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Age-related changes in children's executive functions and strategy selection: A study in computational estimation

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A B S T R A C T

Third, fifth, and seventh graders selected the best strategy (rounding up or rounding down) for estimating answers to two-digit addition problems. Executive function measures were collected for each individual. Data showed that (a) children's skill at both strategy selection and execution improved with age and (b) increased efficiency in executive functions contributed significantly to age-related improvement in children's strategy selection skill. These findings have implications for understanding of age-related differences in computational estimation, strategy selection processes, and mechanisms of strategic development in children.

In this study, we examine the role of executive functions (EFs) in children's arithmetic strategy selection and in its development. Specifically, we investigate whether age-related changes in children's executive functions are related to age-related changes in their strategy selection skills. We chose the domain of mathematical cognition because it is one in which strategic variations in general, and strategy selection in particular, have previously been investigated in great detail. Further, findings in this domain usually generalize to other cognitive domains and tasks in which participants use multiple strategies and select them on a trial-by-trial basis (Siegler, 1996). Before describing the present study, we review previous findings on development in children's arithmetic strategies, age changes in EFs, and relations between EFs and arithmetic strategy and performance.

1. Strategic development in arithmetic

Cognitive strategies greatly influence the development of children's mathematical skills. A strategy can be defined as "a procedure or a set of procedures for achieving a higher level goal or task" (Lemaire &

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Reder, 1999). Previous research has found that children use varying strategies to accomplish cognitive tasks and select them on a trial-by-trial basis. They may thereby adapt flexibly in different contexts to inherent task characteristics, such as problem difficulty, and to situational demands, such as the need to answer quickly and/or accurately. With age, children use the most efficient and problem-appropriate strategies increasingly often, and they execute them more and more efficiently. These phenomena occur in many cognitive domains (Siegler, 1996) in addition to arithmetic (Barrouillet, Mignon, & Thevenot, 2008; Beishuizen, Van Putten, & Van Mulken, 1997; Blöte, Van der Burg, & Klein, 2001; Fuson, 1990; Kuhn & Pease, 2009; Lemaire & Calliès, 2009; Lemaire & Siegler, 1995; Lucangeli, Tressoldi, Bendotti, Bonanomi, & Siegel, 2003; Luwel, Lemaire, & Verschaffel, 2005; Siegler, 1988). A key developmental question is how children select the most efficient strategies more frequently as they grow older.

Several theories have been proposed to account for strategy selection and children's strategic development. Computational models (Lovett and Anderson's 1996 ACT-R model; Lovett and Schunn's 1999 RCCL model; Payne, Bettman, and Johnson's 1993 adaptive decision maker model; Rieskamp and Otto's 2006 SSL model; and Siegler and Arraya's 2005 SCADS* model) share several core assumptions regarding strategy choices and execution. All propose that choosing among multiple strategies involves associative mechanisms, such as activating relative costs/benefits of each strategy and selecting the one that works best on the basis of problem and strategy characteristics. All models assume that strategies including fewer and/or simpler procedures (e.g., solving arithmetic problems like 3×4 directly from memory) are easier to execute than ones involving more numerous and/or more complex procedures (e.g., adding 3 four times). These assumptions proved sufficient to account for most previous findings on strategy choice and execution.

However, these models do not account for several phenomena related to strategy and strategic development. For example, children sometimes use fewer strategies even when they know and can use all available strategies. It is also unknown why relative strategy efficacy does not fully account for strategy choice, or why children sometimes continue to use a strategy when an alternative is slightly faster and/or more accurate (Luwel, Verschaffel, Onghena, & De Corte, 2003; Siegler & Lemaire, 1997). An Einstellung effect, in which an individual habitually applies a previously successful strategy when a better, more efficient strategy is available, suggests that strategy adoption involves more than simply considering problem and strategy characteristics.

The present study examines the potential role of executive processes in the strategies children choose when solving arithmetic problems. We also examine the contribution of executive processes in children's strategic development in the mathematical domain. No previous models of strategy choice or strategic development implicate executive functions (EFs) in optimal strategy selection, nor do any models assume that age-related changes in executive processes contribute to changes in strategies. Positive findings thus have important theoretical implications regarding strategy selection and strategic development.

2. Age-related differences in EFs

EFs are higher-order mental operations concerned with the maintenance, manipulation, planning, monitoring, and regulation of other cognitive processes responsible for perception, memory, reasoning, problem solving, language, and action. These processes involve self-regulation, planning, organization, and the ability to initiate, maintain, switch, and stop sequences of complex behaviour. Core EFs include (a) inhibitory control (resisting habits, temptations, or distractions), (b) working memory (mentally holding and processing information), and (c) cognitive flexibility (adjusting to change) (Diamond, 2006; Diamond, Barnett, Thomas, & Munro, 2007; Eslinger, 1996; Jurado & Rosselli, 2007; Lezak, 1995; Logan, 2000; Miyake et al., 2000; Norman & Shallice, 1986; Rabbit, 1997; Stuss & Benson, 1986).

EFs in adults and age-related changes in EFs in children have been investigated using several procedures. In the approach used here, EFs are investigated via neuropsychological tests thought to engage executive functions (Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Lezak, 1995; Spreen & Strauss, 1998), Such tests include the Trail Making Test, Stroop test, and Excluded Letter Fluency Tests. Children's performance on these tests improves with age (Carlson, 2005; Carlson, Davis, & Leach, 2005;