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Commentary

Strong causal claims require strong evidence: A commentary on Wang and colleagues

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ABSTRACT

In this commentary, we provide a discussion of the findings by Wang, Odic, Halberda, and Feigenson recently published in the *Journal of Experimental Child Psychology* (2016, Vol. 147, pp. 82–99). The article by Wang and colleagues claims to have revealed a causal link between the so-called "approximate number system" (ANS) and young children's symbolic math abilities. We question this assertion of a causal link through a discussion of methodological limitations inherent in their article. More specifically, we assert that (a) Wang and colleagues did not measure the relationship between change in the ANS and change in symbolic number comparison; (b) the ANS manipulation used (hysteresis) may induce a domain-general effect on motivation rather than domain-specific effects on ANS precision; and (c) the outcome measures of symbolic math are problematic both because a between-participants design was employed and because only a select number of items from standardized measures were used. We discuss several possibilities for future research to more directly assess whether a causal relationship exists between the ANS and symbolic math performance in young children.

In a recently published article in the *Journal of Experimental Child Psychology*, Wang et al. (2016) asked a critical question: What is the causal relationship between the approximate number system (ANS) and symbolic number abilities? The ANS refers to a cognitive system that represents quantities

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in a nonverbal and imprecise manner (Feigenson, Dehaene, & Spelke, 2004) and is typically measured by nonsymbolic quantity comparison tasks (e.g., comparing two arrays of dots). One of the hallmark characteristics of the ANS is that it is more difficult to compare the relative magnitude of two nonsymbolic quantities or numerical symbols as the ratio between them (smaller number/larger number) increases (Moyer & Landauer, 1967). There are individual differences and developmental changes in the precision of the ANS (Halberda & Feigenson, 2008), whereby the ratio of the dot arrays that children can accurately discriminate increases with age. Several studies have documented correlations between ANS precision and formal mathematics achievement concurrently (e.g., Halberda, Mazzocco, & Feigenson, 2008) and longitudinally (e.g., Mazzocco, Feigenson, & Halberda, 2011). This has led to the hypothesis that the correlations are driven by the ANS causally influencing mathematics performance. However, such correlational evidence cannot be used to make causal claims. Cognitive training studies, however, offer the potential to manipulate ANS precision in order to experimentally test this causal hypothesis (Bugden, DeWind, & Brannon, 2016; Hyde, Berteletti, & Mou, 2016). Previous ANS training studies have provided evidence that approximate, nonsymbolic training interventions lead to improvements on exact symbolic mathematics performance (Hyde, Khanum, & Spelke, 2014; Obersteiner, Reiss, & Ufer, 2013; Park & Brannon, 2013, 2014; Sella, Tressoldi, Lucangeli, & Zorzi, 2016; Wilson, Dehaene, & Fayol, 2009), but the precise mechanism underlying the improvements remains unclear. These improvements may be driven by overlap in the cognitive operations required to mentally manipulate numerical representations in each format (e.g., Park & Brannon, 2014). Alternatively, if symbolic and nonsymbolic representations of number share underlying neurocognitive substrates, then improving ANS precision of nonsymbolic representations should transfer to symbolic number processing (Hyde et al., 2016). As yet, there is no empirical evidence in support of this latter hypothesis.

Wang and colleagues (2016) aimed to test this hypothesis by determining whether "training experiences can increase ANS precision and ... these changes in precision in turn affect symbolic math" (p. 84). In their study, 5-year-old children completed a nonsymbolic comparison task and either an assessment of receptive vocabulary or an assessment of symbolic mathematics. To manipulate the precision of the ANS, the authors employed a technique where they modified the trial order of the comparison task between participants. In the Easy-First condition, trials were presented in order of increasing difficulty, and in the Hard-First condition, trials were presented in order of decreasing difficulty. This manipulation has previously been shown to influence children's performance on a nonsymbolic task, with children in the Easy-First condition performing better on subsequent trials than those in the Hard-First condition (Odic, Hock, & Halberda, 2014). This is known as the hysteresis effect.

The outcome measures used by Wang and colleagues (2016) consisted of subsets of items from established standardized measures, the Peabody Picture Vocabulary Test (PPVT-4; Dunn & Dunn, 2007) and the Test of Early Mathematics Ability (TEMA-3; Ginsburg & Baroody, 2003). Their results showed that participants in the Easy-First condition were more accurate on the nonsymbolic comparison task compared with the participants in the Hard-First condition, which nicely replicated the findings of Odic and colleagues (2014). Participants in the Easy-First condition also performed better on the symbolic math assessment than participants in the Hard-First condition, but there was no group difference among the participants who completed a receptive vocabulary assessment instead of a symbolic math assessment. These findings were taken as evidence in support of the authors' causal hypothesis.

However, we argue that because Wang and colleagues (2016) did not employ a rigorous randomized controlled trial design, the results do not support the assertion, reflected in the title of their article, that "changing the precision of preschoolers' approximate number system representations changes their symbolic math performance" (p. 82). This is because the results are correlational and instead converge with previous findings that children who perform better on nonsymbolic comparison tasks (in this case only in the Easy-First experimental condition) also tend to perform better on symbolic math assessments. In this commentary, we outline the methodological shortcomings of Wang and colleagues' (2016) study that, in our view, preclude any conclusions about a causal relationship between ANS precision and mathematics achievement. In this way, we challenge the central claims made by the authors against the background of the findings they reported.