively little is known about the earliest stages of its development. Specifically, researchers disagree about *when* children map number words to the ANS; some claim that approximate number word knowledge begins to develop only after children learn the cardinal principle (that the last number reached when counting a set represents the whole set; Le Corre & Carey, 2007), and others claim that approximate number word knowledge begins to develop before children learn the cardinal principle (Wagner & Johnson, 2011).

The timing of the development of approximate number word knowledge has important theoretical ramifications. If children develop approximate number word knowledge only *after* learning the cardinal principle, then approximate number word knowledge *cannot* influence cardinal principle knowledge. In fact, some have argued that understanding the cardinal principle may actually be a necessary precursor to approximate number word knowledge (Le Corre & Carey, 2007). In contrast, if children acquire approximate number word knowledge *before* cardinal principle knowledge, then approximate number word knowledge may have a positive impact on the development of cardinal principle knowledge (Wagner & Johnson, 2011). In addition to these two conflicting causal accounts, we propose a third theoretical model in which exact number word knowledge and approximate number word knowledge develop separately and are not causally related. The goal of the current studies was to clarify the seemingly inconsistent extant findings and to provide insight into the developmental trajectory of children's approximate number word knowledge in relation to their cardinal principle knowledge.

Developmental trajectory of exact number word knowledge

A large body of research has charted the trajectory of how children learn exact cardinal number word meanings (e.g., understanding that the word "three" refers to sets of three entities) and the cardinal principle (for a review, see Carey, 2009). Children learn the cardinal meanings of the first three or four number words slowly and in order; during these stages, they are referred to as "one-knowers," "two-knowers," and so forth (Wynn, 1992). One-knowers know that the word "one" refers to sets of one item, and will use it correctly, but seem to use all other number words to mean merely "more than one" (Wynn, 1992). Several months later, they become "two-knowers," at which point they have learned that "two" refers to sets of two items but seem to use all other number words to mean "more than two." They then go through the same stages for "three" and sometimes "four" (Sarnecka & Lee, 2009; Wynn, 1992). Children in these stages are collectively referred to as "subset-knowers" because