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Age-related differences in strategic monitoring during arithmetic problem solving

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ABSTRACT

We examined the role of metacognitive monitoring in strategic behavior during arithmetic problem solving, a process that is expected to shed light on age-related differences in strategy selection. Young and older adults accomplished better strategy-judgment, better strategy-selection, and strategy-execution tasks. Data showed that participants made better strategy judgments when problems were problems with homogeneous unit digits (i.e., problems with both unit digits smaller or larger than 5; 31 × 62) relative to problems with heterogeneous unit digits (i.e., problems with one unit digit smaller or larger than 5; 31 × 67) and when the better strategy was cued on rounding-up problems (e.g., 68 × 23) compared to rounding-down problems (e.g., 36 × 53). Results also indicated higher rates of better strategy judgment in young than in older adults. These aging effects differed across problem types. Older adults made more accurate judgments on rounding-up problems than on rounding-down problems when the cued strategy was rounding-up, while young adults did not show such problem-related differences. Moreover, strategy selection correlated with strategy judgment, and even more so in older adults than in young adults. To discuss the implications of these findings, we propose a theoretical framework of how strategy judgments occur in young and older adults and discuss how this framework enables to understand relationships between metacognitive monitoring and strategic behaviors when participants solve arithmetic problems.

1. Introduction

Multiple-strategy use is one of the ubiquitous features of human cognition at all ages. Indeed, several decades of research in children (see Siegler, 1996, 2007, for overviews) and during adulthood (see Lemaire, 2016, for an overview) have shown that participants use a variety of strategies to accomplish cognitive tasks. Participants' performance and age-related changes in cognitive performance depend on strategies. One important issue of research on strategies is how participants choose among strategies on a given item. The present study contributes to this issue by investigating strategic monitoring and control during arithmetic problem solving. Specifically, this study examines how participants judge whether a selected strategy for a problem is the better or the poorer strategy.

Previous empirical works on strategies showed that strategy selection and strategy execution are influenced by participants, stimulus, and situation characteristics (Siegler, 2007). These factors act individually and in interaction with each other. For example, Lemaire, Arnaud, and Lecacheur (2004) asked young and older adults to provide estimates of two-digit multiplication problems (e.g., 43 × 38) with a rounding-down strategy (doing 40 × 30 = 1200) or a rounding-up strategy (doing 50 × 40 = 2000), under different levels of speed/accuracy pressures. The authors found that older adults selected and executed the rounding-down strategy more slowly under accuracy-pressure conditions than under no-pressure conditions, especially when they solved easy problems. Young adults, however, were less influenced by the time pressure condition. Such findings show that young and older adults are differently affected by problem and task characteristics.

Computational models of strategy selection proposed several mechanisms to account for how people choose and execute strategies on each problem: Lovett and Anderson's (1996) Adaptive Control of Thought–Rational (ACT–R), Siegler and Shipley's (1995) Adaptive Strategy Choices Model (ASCM), Lovett and Schunn's (1999) Represent, Construct, Choose, Learn (RCCL) model, Neches' (1987) Heuristic Procedure Modification (HPM) model, Rieskamp and Otto's (2006) Strategy Selection Learning (SSL) model, and Siegler and Araya's (2005)

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Strategy, Choice, and Discovery Simulation* (SCADS*). All these models proposed 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. All models also assume that strategies including fewer and/or simpler procedures (e.g., retrieving the correct solution of arithmetic problems like $12 = 3 \times 4$ directly from memory) are easier to execute than strategies including more and/or more complex procedures (e.g., adding 3 four times). Finally, these models assume that based on past experience, children and adults select more and more frequently the better strategy on each problem. So, when participants have to solve a new problem, they assess problem features, they activate strategies available to solve the present problem, select the most strongly associated strategy with the problem to be solved or with a related problem, execute the selected strategy, and store strategy performance relative to the problem features. Associative mechanisms are a key component of these models and have proven sufficient to account for most findings on strategy choices and execution such as the effects of problem difficulty or strategy characteristics.

In addition to associative mechanisms, two of the existing computational models, namely Lovett and Schunn's (1999) RCCL and Siegler and Araya's (2005) SCADS*, assume that strategy choices involve metacognitive mechanisms. In RCCL, the metacognitive system enables participants to interrupt a strategy mid-execution if participants estimate that the current strategy is not the best strategy or if it is an inappropriate strategy. In SCADS*, the metacognitive system which is key to create or discover new strategies, includes the attentional spotlight (devoted to allocate attentional resources to strategy execution, especially when strategies are not automatized), strategy change heuristics (devoted to evaluating efficiency of current strategy and if a recombination of strategy components is possible to create a new, more efficient strategy), and goal-sketch filters (which ensures that the newly created strategies are valid for solving a given category of problems). In sum, models of strategies include metacognitive processes to evaluate 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*). Here, we test the possibility that metacognitive processes are also involved in strategy selection decisions.

Previous empirical works suggest a role for metacognitive processes (Ardiale & Lemaire, 2012, 2013; see also Luwel, Torbeyns, & Verschaffel, 2003) both when a strategy has been selected and is under current execution, as assumed by RCCL, and before a strategy is selected. For example, Ardiale and Lemaire (2012, 2013) asked young and older adults to estimate products of two-digit multiplication problems like 37×64. Problems were displayed with a cue indicating which of two rounding strategies to use. After executing this cued strategy for 1 s, participants could choose to change (or not) strategy if they judged that the cued strategy was not the best strategy for this item (i.e., the strategy that yields the closest estimate to correct product). The authors found that both young and older adults were able to interrupt execution of strategy and switch strategy when the cued strategy was not the best one. Such results suggest that participants are able both to assess current strategic operations to judge whether the selected strategy is the best (meta-strategic monitoring) and to use the outputs of this assessment to regulate their strategic behaviors (meta-strategic control). However, unknown is how young and older adults performed these better strategy judgments, an issue that we pursued in the present experiment. Ardiale and Lemaire (2012, 2013) also found that older adults revised initial strategy selections less often than young adults. Unknown is whether age-related changes in meta-strategic monitoring processes (accomplishing better strategy judgment) or in executive control processes (responsible for switching strategies) are responsible for older adults' being less able to revise initial strategy selections once engaged in strategy execution.

In the metacognitive literature (see Hertzog, 2015; Castel, Middlebrooks, & McGillivray, 2015, for reviews), results on aging effects are conflicting. Some findings suggest that older adults may suffer from metacognitive monitoring impairments; namely, they are less able than young adults to evaluate their own cognitive performance (e.g., Jacoby & Rhodes, 2006). In contrast, other studies do not show any age-related differences in metacognitive monitoring processes (e.g., Price & Murray, 2012). However, even when monitoring processes are spared, studies indicate that their outputs are not necessarily used by older adults to regulate or control their performance (e.g., Hertzog & Hultsch, 2000). For instance, Souchay and Isingrini (2004) found that older adults did not allocate their study time as efficiently as young adults during a self-paced learning task. As most previous studies on aging and metacognition have been carried out in the memory domain, unknown are whether strategic monitoring and control change with age while young and older adults accomplish problem solving tasks. We address this issue in the context of arithmetic problem solving tasks.

1.1. Overview of the present study

As a first step to examine the role of metacognitive processes in strategic behaviors during arithmetic problem solving, we asked young and older participants to accomplish a better strategy judgment task. On each trial, participants were given arithmetic problems and a strategy. They had to decide as quickly as possible if the cued strategy was the better or the poorer of two available strategies (i.e., which strategy yielded the answer that was the closest to the correct product) for each problem. These strategies consist in rounding both operands up or rounding both operands down to their closest decades. Asking participants to choose among a pre-defined set of strategies enables to reduce the variability due to the fact that some people know more strategies than others. Also, previous works have shown that when participants are left free to choose whichever strategies they want to accomplish these tasks, they do use the above mentioned strategies spontaneously. Designs restricting the number of available strategies to choose among do not yield different findings regarding age-related changes in rates of better strategy selection and in strategy performance (e.g., LeFevre, Greenham, & Waheed, 1993; Lemaire, Lecacheur, & Farioli, 2000). Our hypothesis is that to be able to make accurate strategy selection judgments on each problem, participants will have to detect and weigh information enabling them to evaluate which strategy is the better strategy to solve the problem (meta-strategic monitoring), then to decide whether the cued strategy is actually the better (meta-strategic control).

Two types of information can possibly be used by participants to make accurate strategy selection judgments. Indeed, participants (a) select a strategy based on the problem characteristics without considering the cued strategy and/or (b) execute the cued strategy to see whether it was truly the better strategy to provide the closest estimate of the correct product. In this context, to understand processes underlying better strategy judgment in young and older adults, we gave participants a better strategy selection task (i.e., participants were given arithmetic problems and had to select the better strategy among two available strategies) and a strategy execution task (participants were given arithmetic problems and a cue strategy that they had to execute). As these three tasks were given to the same individuals on the same problems, we were able to test whether participants' better strategy judgments were related to strategy selection and strategy execution. If participants try to select a strategy based on problems' characteristics and use the result of this selection when making their strategy judgments, we expect to find a positive relation between strategy judgment and strategy selection performance. However, if participants execute the cued strategy and use the result of this strategy execution as a cue to guide their strategy judgments, we expect to find a positive relation between strategy judgment and strategy execution performance.