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From domain-specific to domain-general? The developmental path of metacognition for strategy selection

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ABSTRACT

We examined the developmental course of metacognition concurrently in arithmetic problem solving and in episodic memory. In Experiment 1, children aged between 8 and 13 were asked to judge the ease with which they would select the better strategy on a given item before actually selecting and executing it. In Experiments 2 and 3, children had to judge their level of confidence in a strategy once selected. Results of these experiments indicated that children are able to accurately judge whether they select the better strategy on a given item in both the arithmetic and the memory domains, and that this ability improves with age. Using a comprehensive set of metacognitive measures, our data support the hypothesis that metacognition is first domain-specific and then generalizes across domains as children mature. Implications of these findings to further our understanding of age-related changes in metacognition and its involvement in strategy selection are discussed.

1. The developmental path of metacognition for strategy selection

Metacognition, typically defined as the ability to evaluate (or monitor) and regulate (or control) the success of cognitive processes (Dunlosky & Metcalfe, 2009), has been regarded as a fundamental skill influencing cognitive performance and learning in domains as diverse as arithmetic, memory, reading, perception, and many others (Kuhn, 2000). Generally, metacognition is viewed as a global ability that is correlated across content domains, suggesting that participants who are good at evaluating their performance for one sort of task also tend to be good at evaluating their performance for another sort of task (Schraw, Dunkle, Bendixen, & Roedel, 1995).

2. Domain-general or domain-specific metacognition processes?

In adults, the assumption that metacognition is domain-general is supported by two types of evidence. First, a number of behavioral studies seem to indicate that inter-individual differences in measures of metacognitive sensitivity (i.e., how well one can discriminate between correct and incorrect responses through the monitoring of one's own performance) correlated across unrelated cognitive tasks (e.g., Gardelle & Mamassian, 2014; McCurdy et al., 2013; Schraw et al., 1995; Song et al., 2011; Veenman, Elshout, & Meijer, 1997; Veenman, Prins, & Verheij, 2003). Second, imaging data suggest that adults' metacognitive abilities for different types of tasks partially depend on common neural structures (Allen et al., 2016; Anderson, Betts, Ferris, & Fincham, 2011; McCurdy et al., 2013; Shimamura, 2000). These results, however, have to be qualified to some extent. Indeed, behavioral correlations observed

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across domains have been shown to depend on the type of metacognitive measures used as well as on whether the performance at the cognitive level is controlled (e.g., Kelemen, Frost, & Weaver, 2000). Furthermore, some imaging studies have failed to find common neural structures when examining adults' metacognitive abilities across domains (e.g., Baird, Smallwood, Gorgolewski, & Margulies, 2013).

In children, the situation is even less clear. Indeed, most experiments testing metacognition in children have been conducted in a single cognitive domain at a time (see Schneider & Löffler, 2016, for an overview). Only a limited number of studies have examined the developmental trend of metacognitive skills concurrently across several domains. The few available data sets suggest that metacognition (understood here as metacognitive sensitivity or monitoring) could be domain-specific early in development and generalize across domains as children mature (Lyons & Ghetti, 2010; Schraw & Nietfeld, 1998; Veenman & Spaans, 2005; Vo, Li, Kornell, Pouget, & Cantlon, 2014). For example, Vo et al. (2014) have shown that 5- to 8-year-olds' metacognition for a numerical discrimination task was unrelated to their metacognition for an emotion discrimination task. Moreover, Veenman and Spaans (2005) found that metacognition correlates between domains at age 15. These results suggest that a shift from a domain-specific to a domain-general metacognition could occur between these ages. To date, however, this hypothesis has never been directly tested.

Determining the developmental trajectory of whether and how metacognition generalizes across domains could be crucial in at least two respects. From a theoretical perspective, this would shed new light on how metacognition develops throughout childhood while helping us to improve our understanding of both the functioning and the cognitive architecture of metacognitive processes. From a practical perspective, determining when metacognition becomes domain-general and thereby the conditions for such a generalization could have a major impact on metacognitive revalidation programs. Indeed, if metacognition does not depend on domains, it implies that metacognitive interventions in one domain (e.g., arithmetic, memory, or reading) could have positive effects across all domains. For these reasons, the first aim of the present study was to examine age-related differences in the relations between measures of metacognitive sensitivity for two different cognitive tasks in children aged from 8 to 13 years. Specifically, participants were asked to evaluate their performance on a strategy selection task in two independent cognitive domains: arithmetic and memory.

3. Metacognition and strategy selection

Several decades of research in children (see Siegler, 1996, 2007, for overviews) and during adulthood (see Lemaire, 2016, for an overview) have shown that people use a variety of strategies to accomplish cognitive tasks. This plethora of studies indicates that participants' performance and age-related changes in cognitive performance depend on strategies. Yet, despite extensive research seeking to understand how people choose among strategies on a given item (e.g., Metcalfe & Campbell, 2011; Thevenot, Fanget, & Fayol, 2007), participants' ability to monitor their chance of selecting the better strategy in the future (i.e., prospective judgment) or to estimate their level of confidence associated with a selected strategy (i.e., retrospective judgment) has been examined neither in the arithmetic domain nor in the memory domain. As four decades of studies – mainly in the memory domain – have established that the influence of metacognitive processes on cognitive performance is exerted through the implementation of effective strategies (e.g., DeMarie, Miller, Ferron, & Cunningham, 2004; Geurten, Catale, & Meulemans, 2016; Geurten, Lejeune, & Meulemans, 2016; Nelson & Narens, 1990; see Dunlosky & Metcalfe, 2009 for an overview), it is surprising that so little has been done to investigate how accurate participants are in estimating whether they selected (or will select) the most effective strategy on a given item. Some data suggest that both adults and children can use better strategy judgments to change strategy while executing an already-selected strategy (e.g., Ardiale & Lemaire, 2012, 2013; Siegler & Crowley, 1994). For example, Ardiale and Lemaire asked children and adults to execute pre-selected arithmetic strategies on arithmetic problems. After participants started to execute cued strategy for 1 s. (too short to fully complete strategy execution), they were asked to judge whether the cued strategy was the better or poorer strategy for that problem. They were also given the possibility to switch strategy in case they judge the cued strategy to be the poorer strategy. Data showed that children provided better strategy judgments and switched more and more often as they grew older. Note however that one important limitation of Ardiale and Lemaire's work is that children's better strategy judgments were not based on children's strategy selection but on strategies selected by the experimenter. Unknown is how children monitor their chances of selecting the better strategy on each item and how such strategy monitoring changes with age.

In the arithmetic field, some theoretical assumptions made by computational models of strategy selection are consistent with the hypothesis that being able to introspect on how easy it would be to select the better strategy or on the level of uncertainty associated with the selected strategy increases the likelihood to be better at choosing the best strategy on each item. Generally, computational models propose that choosing among multiple strategies crucially involves associative mechanisms such as activating the relative costs/benefits of each strategy and selecting the strategy that works best for a given problem on the basis of problem and strategy characteristics (e.g., Lovett & Anderson, 1996; Siegler & Shipley, 1995; Lovett & Schunn, 1999; Neches, 1987; Rieskamp & Otto, 2006; Siegler & Araya, 2005). In addition to associative mechanisms, two of the existing computational models assume that strategy choices involve metacognitive mechanisms. Specifically, in the Lovett and Schunnös (1999) Represent, Construct, Choose, Learn model (RCCL), the metacognitive system enables participants to interrupt a strategy mid-execution if they estimate that the current strategy is not the best one or if it is inappropriate. In Siegler and Arayaös (2005) Strategy, Choice, and Discovery Simulation* (SCADS*), the metacognitive system is crucial to create or discover new strategies. In sum, models of strategies include metacognitive processes to evaluate the strategies once selected and, possibly to interrupt strategies mid-execution to switch for a better strategy (RCCL) or to create and discover new legitimate strategies (SCADS).

In this context, the second aim of the present study was to examine metacognitive sensitivity for strategy selection at different ages in two unrelated cognitive domains. Our goal was to investigate whether children are able to make accurate metacognitive