Aging and List–Wide Modulations of Strategy Execution: A Study in Arithmetic

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Aging and List-Wide Modulations of Strategy Execution: A Study in Arithmetic

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ABSTRACT

Background/Study Context: This study aimed at further our understanding of the cognitive processes involved during strategy execution, and how the processes involved change with age. More specifically, the main goal was to investigate whether poorer-strategy effects (i.e., poorer performance when a cued strategy is not the best) and sequential modulations of poorer-strategy effects (i.e., decreased poorer-strategy effects on current problems following poorer-strategy problems compared with after better-strategy problems) are influenced by proportions of poorer-strategy problems.

Methods: We used a computational estimation task (i.e., providing approximate products to two-digit multiplication problems such as 38 × 74) with problems sets including 75%, 50%, or 25% of poorer-strategy problems (i.e., participants have to estimate products with another strategy than the better strategy). The remaining problems were cued with the better strategy. Age-related differences were also investigated.

Results: We found that proportions of poorer-strategy problems influenced sequential modulations of poorer-strategy effects. Indeed, sequential modulations of poorer-strategy effects were larger when proportions of poorer-strategy problems were equal than unequal. Moreover, proportion effects were different for young and older adults, as older adults benefited more from low proportions of poorer-strategy problems compared with young adults.

Conclusion: These findings have important implications regarding cognitive control mechanisms underlying both list-wide and trial-to-trial modulations of strategy execution, and how these processes change during aging.

Several decades of research have established that we use a wide variety of strategies to accomplish cognitive tasks and that cognitive performance depends on these strategies (Siegler, 2007). A strategy can be defined as “a procedure or a set of procedures for achieving a higher level goal or task” (Lemaire & Reder, 1999, p. 365). One important issue is what factors influence execution of a given strategy once it is selected to solve a given problem. Previous research revealed that strategy execution is influenced by characteristics of problems (e.g., problem size, odd/even status of numbers; e.g., Allen et al., 2005; Ashcraft & Battaglia, 1978), strategies (e.g., harder/easier strategies; e.g., Siegler & Lemaire, 1997), situations (e.g., presentation format, memory load, speed/accuracy...
emphasis; e.g., Campbell & Austin, 2002; Trbovich & LeFèvre, 2003), and participants (e.g., age, expertise, culture; e.g., Allen, Ashcraft, & Weber, 1992; Campbell & Xue, 2001; Geary et al., 1991; Lemaire, Arnaud, & Lecacheur, 2004). Strategic processing has been found to change with aging during adulthood (see Lemaire, 2010, 2016; Uittenhove & Lemaire, 2015). Indeed, older adults use fewer strategies, use available strategies in different proportions, and select and execute these strategies less efficiently than young adults. However, several issues regarding strategic processing remain unaddressed. For example, what cognitive processes are involved during strategy execution? Is strategy execution modulated by context? Does aging affect contextual processing during strategy execution? Of particular interest in the present study, it is unknown whether strategy execution on a given problem can be influenced by context effects, such as the statistical structure of problems sets.

In this study, we aimed at investigating whether context influences poorer-strategy effects, and aging effects therein. Poorer-strategy effects refer to poorer performance when a cued strategy is not the best, and they are larger in older than in young adults (e.g., Ardiale & Lemaire, 2012; Geary & Brown, 1991; Hinault, Dufau, & Lemaire, 2014; Lemaire et al., 2004; Lemaire & Hinault, 2014; Lemaire & Leclère, 2014; Uittenhove & Lemaire, 2012). For example, Lemaire and Hinault (2014) used a computational estimation task in which participants had to estimate products of two-digit multiplication problems (e.g., $36 \times 72$) with rounding down-up or rounding up-down strategies. In the rounding down-up strategy, participants had to round the first operand down to the nearest decade and the second operand up to the nearest decade (e.g., doing $30 \times 80 = 2400$ to estimate $36 \times 72$). Participants had to do the opposite in the rounding up-down strategy (e.g., doing $40 \times 70 = 2800$ to estimate $36 \times 72$). Depending upon the size of unit digits, the cued strategy can be the better strategy (i.e., it yields the closest estimate to the product) or the poorer strategy. Thus, the rounding down-up is the better strategy when unit digit of the first operand is smaller than 5 and that of the second operand larger than 5 (e.g., $32 \times 76$). The opposite is true for rounding up-down strategy (e.g., $36 \times 72$). Lemaire and Hinault (2014) found that participants had longer latencies and made more mistakes when the cued strategy was the poorer strategy compared with when it was the better strategy. Such poorer-strategy effects were explained by assuming that participants need to inhibit the tendency to use the better strategy to execute the required, poorer strategy on poorer-strategy problems. These inhibitory processes are not needed when the better strategy is cued, resulting in shorter latencies and fewer errors. Moreover, Lemaire and Hinault found age-related differences with increased poorer-strategy effects in older adults than in young adults. Results are consistent with declined inhibitory processes with aging (Hasher & Zacks, 1988; see Craik & Salthouse, 2007, and Salthouse, 2010, for reviews), the better strategy being less efficiently inhibited by older adults than by young adults when the poorer strategy was cued and executed.

Lemaire and Hinault (2014) also found that poorer-strategy effects on a given problem were modulated by the strategy executed on the immediately preceding problem (see also Hinault et al., 2014). Sequential modulations of poorer-strategy effects refer to reduced poorer-strategy effects following poorer-strategy problems compared with after better-strategy problems. Such findings were interpreted as resulting from the need for higher level of control to execute the cued poorer strategy on current poorer-strategy problems. This higher control is then maintained from one trial to the next, leading to a more efficient conflict resolution, and decreased poorer-strategy effects on the next problems.
contrast, control is lower (or not even involved) when immediately preceding problems were solved with the better strategy, because preparatory mechanisms were not engaged. This results in increased poorer-strategy effects on the next problems. With aging, reduced sequential modulations of poorer-strategy effects have been observed. As a poorer strategy is harder than a better strategy, with fewer resources, older adults did not have enough resources left free to prepare themselves on subsequent problems.

Poorer-strategy effects, and sequential modulations of strategy execution, and aging effects therein, have important theoretical implications. Indeed, computational models of strategies (e.g., Lovett & Anderson, 1996; Lovett & Schunn, 1999; Payne, Bettman, & Johnson, 1993; Rieskamp & Otto, 2006; Siegler & Arraya, 2005) share two main core assumptions. These assume that strategies are selected and executed on a problem-by-problem basis and that relative strategy efficiency is the result of the number/type of procedures involved in each strategy. In contrast, sequential modulations of poorer-strategy effects, as well as other sequential modulations (e.g., Ardiale & Lemaire, 2012; Lemaire & Leclère, 2014; Uittenhove, Burger, Taconnat, & Lemaire, 2015; Uittenhove & Lemaire, 2012), suggest that strategy selection and execution on a given problem are not independent of the strategies previously selected and executed and that strategy efficiency is not only the result of strategy complexity.

The present study aimed at investigating if larger-scale, whole-task context could also influence strategy execution in general, and cognitive control during strategy execution in particular. Sequential modulations of poorer-strategy effects were assumed to involve cognitive control mechanisms, similar to those observed in conflict tasks (i.e., Stroop, Simon, and flanker tasks). In conflict tasks, congruency effects refer to longer latencies and larger percentages of errors for incongruent compared with congruent items. Congruency effects are influenced by congruency of immediately preceding items, being smaller after incongruent items than following congruent items (i.e., congruency sequence effects; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Gratton, Coles, & Donchin, 1992; Kerns, 2004; Kunde & Wühr, 2006; Riggio, Gherri, & Lupiáñez, 2012; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; see Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014, for a review).

In addition, congruency effects have also been shown to be influenced by the whole-task context. Indeed, in conflict tasks, proportion congruency effects refer to reduced congruency effects in mostly incongruent tasks (e.g., 75% of the trials are incongruent trials, 25% are congruent trials) and increased effects in mostly congruent tasks (e.g., 25% of the trials are incongruent trials, 75% are congruent trials) (Carter et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; Logan, Zbrodoff, & Williamson, 1984; West & Baylis, 1998; see Bugg & Crump, 2012, for a review). These effects were interpreted as frequent conflict processing in mostly incongruent tasks leading to the recruitment of additional executive resources to more efficiently monitor conflict. Indeed, more frequent incongruent trials increase the frequency of conflict processing in mostly incongruent tasks. This led participants to better anticipate and to prepare proactively to process incongruent trials. Conversely, in mostly congruent tasks, conflict is less frequent and inhibitory processes are less prepared, which makes conflict monitoring less efficient to process incongruent trials. With aging, congruency effects in mostly incongruent lists are increased relative to young adults, in line with less efficient inhibitory processes (Bélanger, Belleville, & Gauthier, 2010).
The main goal of this study was to test if poorer-strategy effects and sequential modulations of poorer-strategy effects can be influenced by list-wide proportions of poorer-strategy problems. To achieve this end, we used the same type of computational estimation task as Lemaire and Hinault (2014). In addition to the equal-proportion condition, we used two conditions in which proportions of poorer-strategy problems were high (75% of problems) or low (25% of problems), relative to better-strategy problems. So far, no studies have been conducted to determine if strategy execution could also be influenced by list-wide proportions of problems, above and beyond trial-to-trial influences. Indeed, we do not know if participants are equally, more, or less efficient at executing a cued poorer strategy when the task includes more or fewer poorer-strategy problems. Results were expected to document if adjustments of control processes during strategy execution can occur at the whole-task level, in addition to trial-to-trial adjustments, and aging effects therein.

Following previous studies on congruency effects showing that inhibitory processes are less efficient when conflict is not frequent (e.g., Bugg & Chanani, 2011), poorer-strategy effects were expected to increase when the task includes fewer poorer-strategy problems. Also, poorer-strategy effects were expected to decrease when proportions of poorer-strategy problems are high. Alternatively, given that computational estimation tasks are more demanding and involve more processes than conflict tasks, it is possible that there are not enough resources to implement efficient adjustments of control processes when proportions of poorer-strategy problems are high. Following previous results of increased congruency effects in mostly incongruent task in older adults compared with young adults (Bélanger et al., 2010), we also expected larger influence on poorer-strategy effects in older adults than in young adults when proportions of poorer-strategy problems are high.

The final original goal of this study was to test if sequential modulations of poorer-strategy effects could also be influenced by list-wide proportions of poorer-strategy problems. Indeed, although list-wide and trial-to-trial adjustments of cognitive control processes had not previously been studied together, trial-to-trial adjustments were also expected to vary with proportions of poorer-strategy problems. We expected sequential modulations of poorer-strategy effects to differ as a function of proportions of poorer-strategy problems. Sequential modulations of poorer-strategy effects were expected to be more efficient when control mechanisms are more activated, as in high proportions of poorer-strategy problems. Indeed, frequent conflict was expected to yield higher expectation of upcoming poorer-strategy problems, leading to better preparation from one trial to the next compared with when conflict is less frequent. Alternatively, given that computational estimation tasks are more resource-demanding and involve several processes compared with conflict tasks, high proportions of poorer-strategy problems can be too demanding, preventing participants to engage efficient preparation. We also expected to observe aging effects, with more efficient sequential modulations in older adults in less demanding, lower proportions of poorer-strategy problems. With fewer resources, it is possible that efficient sequential modulations of poorer-strategy effects can be observed in less demanding conditions, because executive resources are more available. Alternatively, high-functioning older adults could be as able as young adults to successfully implement sequential modulations of poorer-strategy effects when conflict is frequent.
Methods

Participants

A total of 150 participants were volunteers to take this experiment. All participants gave their informed consent prior to their inclusion in the study. They were divided into two groups: 75 young adults and 75 older adults (see participants’ characteristics in Table 1). All reported normal or corrected-to-normal vision. Participants were not informed on the purpose of the experiment.

Stimuli

Participants had to solve 128 two-digit multiplication problems (e.g., 48 × 72). Half the problems were rounding up-down problems and half rounding down-up problems. The unit digit of the first operand was smaller than 5 and that of the second operand larger than 5 in the rounding down-up problems (e.g., 54 × 36). The reverse was true for the rounding up-down problems (e.g., 46 × 72). There were two types of problems, better-strategy and poorer-strategy problems. The better strategy was cued on better-strategy problems such that half the rounding down-up problems were cued with the rounding down-up strategy and half rounding up-down problems were cued with the rounding up-down strategy. The poorer strategy was cued on poorer-strategy problems such that half the rounding down-up problems were cued with the rounding up-down strategy and half the rounding up-down problems were cued with the rounding down-up strategy. Poorer-strategy and better-strategy items were matched on correct products (2688 vs. 2609, respectively; F < 1) and mean percent deviations between correct products and estimates (10% vs. 7.3%; F < 1).

To study sequential modulations of poorer-strategy effects, four types of trials were tested (Table 2): better-better trials (i.e., both current and previous problems were solved with the better strategy), better-poorer trials (i.e., current problems were solved with the poorer strategy and previous problems with the better strategy), poorer-better trials (i.e., current problems were solved with the better strategy and previous problems with the poorer strategy), and poorer-poorer trials (i.e., both current and previous

Table 1. Participants’ characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Young adults</th>
<th>Older adults</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>75</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Age in years and months</td>
<td>21.7 (2.8)</td>
<td>73 (7.1)</td>
<td></td>
</tr>
<tr>
<td>Years of education</td>
<td>14.2 (1.4)</td>
<td>10.6 (2.5)</td>
<td>40.9***</td>
</tr>
<tr>
<td>MHVS</td>
<td>22 (3.7)</td>
<td>25 (4.4)</td>
<td>26.8***</td>
</tr>
<tr>
<td>Arithmetic fluency</td>
<td>40.4 (15.1)</td>
<td>61 (24)</td>
<td>39.1***</td>
</tr>
<tr>
<td>MMSE</td>
<td>—</td>
<td>28.8 (1.2)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Data inside parentheses are SEM. MHVS = French version of the Mill-Hill Vocabulary Scale (Deltour, 1993). MHVS consists of 33 items distributed across three pages. Each item was a target word followed by six proposed words, and the task consisted in identifying which of the proposed word had the same meaning as the target word. Arithmetic fluency = score obtained in a paper-and-pencil arithmetic test (French Kit; French, Ekstrom, & Price, 1963) in which participants have to solve as many basic arithmetic problems (e.g., 53 – 18) as possible in 8 min. MMSE = Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). None of the older adults obtain an MMSE score lower than 27; therefore, none were excluded. Participants took the MHVS and then the arithmetic fluency tests after the computational estimation task.

*p < .05; **p < .01; ***p < .001. Subgroups were controlled to not differ in MHVS or arithmetic fluency.
problems were solved with the poorer strategy). Poorer-strategy effects following better-strategy problems were calculated by subtracting latencies on better-better trials from latencies on better-poorer trials. Poorer-strategy effects following poorer-strategy problems were calculated by subtracting latencies of poorer-better trials from latencies on poorer-poorer trials. Sequential modulations of poorer-strategy effects were calculated by subtracting poorer-strategy effects following poorer-strategy problems from poorer-strategy effects following better-strategy problems. Indeed, efficient sequential modulations of strategy execution are defined as smaller interference (i.e., reduced poorer-strategy effects) after execution of the poorer relative to after the better strategy. As an example, if one participant has poorer-strategy effects of 400 ms following the better strategy, and of 150 ms after execution of the poorer strategy, then sequential modulations of poorer-strategy effects are equal to 250 ms. This means that interference (i.e., poorer-strategy effects) on the second problem of a trial decreases by 250 ms when participants executed the poorer strategy on the first problem compared with after the better strategy.

There were three conditions of proportions of poorer-strategy problems. In the equal-proportion condition, participants saw an equal number of each type of trials. Thus, in this condition, participants saw 32 better-better, 32 better-poorer, 32 poorer-better, 32 poorer-poorer trials. In the high-proportion condition, 75% of problems were cued with the poorer strategy and 25% of problems were cued with the better strategy. This resulted in 80 poorer-poorer trials, 16 better-better trials, 16 better-poorer trials, and 16 poorer-better trials. In the low-proportion condition, 25% of problems were cued with the poorer strategy and 75% of problems were cued with the better strategy, resulting in 80 better-better trials, 16 better-poorer trials, 16 poorer-better trials, and 16 poorer-poorer trials. Participants were randomly assigned to one of the three groups.

Following previous findings in arithmetic (see Geary, 1994, and Campbell, 2005, for reviews), we controlled the following factors while selecting problems: (a) no operands had a 0-unit digit; (b) no operands had a 5-unit digit; (c) no digits were repeated within operands; (d) no reverse orders of operands were used; (e) the first operand was larger than the second in half the problems, and vice versa; (f) no operand had its closest decade equal to 0, 10, or 100; and (g) differences between correct products and estimates were matched across strategies (i.e., mean percent deviations were equal when participants used the rounding down-up or the rounding up-down strategy on all problems).

<table>
<thead>
<tr>
<th>Problem in a trial</th>
<th>Type of trials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Better-better</td>
</tr>
<tr>
<td>First problem</td>
<td>34 × 68 (DU)</td>
</tr>
<tr>
<td>Second problem</td>
<td>67 × 82 (UD)</td>
</tr>
</tbody>
</table>

Note. The effects refer to reduced differences between current better- and poorer-strategy problems when previous problems were solved with the poorer strategy, relative to after the better strategy. Conditions differ on the bases of the cued strategy on the current and previous trials. DU refers to the rounding down-up strategy, whereas UD refers to the rounding up-down strategy.
Procedure

Participants were individually tested in one session that lasted approximately 60 min. Stimuli were presented on a 800 × 600 resolution screen in a 48-point bold courier font (black color) in the center of a 15.4-inch computer screen controlled by a DELL Latitude 120 computer. When presented with the multiplication problems, participants had to estimate the products as fast and as accurately as possible using the cued strategy. Only the two mixed-rounding strategies were allowed, and participants were explained these strategies. Rounding down-up was described as rounding the first operand down to the nearest decade and the second up to the nearest decade, for instance, doing 40 × 70 to estimate 43 × 68. Rounding up-down was explained as rounding the first operand up to the nearest decade and the second operand down to nearest decade, for instance, doing 40 × 60 to estimate 38 × 64. Instructions were given verbally. After an initial practice period including 10 problems (five with each strategy), participants practiced the experimental task on nine problems. The experiment included two blocks of 43 problems and one block of 42 problems. Participants had 5-min breaks in-between each block.

Results

Latencies larger than the mean of the condition + 2 standard deviations (i.e., 4.2% and 3.5% in young and older adults, respectively) were removed as well as latencies for erroneously solved problems. Furthermore, the first problem after each error was excluded from data analyses. Mean solution times, percentages of errors in strategy selection, and percentages of errors in strategy execution were analyzed using 2 (age: young adults, older adults) × 3 (proportions of poorer-strategy problems: equal, low, high) × 2 (strategy on the previous problem: poorer, better) × 2 (strategy on the current problem: poorer, better) mixed-design analyses of variance (ANOVAs), with age and proportions as between-participants factors (see means in Table 3). Analyses were rerun with arithmetic fluency as a covariate in ANOVAs, but the same results were found.

Older adults were slower than young adults (6421 vs. 5688 ms, respectively), \( F(1, 144) = 9.02, \text{MSE} = 559877.81, \eta^2_p = .06 \). Overall, participants were faster after poorer-strategy problems compared with following better-strategy problems (6014 vs. 6094 ms, respectively), \( F(1, 144) = 5.12, \text{MSE} = 6546.63, \eta^2_p = .03 \). Furthermore, overall, participants were 187 ms faster on current problems when solved with the better strategy compared with when solved with the poorer strategy, \( F(1, 144) = 23.41, \text{MSE} = 36560.16, \eta^2_p = .14 \). These poorer-strategy effects were larger in older adults (269 ms) than in young adults (106 ms), as shown by the significant Age × Strategy on the Current Problem interaction, \( F(1, 144) = 4.42, \text{MSE} = 6902.32, \eta^2_p = .03 \). Most importantly, the Proportions × Strategy on the Previous Problem × Strategy on the Current Problem (\( F(2, 144) = 16.85, \text{MSE} = 21908.00, \eta^2_p = .19 \)) and the Age × Proportions × Strategy on the Previous Problem × Strategy on the Current Problem (\( F(2, 144) = 5.33, \text{MSE} = 6932.47, \eta^2_p = .07 \)) interactions were significant. Furthermore, additional analyses revealed that the Age × Strategy on the Previous Problem × Strategy on the Current Problem interaction was significant in both equal (\( F(1, 48) = 5.75, \text{MSE} = 4903.38, \eta^2_p = .11 \)) and low (\( F(1, 48) = 5.62, \text{MSE} = 15723.17, \eta^2_p = .11 \)) proportions of poorer-strategy problems, but not in high-proportion condition (\( F < 3 \)). Separate analyses were conducted to study sequential
modulations of poorer-strategy effects in young and older adults. As can be seen in Figure 1, magnitudes of sequential modulations of poorer-strategy effects varied with proportions of poorer-strategy problems, and these effects differed between young adults and older adults.

In young adults, sequential modulations of poorer-strategy effects were found in equal-proportion condition, as participants’ poorer-strategy effects on current problems decreased following poorer-strategy problems relative to after the execution of the better strategy. Indeed, poorer-strategy effects were significant only after better-strategy problems (203 ms; $F(1, 24) = 17.92$, $MSE = 47.88$, $\eta^2_p = .43$) and not significant following poorer-strategy problems (−125 ms; $F < 2.5$). In low-proportion condition, no significant sequential modulations of poorer-strategy effects were found (−139 ms). Poorer-strategy effects were not found after better-strategy problems (68 ms; $Fs < 1$) but were marginally significant after poorer-strategy problems (207 ms; $F(1, 24) = 4.20$, $p = .05$, $MSE = 101.06$, $\eta^2_p = .15$). In high-proportion condition, poorer-strategy effects were significant after poorer-strategy problems (450 ms; $F(1, 24) = 16.83$, $MSE = 109.62$, $\eta^2_p = .41$), but not
significant after better-strategy problems (−165 ms; $F < 1.5$), indicating significant reversed sequential modulations of poorer-strategy effects (−615 ms).

In contrast to young adults, in equal-proportion condition, no sequential modulations of poorer-strategy effects were found in older adults (54 ms; $F < 1$). Most importantly, older adults showed sequential modulations of poorer-strategy effects in low-proportion condition (361 ms), with significant poorer-strategy effects only after better-strategy problems (527 ms; $F(1, 24) = 13.10$, $MSE = 145.64$, $\eta^2_p = .35$) and not after poorer-strategy problems (176 ms; $F < 2.5$). Moreover, like in young adults, reversed sequential modulations of poorer-strategy effects were found in high-proportion condition (−309 ms), poorer-strategy effects being significant only after poorer-strategy problems (275 ms; $F(1, 24) = 5.82$, $MSE = 144.05$, $\eta^2_p = .20$) and not significant after better-strategy problems (−34 ms; $F < 1$).

Analyses of errors in strategy selection revealed that participants selected the wrong strategy more often when executing the poorer compared with the better strategy (5.5% vs. 4.0%; $F(1, 144) = 16.27$, $MSE = 2.57$, $\eta^2_p = .10$). Analyses of errors in strategy execution revealed that participants made more mistakes in equal-proportion condition compared with low- or high-proportion condition (4.9% vs. 4.1% and 2.9%, respectively; $F(2, 144) = 3.20$, $MSE = 2.79$, $\eta^2_p = .04$). Moreover, error rates were larger when previous problems were solved with the poorer-strategy compared with following better-strategy problems (4.4% vs. 3.5%; $F(1, 144) = 8.93$, $MSE = .76$, $\eta^2_p = .06$). Most importantly, the Proportions × Strategy on the Previous Problem × Strategy on the Current Problem interaction was significant, $F(2, 144) = 6.37$, $MSE = 1.33$, $\eta^2_p = .08$. Contrasts revealed that sequential modulations were only present in low-proportion condition ($F(1, 49) = 8.29$, $MSE = 3.45$, $\eta^2_p = .15$), with poorer-strategy effects significant when previous problems were solved with the better strategy ($F(1, 49) = 7.66$, $MSE = .70$, $\eta^2_p = .15$) and nonsignificant after poorer-strategy problems ($F < 3$).
Discussion

The aim of the present study was to further our understanding of (a) the cognitive processes involved during strategy execution; (b) how strategy execution is modulated by statistical structure of stimuli (i.e., proportions of different types of problems); and (c) how the processes involved change with age. More specifically, this study aimed at determining whether poorer-strategy effects and sequential modulations of poorer-strategy effects are influenced by proportion effects, and how aging modulates these proportion effects. First, proportion effects were not found on overall poorer-strategy effects. Given that having to process many poorer-strategy problems is very resource-demanding, it could prevent people from implementing higher-level control like in conflict task. Indeed, computational estimation tasks are more resource-demanding than conflict tasks, involving multistep processing and resulting in longer latencies. We can also hypothesize that modulations of poorer-strategy effects as a function of the immediately executed strategy interfered with overall proportion effects on current problems. Indeed, the present findings showed that sequential modulations of poorer-strategy effects were influenced by proportion effects. We also found age-related differences in these proportion effects. In sum, these findings (a) newly reveal that strategy execution on current problems is not only influenced by the strategies executed on previous problems but also during the entire task and (b) have important implications for better understanding how control processes influence strategy execution, and how such influence change with aging.

The most crucial and original findings in this study concerns how proportion effects on sequential modulations of poorer-strategy effects differed in young adults and older adults. In young adults, our results in the equal-proportion condition replicate results found in previous studies (Hinault et al., 2014; Lemaire & Hinault, 2014). Sequential modulations of poorer-strategy effects were interpreted as reflecting increased level of control and preparation to conflict processing after executing a poorer strategy on current problems, thus yielding more efficient strategy execution on the next problems relative to when a better strategy has just been executed. Interestingly, we found reversed sequential modulations of poorer-strategy effects in high proportions of poorer-strategy problems. This pattern can be interpreted as reflecting strategy sequential difficulty effects (i.e., better performance on a given problem after executing an easier strategy on the immediately preceding problem compared with following a harder strategy; Schneider & Anderson, 2010; Uittenhove & Lemaire, 2012, 2013a, 2013b). Indeed, as harder poorer-strategy problems are more frequent, participants may not have enough resources to efficiently prepare themselves to monitor conflict from one problem to the next. The present results suggest that cognitive control processes are influenced by task context, being less efficient when proportions of poorer-strategy problems were higher than proportions of better-strategy problems. Thus, sequential modulations of poorer-strategy effects is reversed when conflict is too frequent.

Also, young adults did not show sequential modulations of poorer-strategy effects in low proportions of poorer-strategy problems. The present results led to the hypothesis that sequential modulations of control processes are not triggered if conflict is not frequent enough. These findings are in favor of a specific level of conflict necessary for the involvement of sequential modulations. When proportions of poorer-strategy problems are low, it is possible that activations do not exceed threshold to engage control processes.
leading to an absence of sequential modulations of poorer-strategy effects. Moreover, poorer-strategy effects were marginally more important after poorer-strategy problems compared with after better-strategy problems, consistent with no preparation from one trial to the next. Regarding previous findings in conflict tasks (see Bugg & Crump, 2012, for a review), these results revealed that proportion effects influence not only cognitive control processes on a given problem but also trial-to-trial adjustments of cognitive control processes.

Regarding older adults, in equal-proportion condition, poorer-strategy effects were not influenced by the execution of better or poorer strategy on the immediately preceding problem. This finding is consistent with that overall older adults reduced sequential modulations of strategy execution compared with young adults, as observed in Lemaire and Hinault (2014), and reduction of inhibition efficiency in conflict tasks (Bélanger et al., 2010). When proportions of poorer-strategy problems were high, older adults showed reversed sequential modulations of poorer-strategy effects and did not differ from young adults. We can consider that the same interpretation as for young adults apply for older adults.

Most importantly, and unlike young adults, sequential modulations of poorer-strategy effects were found when proportions of poorer-strategy problems were the lowest. We can hypothesize that sequential modulations of control processes are still efficient in older adults but are implemented only if cognitive demand does not exceed executive resources capacity, as in equal- or high-proportion conditions. Low proportions of poorer-strategy problems seem to leave enough executive resources available to allow efficient trail-to-trial preparation. Lower proportions of poorer-strategy problems could also make interference more salient, thus improving older adults’ propensity to prepare themselves from one trial to the next. This resulted in efficient reduction of poorer-strategy effects following poorer-strategy problems compared with after better-strategy problems.

The present study is, to our knowledge, the first to show list-wide adjustments of control processes during strategy execution. Thus, strategy execution is influenced by control processes, not only as a function of the strategy executed on the previous problems but also by list-wide proportions of problems cued with a poorer strategy. One major assumption of strategy models (Lovett & Anderson, 1996; Lovett & Schunn, 1999; Payne et al., 1993; Rieskamp & Otto, 2006; Siegler & Arraya, 2005) is that strategy selection and execution operate on each problems independently. In contrast, these findings revealed that strategy execution is modulated from trial to trial by cognitive control processes and that these processes are influenced by the context in which participants select and execute strategies. Results also revealed that list-wide adjustments on these control processes influence age-related differences in strategy performance. Models should include assumptions about how trial-to-trial and list-wide adjustments of cognitive control processes influence strategy execution to explain these findings.

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