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The codevelopment of skill at and preference for use of retrieval-based processes for solving addition problems: Individual and sex differences from first to sixth grades

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ABSTRACT

The ability to retrieve basic arithmetic facts from long-term memory contributes to individual and perhaps sex differences in mathematics achievement. The current study tracked the codevelopment of preference for using retrieval over other strategies to solve single-digit addition problems, independent of accuracy, and skilled use of retrieval (i.e., accuracy and reaction time [RT]) from first to sixth grades inclusive ($N = 311$). Accurate retrieval in first grade was related to working memory capacity and intelligence, and it predicted a preference for retrieval in second grade. In later grades, the relation between skill and preference changed such that preference in one grade predicted accuracy and RT in the next grade as RT and accuracy continued to predict future gains in preference. In comparison with girls, boys had a consistent preference for retrieval over other strategies and had faster retrieval speeds, but the sex difference in retrieval accuracy varied across grades. Results indicate that ability influences early skilled retrieval, but both practice and skill influence each other in a feedback loop later in development and provide insights into the source of the sex difference in problem-solving approaches.

Introduction

The strategies children use to solve addition problems have been well characterized and range from finger counting to retrieval of answers from long-term memory (Carpenter & Moser, 1984; Geary,

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Brown, & Samaranayake, 1991; Siegler & Shrager, 1984). Fast and accurate retrieval has been identified as an important outcome for children by the National Mathematics Advisory Panel (2008) and the National Council of Teachers of Mathematics (2006), and indeed the more basic facts that can be correctly retrieved, the higher the performance on paper-and-pencil arithmetical ability and mathematics achievement tests for children and adults (Geary, Bow-Thomas, Liu, & Siegler, 1996; Geary & Widaman, 1987; Siegler, 1988).

Identification of the mechanisms underlying the development of children's ability to retrieve facts, thus, is an important educational and scientific goal. Children's use of counting strategies appears to contribute to the formation of the long-term memory representations needed to support fact retrieval and, thereby, is one such mechanism (Siegler, 1987; Siegler & Shrager, 1984), but this does not appear to be the only one. Brain imaging and cognitive studies indicate that retrieval of basic addition facts engages the prefrontal cortex, requires attentional control, and is a more active and effortful process for children compared with adults (Cho, Ryali, Geary, & Menon, 2011; Geary, Hoard, Nugent, & Bailey, 2012; Rivera, Reiss, Eckert, & Menon, 2005).

The implication is that individual differences in the capacity of the central executive component of working memory and perhaps other domain-general abilities contribute to individual differences in children's early ability to correctly retrieve basic facts. Siegler (1988) found, however, that some children who were capable of skilled retrieval did not always use retrieval but rather relied on counting or other procedures for problem solving, whereas other children used retrieval even when their answers were likely to be incorrect. In other words, preference for the use of one problem-solving approach over another can influence strategy choices independent of skill and domain-general abilities.

The relation between preference for retrieval and skilled use of retrieval is not well understood but can be framed with two separate but not mutually exclusive hypotheses. In general, the talent hypothesis for the codevelopment of preference and skill is that early talent at some activity influences one's preference for that activity in the future. In the context of the codevelopment of skill at and preference for retrieval as a strategy in single-digit addition, the talent hypothesis is that individual differences in working memory or other general cognitive abilities influence early skilled retrieval as well as grade-to-grade increases in skill. Skilled retrieval in turn contributes to a later preference for retrieval over other strategies.

The second hypothesis that might explain the codevelopment of preference and skill is the practice hypothesis. In general, an early preference for some activity causes individuals to practice that activity more, thereby increasing their future skill at that activity. In the context of the codevelopment of skill at and preference for retrieval as a strategy in single-digit addition, the practice hypothesis is that a preference for retrieval contributes to growth in skilled retrieval. In this case, the developmental emergence of retrieval skill is preceded by an earlier preference for use of retrieval over other strategies independent of working memory or other domain-general competencies. It is likely that the practice and talent hypotheses both are important for explaining the codevelopment of skill and preference in many domains. This is because if skill can influence practice, and practice can influence skill, a feedback loop may arise where individuals who prefer to participate in some activity will practice it more, which increases their skill, which in turn may further increase their preference, and so on.

The question of the developmental relation between preference for and skilled use of retrieval is also important because there are early emerging sex differences on these dimensions (Carr & Davis, 2001), and there is some evidence that skilled retrieval, which is higher in males, results in a sex difference on mathematics tests in which basic arithmetic is embedded (Royer, Tronsky, Chan, Jackson, & Marchant, 1999). By analyzing the cross-lagged relation between preference and skill from first to sixth grades inclusive, we were able to test these hypotheses. We demonstrate that the direction of the relation between skilled retrieval and preference for use of retrieval varies across grades and that the pattern of relations differs for boys and girls.

Addition development

By the time children start first grade, most of them have developed a suite of strategies that can be used to solve formal addition problems, for example, "How much is 3 + 2?" (Carpenter & Moser, 1984; Geary, 1990; Siegler, 1987). Most of these children will use counting to solve at least some of the