Aging and strategy switch costs: A study in arithmetic problem solving

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ABSTRACT
The present experiment investigated age-related differences in strategy switch costs when participants have to switch (or repeat) between two versus three strategies across consecutive problems. Young and older adults had to solve two-digit addition problems (e.g., 47 + 84). On each problem, the strategy to be used was cued. Participants were cued to switch or repeat strategy from one trial to the next on half the trials. The data showed strategy switch costs (i.e., participants’ performance was poorer when they switched between strategies relative to when they repeated a strategy). Furthermore, there were no age differences in magnitudes of strategy-switch costs when switching between two strategies, in contrast to increased switch costs with age when participants switched between three strategies. Increased strategy switch costs with age and number of strategies may result from variations in executive control during strategy execution and may be crucial in a number of strategic variations during cognitive aging.

Vieillissement et coûts de changement stratégique : une étude en résolution de problèmes arithmétiques

RÉSUMÉ
Dans cette expérience, nous avons étudié les différences liées à l’âge dans les coûts de changements stratégiques lorsque les participants devaient changer (ou répéter) de stratégie. Nous avons manipulé le nombre de stratégies disponibles (c’est-à-dire, deux vs. trois stratégies). Des groupes d’adultes jeunes et âgés devaient résoudre des additions à deux chiffres (par ex., 47 + 84). Pour chaque problème, la stratégie à exécuter était indiquée. Les participants devaient changer ou répéter la stratégie d’un essai à l’autre pour la moitié des essais. Les données ont montré que les coûts de changement stratégique (c’est-à-dire, les participants étaient moins performants lorsqu’ils changeaient de stratégie que lorsqu’ils répétaient une stratégie) étaient plus élevés dans la condition deux que dans la condition

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Arithmetic problem solving is of particular interest because the effects of aging on number processing differ from other findings about cognitive aging in general. In most of arithmetic tasks, age-related differences increased with problem complexity (see Duverne & Lemaire, 2005, for an overview). When solving simple arithmetic problems (e.g., 8 - 4 = ?) older adults were as good as, or even better, than younger adults, as older adults may compensate aging effect by experience or initial formal training (Geary, Frensch, & Wiley, 1993; Geary & Wiley, 1991). However, in more complex arithmetic tasks (e.g., verifying equations such as 5 + 3 - 1 + 4 - 1 = 6 or 72 - 9 = 63), younger adults outperformed older adults (Salthouse & Coon, 1994). One possible explanation was that young and older adults used different strategies.

In the last 25 years, a number of studies have shown that young and older adults use several strategies to accomplish cognitive tasks in a wide variety of cognitive domains like problem solving, reasoning, language, decision making, or memory (see, Lemaire, 2010 for a review). These studies also showed that young and older adults differ in strategy repertoire (i.e., which strategies and the number of strategies used), strategy distribution (i.e., the frequency of use of each listed strategy), strategy selection (i.e., the choice of one strategy among available strategies), and strategy execution (i.e., the speed and accuracy of each strategy). For example, older adults are less skilled at selecting the best strategy (i.e., the strategy that yields the most accurate estimate) on each problem than young adults. One plausible assumption for strategic variations with age may be the difficulty in older adults to disengage from the strategy previously chosen and executed to activate, select and execute another strategy, probably better than the previous strategy. The goal of this study was to determine whether young and older adults differ in another strategy dimension, namely strategy switching. Strategy switching refers to the skills...
of switching strategy from one item to the next when it is appropriate to use two different strategies on two consecutive trials. As older adults may have difficulties to disengage from the executed strategy and flexibly alternate between strategies, the present study tested whether switching strategies incurs larger strategy switch costs in older than in younger adults.

Following task switching paradigm, previous studies in strategy-switch costs (Lemaire & Lecacheur, 2010; Luwel et al., 2009; Schillemans et al., 2009) found that young adults had better performance when they repeat the same strategy than when they switch from a strategy to another on two consecutive trials. In task-switching as in strategy-switching experiments, participants were presented two (or more) tasks/strategies, each one associated with a specific cue. A stimulus appeared preceded by or simultaneously with the cue which indicates the task/strategy to perform on each trial. On two consecutive trials, participants could either repeat the same task/strategy or switch tasks/strategies. Usually, participants’ performance is better when they repeat the same task than when they accomplish different tasks (see Meiran, 2010; Vandierendonck et al., 2010, for recent reviews), or when they repeat the same strategy than when they perform different strategies on consecutive trials (Lemaire & Lecacheur, 2010; Luwel, Schillemans, Onghena, & Verschaffel, 2009; Schillemans, Luwel, Bulté, Onghena, & Verschaffel, 2009). For example, Lemaire and Lecacheur (2010) asked young adults to accomplish computational estimation tasks (i.e., providing approximate products to two-digit multiplication problems such as $46 \times 74$). On each trial, participants were cued to perform a given rounding strategy (e.g., doing $40 \times 70$ vs. doing $50 \times 80$ to estimate $46 \times 73$). Participants were faster when they were asked to repeat the same strategy across two consecutive trials as compared to when they had to use two different strategies.

As strategy-switch costs bear some similarities with task switch costs (e.g., both types of switch costs consist in better performance on repeated-trials than on unrepeated-trials), Lemaire and Lecacheur (2010) proposed that strategy switch costs may result from the contribution of two sets of processes: priming (e.g., Allport & Wylie, 2000) and strategy set reconfiguration processes (Meiran, 2010; Vandierendonck et al., 2010). When a strategy has just been used, the procedures for this strategy are still activated and available. These strategy procedures are consequently retrieved and executed more quickly in the repeated-strategy than in unrepeated-strategy condition. Such strategy priming processes would lead participants to be faster in the repeated-strategy condition. Moreover, strategy-set reconfiguration processes may also contribute to strategy-switch costs. Once participants have executed a given strategy,
the cognitive system must be reconfigured to use the same or a different strategy. Such a strategy set reconfiguration involves a series of executive control processes, such as shifting attention (from the just-executed strategy to the new strategy), retrieving task goals, rules, or procedures (of the new strategy), and activating, executing, and ordering component procedures of the to-be-executed strategy, as well as inhibiting irrelevant strategies (such as the just-executed strategies). In other words, once a problem has been solved with a given strategy, participants must disengage from the just-executed strategy or inhibit activated procedures of this now-irrelevant strategy and must make other strategies available in working memory or activate procedures of the relevant, to-be-executed strategy. The extra time required by unrepeated-strategy trials can be interpreted as the duration of these reconfiguration processes.

Moreover, previous works also found age-related increase in task-switch costs (e.g., Meiran, Gotler, & Perlman, 2001; Kramer, Han, & Gopher, 1999; Kray, Li & Lindenberger, 2002; Themanson, Hillman, & Curtin, 2006; Van Asselen & Ridderinkhof, 2001). For example, Kray, Li and Lindenberger (2002) compared young and older adults’ performance when participants had to decide (a) if the stimulus was an animal or not, (b) if the number of syllables was equal to one or two, (c) if the number of letters was odd or even, or (d) if the word contained the letter H or not. In the repeated-task condition, participants had to repeat the same task on two consecutive trials (e.g., categorizing the stimulus as an animal or not). In the unrepeated-task condition, participants had to switch between tasks on two consecutive trials (e.g., animal categorisation on one trial and deciding if the word contained the letter H or not on next trial). Results showed that task switch costs (i.e., difference in performance between the unrepeated-task and repeated-task conditions) increased with age.

However, no previous studies tested whether strategy-switch costs evolve with age. The present study aimed at replicating strategy switch costs in young adults and investigating age-related differences in strategy switch costs. As strategy and task switching may involve the same priming and reconfiguration processes, some similar results regarding age effects on switch costs would be expected.

Note though that several studies found no age-related increase in task-switch costs (Adrover-Roig & Barcelo, 2010; Kray & Lindenberger, 2000; Lien, Ruthruff, & Kuhns, 2008; Mayr & Liebscher, 2001; Reimers & Maylor, 2005; West & Travers, 2008). For example, Kray and Lindenberger (2000) investigated age-relate differences in task switch costs. Participants performed a problem-verification task (e.g., 23 < 52, “yes”) or a similarity judgement task (e.g., 4, 3, 5, 4, “no”, because the digit “4” appeared two times). When comparing participants’ performance on unrepeated-to
repeated-task consecutive trials, the authors found comparable task switch costs in young and in older adults.

One possible key factor for observing age differences in switch costs is the number of tasks or strategies to switch among. When they tested task-switch costs with two tasks, Kray and Lindenberger (2000) found no age differences in task switch costs. However, Kray et al., (2002) found increased task-switch costs with age when participants had to switch between four tasks. Such findings led us to manipulate the number of strategies to investigate age-related differences in strategy switch costs. Specifically, we tested the prediction that age-related differences in strategy switch costs are larger in the three-strategy condition than in the two-strategy condition. This should occur as it is harder to switch among more than among fewer strategies. Indeed, switching among more strategies involves both maintaining more strategies in working memory and activating the relevant strategy while inhibiting more irrelevant strategies. Such processing resources, likely crucial for strategy switching (e.g., processing speed, inhibition, and cognitive flexibility), are known to decrease with age. Larger processing demands combined with fewer processing resources in the three-strategy than in the two-strategy condition might lead older adults to have more difficulties to switch strategy from one strategy to another under the most difficult strategy-condition.

In the present experiment, young and older adults’ strategy switch costs were investigated in a complex addition problem-solving task (i.e., solving two-digit addition problems like 47 + 84). Previous studies showed that young and older adults use several strategies to solve two-digit addition problems and used the target strategies investigated here (e.g., Geary & Wiley, 1991; Lemaire & Arnaud, 2008; Hodzik & Lemaire, 2011). For each problem, participants were cued which strategy to use. We compared strategy-switch costs in the two-strategy condition and in the three-strategy condition. In the two-strategy condition, participants had to switch between unit (i.e., adding 7 + 4 + 40 + 80 to solve 47 + 84) and decade (i.e., adding 40 + 80 + 7 + 4) strategies. In the three-strategy condition, participants had to switch between unit, decade, and borrowing (i.e., adding 47 + 4 + 80) strategies. In both switching conditions, switching rates were kept constant so that participants repeated the same strategy on two consecutive problems in 50% of trials and switched strategy on the other trials. If switching among strategies incur more costs in older adults, we should observe (a) larger strategy-switch costs in older than in young adults, and (b) larger effects of the number of strategies on strategy-switch costs in older than in young adults, so that difference in strategy-switch costs between three- and two-strategy conditions should be larger in older than in young adults.
METHOD

Participants. Forty young (35 women, age range: 18-35 years) and 40 older adults (22 women, age range: 56-79 years) were tested. Young and older adults were randomly assigned to the two-strategy or three-strategy condition. Young adults were undergraduate students from Aix-Marseille University (Marseille, France). Older adults were volunteers from the community with no cognitive or health-related problems.

Before the experiment, all older adults accomplished the Mini Mental-State Examination which is a clinical test that provides a global measure of cognitive impairment in older adults (MMSE; Folstein, Folstein, & McHugh, 1975). No older adults were excluded because they all had scores larger than the usual cut-off score of 27 (mean: 29.2).

Next, in order to control for the influence of arithmetic skills, participants completed the French Kit (French, Ekstrom, & Price, 1963) which assesses participants’ arithmetic fluency. The task was to solve as quickly and accurately as possible arithmetic problems presented on paper. Participants completed both the addition (i.e., series of addition problems like 69 + 93 + 85 presented in columns) and the subtraction-multiplication subtests (e.g., alternating series of subtraction problems like 98 - 75 and multiplication problems like 86 × 4 presented in columns). Each subtest consisted of two pages of problems. All participants were given two minutes per page. Number of correct answers on each of the addition and the subtraction-multiplication tests were summed to yield a total arithmetic score.

Then, to assess crystallized intelligence, the French version of Mill-Hill Vocabulary Scale (MHVS; Deltour, 1993; Raven, 1951) was administered. The task was to identify which of the proposed words had the same meaning as the target word. MHVS consists of 33 items distributed across three pages. Each item was a target word followed by six proposed words. The number of correct items represented the level of verbal ability. Participants’ characteristics are summarized in Table 1.

Stimuli. Each participant solved 96 complex addition problems. These problems were composed of two two-digit numbers with a mean sum of 96.5 (range: 42 - 162).

Problems were selected with several constraints. First, size of correct sum was comparable across the two- and three-strategy conditions. In the two-strategy condition, half the problems had to be solved with the unit strategy (mean sum = 96, standard deviation = 27.7, range = 43-162), the other problems with the decade strategy (mean sum = 97, standard deviation = 27.6, range = 42-152). In the three-strategy condition, one third of problems had to be solved with the unit strategy (mean sum = 96, standard deviation = 26.4, range = 44-152), one third of problems with the decade strategy (mean sum = 98, standard deviation = 28.2, range = 52-162), and one third of problems with the borrowing strategy (mean sum = 96, standard deviation = 29, range = 42-136).

The participants used the same strategy on two consecutive problems for half the trials (repeated-strategy trials) and a different strategy for the other trials.
Table 1. Characteristics and mean scores, for each group (young and older adults) and each experimental condition (two and three strategies)

<table>
<thead>
<tr>
<th>Group Experimental Condition</th>
<th>Young Adults</th>
<th>Older Adults</th>
<th>Group Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>20</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>Age</td>
<td>23.0</td>
<td>22.7</td>
<td>0.03</td>
</tr>
<tr>
<td>Years of education</td>
<td>14.6</td>
<td>14.7</td>
<td>0.04</td>
</tr>
<tr>
<td>MHVS</td>
<td>22.8</td>
<td>23.6</td>
<td>0.37</td>
</tr>
<tr>
<td>Arithmetic Fluency</td>
<td>65.1</td>
<td>56.7</td>
<td>1.74</td>
</tr>
<tr>
<td>MMSE</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note. MHVS = French version of the Mill-Hill Vocabulary Scale (Raven, 1951); Arithmetic fluency = Score obtained on a paper-and-pencil arithmetic test in which participants had to solve as many basic arithmetic problems (e.g., 47 - 32) as possible in 8 min; MMSE = Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). None of the older adults obtained an MMSE score lower than 27; therefore, none were excluded. *p < .05, **p < .001.

(unrepeated-strategy trials). Mean sums were equated between repeated-strategy and unrepeated-strategy trials.

Following previous findings in arithmetic (see Ashcraft, 1995; Campbell, 2005; Dehaene, 1997; Geary, 1994, for overviews), problems were selected with several other constraints: (a) half the problems had carry on units (e.g., 54 + 68); (b) half the problems had their larger operand on the left position (e.g., 46 + 12); (c) none of the operands had the tens or units digits equal to 0; (d) none of the operands had unit digits equal to 5; (e) none of the pairs of operands had the same ten and unit digits (e.g., 34 + 38, 34 + 54), the same ten and unit digits (e.g., 33 + 88), or the same operands (e.g., 31 + 31); (f) none of the problems were the reverse of another problem (i.e., if 72 + 64 was used, 64 + 72 was not used), and (g) a quarter of problems had two even operands (e.g., 86 + 12), two odd operands (e.g., 23 + 49), one even and one odd operand (e.g., 26 + 87), or one odd and one even operand (e.g., 43 + 68).

Procedure. Participants were individually tested in one session which lasted approximately 45-60 minutes. First, they performed the paper-and-pencil tasks (i.e., MMSE, French Kit, and MHVS). Second, they accomplished the experimental task. Participants solved six training problems similar to (but different from) experimental problems to familiarize themselves with apparatus, procedure, and task.
Each trial began with a white screen of a 14-inch computer screen controlled by a Dell Latitude ATG D620 computer for 1000 milliseconds. It was followed by a fixation point (“*”) in the center of the screen for 1000 milliseconds. Then, the problem and the cue were simultaneously displayed on the computer screen. The cue appeared 2.5 cm above the problem and, together with the problem, remained on the screen until the participants’ response. The word “dizaine” (i.e., decade in French) cued the participants to solve the current problem with the decade strategy (i.e., adding both decades and then both unit-digits), the word “unité” (i.e., unit in French) prompted the participants to use the unit strategy (i.e., adding both unit-digits and then both decades), the word “transfert” (i.e., borrowing in French) cued the participants to use the borrowing strategy (i.e., adding one unit digit to an operand and then the decade). Problems were presented horizontally in the center of the screen in the form of \(a + b\) and in 48-point Arial font. The symbol and numbers presented in Arabic format were separated by spaces equal to the width of one character. Following previous studies (Ardiale & Lemaire, 2012; Lemaire & Arnaud, 2008; Lemaire et al., 2004; Lemaire & Lecacheur, 2010; Uittenhove & Lemaire, 2012), a timer was started at the beginning of the problem presentation and ended when the experimenter pressed on the space bar of the computer keyboard, which happened as soon as possible when participants started to state their response orally. The experimenter was blind to our predictions. Participants were asked to calculate out loud so as to control that they executed the cued strategy. After each problem, the experimenter recorded participants’ responses and noted whether participants executed the cued strategy (which happened on 100% of trials) or another strategy. The experiment was controlled by the E-Prime software.

RESULTS

Analyses were run after discarding the first trial of each block because they were neither unrepeated-strategy nor repeated-strategy trials. Only solution times for correct responses immediately preceded by a correct response were analyzed. Solution times larger than two standard deviations above the mean of each participant were also discarded (4%). For all the results\(^1\), unless otherwise noted, differences are significant to at least \(p < .05\).

Number of Strategies Effects.

The results were analyzed to (1) replicate strategy switch costs (i.e., poorer performance when participants used different strategies across two consecutive problems than when they used the same strategy) in young

\(^1\)The same analyses were also performed with arithmetic fluency and years of education as covariates. Results were similar.
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Table 2. Switch costs as a function of age and the number of strategies

<table>
<thead>
<tr>
<th>Condition</th>
<th>Young Adults</th>
<th></th>
<th>Older Adults</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeated</td>
<td>Unrepeated</td>
<td>SSC</td>
<td>Repeated</td>
</tr>
<tr>
<td>Two strategies</td>
<td>5165</td>
<td>5466</td>
<td>300</td>
<td>6303</td>
</tr>
<tr>
<td>Three strategies</td>
<td>5789</td>
<td>6194</td>
<td>405</td>
<td>6008</td>
</tr>
<tr>
<td>Percentages of Errors</td>
<td>7.1</td>
<td>5.2</td>
<td>-1.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Two strategies</td>
<td>7.1</td>
<td>8.6</td>
<td>1.5</td>
<td>10.7</td>
</tr>
<tr>
<td>Three strategies</td>
<td>7.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Repeated, repeated-strategy trial; unrepeated, unrepeated-strategy trial; SSC, strategy switch cost (difference between unrepeated and repeated strategy trials).

adults and (2) determine whether strategy switch costs increase with participants’ age and vary with the number of strategies. We carried out repeated measures ANOVAs with a 2 (Age: young vs. older adults) × 2 (Number of strategies: 2 vs. 3 strategies) × 2 (Trial: repeated strategy vs. unrepeated strategy) design with the first factors as between-subject factors. These analyses were performed on mean solution latencies and percentages of errors for the two strategies used (i.e., unit and decade strategies) in the two- and three-strategy conditions (see Table 2 for means). We considered the strategy participants switch to for unrepeated trials.

**Solution Latencies.** All participants were 430 ms slower when they used different strategies on two consecutive problems (6246 ms) than when they used the same strategy (5816 ms), as revealed by trial effect, $F(1,76) = 60.4$, $MSe = 122562$, $\eta^2_p = 0.44$. Moreover, Number of Strategies × Trial, $F(1,76) = 12.7$, $MSe = 122562$, $\eta^2_p = 0.14$, and Age × Number of Strategies × Trial, $F(1,76) = 6.8$, $MSe = 122562$, $\eta^2_p = 0.08$, interactions were significant. In order to understand these interactions, we conducted an ANOVA with a 2(young, older adults) × 2 (two-, three-strategy conditions) on strategy switch costs (difference means solution times between unrepeated and repeated strategy trials). This analysis revealed that strategy switch costs were larger in the three-strategy condition (627 ms) than in the two-strategy condition (233 ms), $F(1,76) = 12.65$, $MSe = 245124$, $\eta^2_p = 0.14$. Interestingly, the Age × Number of Strategies interaction, $F(1,76) = 6.83$, $MSe = 245124$, $\eta^2_p = 0.08$, revealed that strategy switch costs were similar when young adults switched between two (300 ms) and three strategies (405 ms), $F < 1$. However, strategy switch costs were larger when older adults switched between three (849 ms) than two strategies.
young and older adults’ strategy-switch costs were of comparable magnitudes when participants switched between two strategies, $F < 1$. In contrast, under the three-strategies condition, strategy switch costs were larger in older than in young adults, $F(1,76) = 8.06, MSe = 245124, \eta^2_p = 0.10$.

**Percentages of errors.** Participants made less errors in the two-strategy (5.6%) than in the three-strategy condition (7.7%), $F(1,76) = 5.03, MSe = 35.71, \eta^2_p = 0.06$. No other main effects or interaction came out significant.

In sum, we found strategy-switch costs during strategy execution. Participants showed poorer performance on a given trial when they executed different strategies on two consecutive trials than when they executed the same strategy. Most originally and importantly, such strategy switch costs were influenced by the number of strategies only in older adults. Strategy switch costs were of comparable magnitudes in young and older adults when participants switched between two strategies but were larger in older adults when they switched between three strategies.

**Strategy-Specific Effects**

We also explored whether age-related differences in strategy switch costs varied as a function of the specific-strategy processing for executing each of the three strategies. For example, unit and decade strategies involve similar process occurring in a different sequence (i.e., adding unit-digits before/after adding decades). Moreover, borrowing strategy involves one process less, but the manipulation of larger numbers than the other two strategies. To investigate strategy-specific effects, we first conducted a repeated measures ANOVA with 2 (Age: young vs. older adults) $\times$ 2 (Trial: repeated strategy vs. unrepeated strategy) $\times$ 2 (Strategy: unit vs. decade strategies) design in the two-strategy condition. Analysis on solution times revealed main effects of age, $F(1,38) = 4.49, MSe = 10194315, \eta^2_p = 0.11$, and trial, $F(1,38) = 22.62, MSe = 96117, \eta^2_p = 0.37$. Young adults (5315 ms) were faster than older adults (6386), and all participants were 233 ms faster on repeated (5734 ms) than on unrepeated strategy trials (5967 ms). No main or interaction effects came out significant on percentages of errors.

We then conducted a repeated measures ANOVA with 2 (Age: young vs. older adults) $\times$ 2 (Trial: repeated strategy vs. unrepeated strategy) $\times$ 3 (Strategy: unit vs. decade vs. borrowing strategies) design. Participants were faster when they repeated the same strategy (6202 ms) than when they switched strategies on consecutive trials (6656 ms), $F(1,38) = 31.49,$
$MSe = 394034, \eta^2_p = 0.45$. The main effect of strategy, $F(2,96) = 13.33, MSe = 866123, \eta^2_p = 0.26$, showed that participants were slower when they executed the borrowing strategy (6863 ms) than when executing the decade strategy (6268 ms, $F(1,38) = 19.39, MSe = 730882, \eta^2_p = 0.34$) and the unit strategy (6156 ms, $F(1,38) = 16.16, MSe = 1236600, \eta^2_p = 0.30$), but they were equally fast at executing the decade and the unit strategies (6268 vs. 6156 ms, $F < 1$). This ANOVA also yielded significant interactions involving the trial factor, Age × Trial, $F(1,38) = 15.38, MSe = 394034, \eta^2_p = 0.29$, and Strategy × Trial, $F(1,38) = 3.8, MSe = 499562, \eta^2_p = 0.09$. Therefore we ran an ANOVA on strategy switch costs with an Age × Strategy design. Results showed larger switch costs in older (773 ms) than in young adults (137 ms), $F(1,38) = 15.38, MSe = 788068, \eta^2_p = 0.29$. Strategy switch costs when switching to the borrowing strategy (110 ms) were smaller than strategy switch costs of the decade strategy (644 ms, $F(1,38) = 9.94, MSe = 573306, \eta^2_p = 0.21$), and tended to be smaller than switch costs of the unit strategy (610 ms, $F(1,38) = 3.84, MSe = 1298109, \eta^2_p = 0.09, p = 0.057$). The decade and the unit strategies had comparable strategy switch costs (644 vs. 610 ms, $F < 1$).

Analysis on percentages of errors only showed a significant Age × Strategy interaction, $F(2,76) = 3.35, MSe = 50.46 \eta^2_p = 0.08$. This interaction resulted from age-related differences for the unit strategy ($F(1,38) = 6.07, MSe = 58.53, \eta^2_p = 0.02$), such that young adults (6.3%) made fewer errors than older adults (10.5%), in contrast to no age differences for the decade strategy ($F < 1$) or the borrowing strategy ($F < 2$).

**DISCUSSION**

In the present study, young and older adults had to solve two-digit addition problems like 48 + 67. The strategy to be executed on each problem was cued. Participants were cued to use the same strategy on two consecutive problems on half the trials and to use different strategies on the other trials. We compared performance on repeated-strategy and unrepeated-strategy trials, in two-strategy versus three-strategy condition. The results showed larger strategy-switch costs (performance for unrepeated trials - performance for repeated trials) in older adults as compared to young adults, only in the three-strategy condition. These findings have important implications regarding aging effects on strategic aspects of cognitive performance.
Strategy switch costs suggest that participants have more difficulties to execute processes that enable them to use different strategies on consecutive problems. To switch strategy, participants must disengage from the just-executed strategy or inhibit activated procedures of the now-irrelevant strategy and must make other strategies available in working memory or activate procedures of the relevant, to-be-executed strategy. Unrepeated strategy trials may involve cognitive flexibility and inhibitory processes, two component processes of strategy set reconfiguration processes. It is also possible that priming processes contributed to strategy-switch costs. Priming processes would make the just-executed strategy more available in repeated-strategy trials, so that participants would benefit more from having just executed a strategy when the same strategy has to be used again on the next trial. This is possible if activation of the just-executed strategy decays more quickly for unrepeated than for repeated trials.

Another interesting and original result of this experiment is the Age × Number of Strategy × Trial interaction. Strategy-switch costs increased in older adults but not in young adults when using three strategies as compared to two strategies. Increased strategy-switch costs in older adults as a function of the number of strategies suggest that it is harder to switch among more than among fewer strategies. Switching between more strategies may require more processing demands for maintaining active in memory a larger set of strategies when activating and executing the cued strategy. As cognitive resource processing and memory capacities decrease with age, older adults may have more difficulties than young adults to keep active in memory and to process more strategy procedures (e.g., Braver et al., 2001; Reuter-Lorenz & Sylvester, 2005; Salthouse, 1996, for reviews).

Note that, as we added a hard strategy (i.e., the borrowing strategy) in the three-strategy condition, participants may have more difficulties to execute and to disengage from a hard than from easier strategies (i.e., the decade and the unit strategies). As young adults showed no increase in strategy switch costs between the two- and the three-strategy condition, asymmetry of strategy switch costs may be specific to older adults. However, strategy-specific effects analysis revealed no interaction involving the age factor. This means that older adults performed and inhibit as well as young adults the harder strategy. Larger general strategy switch costs in older adults under the three-strategy condition may result from maintaining active three strategies.

Alternatively or complimentarily such increased strategy switch costs can be interpreted as an increased uncertainty of the strategy to be selected on the next trial. Indeed, when they switched strategy on a given problem under two-strategy condition, older adults knew which alternative strategy
they had to switch to. They could prepare to switch to this alternative strategy. Such switching preparation may help them to switch more quickly between two than three strategies. In the three-strategy condition, after executing a strategy on a given problem, participants could not prepare (or could prepare less) for the upcoming strategy as they did not know which of the two other strategies they would have to switch to.

It was interesting to find that aging effects on strategy switch costs parallel aging effects on task switch costs. Indeed, Kray and Lindenberger (2000) found comparable task switch costs in young and older adults when participants were asked to switch between two tasks, whereas Kray et al. (2002) found larger task-switch costs in older adults when participants switched between four tasks. Similarly, here, we found no age-related differences in strategy switch costs under the two-strategy condition but larger strategy-switch costs under the three-strategy condition. In both cases, it seems that larger number of strategies or tasks is crucial to observe age-related differences in switching costs. Such results provide further evidence for similarities between task and strategy switching processes.

The present findings may also have some implications on strategic variations with age. Regarding strategy repertoire, Hodzik and Lemaire (2011) (see also Lemaire & Arnaud, 2008) showed that young and older adults shared the same strategy repertoire to solve arithmetic problems like 46 + 73. However, older adults used fewer strategies than young adults (2.1 vs. 3 strategies). Moreover, the decrease in the number of strategies use was correlated with decrease in executive functions such as cognitive flexibility and inhibition. Executive functions are defined as a set of processes aimed at controlling and regulating behaviors and actions (e.g., Diamond, 2006; Miyake et al., 2000). For example, Miyake et al. (2000) distinguished three executive functions: inhibition (i.e., preventing from giving inappropriate or automatic responses when irrelevant for the task), updating (i.e., active control and manipulation of incoming information in working memory), and cognitive flexibility (i.e., switching two cognitive entities). These results were interpreted as the fact that older adults may have more difficulties to maintain active and to switch among several strategies than young adults. The present findings suggest that older adults may use fewer strategies than young adults because switching among three strategies involves more cognitive switch costs than switching between two strategies. Interestingly, young adults used on average three strategies which correspond to the lack of increased strategy switch costs in the tree-strategy condition in the present study. Future studies should investigate the relationship between the number of strategy used and strategy switch costs with age.
Regarding strategy selection, many studies found that older adults are less able than young adults to select the best strategy on each problem (see Lemaire, 2010, for a review). One possibility is that older adults tend to switch strategy across problems less often than young adults, even if problem characteristics suggest to not using the same strategy on the current problem as on the previous problem. The present findings suggest that switching between two strategies incurs no age-related differences. Future studies should determine whether, like Lemaire and Lecacheur (2010) found in young adults, older adults tend to repeat the same strategy on two consecutive trials when they are asked to select strategies. The present findings suggest that older adults would use the same strategy on two consecutive trials more often than young adults. Such larger tendency to repeat the same strategy across trials in older adults might contribute to their poorer skills at selecting the best strategy. Future studies could address this issue by directly examining relationships among strategy switch costs, participants’ tendency to repeat strategy across trials, and percent best strategies selected on a given problem.

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