Age-related differences in children’s strategy repetition: A study in arithmetic

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ABSTRACT

Third and fifth graders (Experiment 1) and fifth and seventh graders (Experiment 2) accomplished computational estimation tasks in which they provided estimates to two-digit arithmetic problems (e.g., 34 + 68). Participants saw trials, each including three consecutive problems. Each trial was separated by a letter judgment task (i.e., participants needed to say whether a series of four letters included only vowels, only consonants, or both types of letters). On each problem, children were asked to select the better of the following strategies: rounding down (i.e., rounding both operands down to the nearest decades; e.g., 30 + 60 = 90) or rounding up (rounding both operands up to the nearest decades; e.g., 40 + 70 = 110). Half of the trials were repeated strategy trials (i.e., the better strategy was the same for the first two prime problems and the last target problem) and half were unrepeated strategy trials (i.e., the better strategy was different for prime and target problems). We found that (a) children repeated the same strategy over successive problems, even when they should change strategies to obtain better performance, (b) strategy repetitions decreased with age, (c) repeating the same strategy gave children performance benefits, and (d) these strategy repetition benefits were similar across grades. These effects of strategy repetition during strategy selection and strategy execution have important empirical and theoretical implications regarding how children choose among strategies, how children execute selected strategies on each problem, and how strategic variations change with age.

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Introduction

Children use a variety of strategies to accomplish cognitive tasks. A strategy is “a procedure or a set of procedures to achieve a higher level goal” (Lemaire & Reder, 1999, p. 365). In a wide variety of cognitive tasks, previous research found that children’s performance depends on which strategies they use and that children of all ages choose strategies on a trial-by-trial basis. Developmental research has shown that cognitive growth can be characterized by overlapping waves (Siegler, 1998). That is, in many situations children rely on different strategies or representations, and what changes with children’s age is not which strategy or representation is used at any given age followed by another strategy or representation. Rather, cognitive development is characterized by age-related changes in several strategy dimensions (Lemaire & Siegler, 1995). That is, cognitive development is accompanied by age-related changes in strategy repertoire (or which strategies are used), in strategy distribution (or how often each strategy is used), in strategy execution (or relative strategy performance), and in strategy selection (or how children choose among strategies on each problem). Developmental research has also shown that age-related changes in children’s strategy use and strategy execution depend on participants, problems, strategy, and situation characteristics (see Siegler, 2007). The current study contributes to our knowledge of age-related changes in strategy use and strategy execution by showing that children tend to repeat the same strategy over successive problems even when they should change strategies to obtain better performance, that strategy repetitions decrease with age, that repeating the same strategy gives children performance benefits, and that these strategy repetition benefits are age invariant.

The current study focused on children’s strategy repetitions for several reasons. First, strategy repetitions have been investigated in adults (e.g., Lemaire & Brun, 2014a; Lemaire & Leclère, 2014a, 2014b; Luchins, 1942; Luwel, Schillemans, Onghena, & Verschaffel, 2009). However, they have never been studied in children. So, we do not know whether children tend to repeat the same strategy over consecutive problems like adults do, whether strategy repetitions are associated with performance benefits, and whether and how strategy repetitions during strategy selection and strategy execution change with children’s age. Second, strategy repetitions are interesting phenomena that speak to theoretical models of strategy choices and of strategic development.

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) model, Siegler and Shipley’s (1995) adaptive strategy choice model (ASCM), Lovett and Schunn’s (1999) represent, construct, choose, learn (RCCL) model, Payne, Bettman, and Johnson’s (1993) adaptive decision maker, Rieskamp and Otto’s (2006) strategy selection learning (SSL) model, and Siegler and Arraya’s (2005) strategy, choice, and discovery simulation (SCADS). All of these models proposed that choosing among multiple strategies crucially involves associative mechanisms such as activating the relative costs and 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 such as 12 = 3 × 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 select the better strategy more and more frequently on each problem. So, when children need to solve a new problem, they assess problem features, activate strategies available to solve the current 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 the key components of these models’ assumptions and have proven to be sufficient to account for most findings on strategy choices and execution such as the effects of problem difficulty or strategy characteristics. In the current study, we tested effects of strategy repetitions during strategy selection and execution in children because finding these effects in children and observing that their magnitudes change with children’s age would have important implications for some core assumptions of computational models of strategic development. Indeed, finding that children tend to repeat the same
strategy across two consecutive problems would be inconsistent with some important assumptions made by all current models of strategic development. First, strategy repetitions would challenge the assumption that children choose strategies on each problem independent of the strategy they selected on the immediately previous problem. In addition, models of strategies assume that relative strategy performance depends on the number and type of procedures involved in each strategy (i.e., a harder strategy includes more procedures and/or more difficult procedures). Findings that relative strategy performance is influenced by strategy repetitions would challenge this assumption. Finally, finding effects of strategy repetitions would constrain theoretical models to take into account the possibility that children of different ages aim at minimizing demands on executive resources when selecting and executing strategies.

It is likely that children, like adults, tend to reuse a strategy that they had used on the previous problem. Ever since the pioneering work of Luchins (1942; Luchins & Luchins, 1950), several studies have documented a general class of phenomena originally referred to as Einstellung or problem set effects. As in the water jar task used by Luchins or analogues such as the building sticks task used by Lovett and Anderson (1996), participants tend to reuse an operator on current problems that they used on preceding problems even if a different operator is more efficient. Strategy repetition effects, which are a specific case of these Einstellung effects, have been found in different numerical problem solving tasks such as numerosity estimation tasks (e.g., Luwel et al., 2009; Schillemans, Luwel, Bulté, Ongena, & Verschaffel, 2009; Schillemans, Luwel, Ceulemans, Ongena, & Verschaffel, 2012; Schillemans, Luwel, Ongena, & Verschaffel, 2011) and arithmetic problem solving tasks (e.g., Lemaire & Brun, 2014a, 2014b; Lemaire & Leclère, 2014a, 2014b). Strategy repetitions involve observing that adults tend to repeat the same strategy over two consecutive problems when participants select strategies and tend to execute a strategy faster on a problem after using it on a preceding problem. Lemaire and Leclère (2014a, 2014b) accounted for strategy repetitions in adults by assuming that changing strategies from one trial to the next requires extra cognitive resources. To change strategies, participants need to 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-selected/executed strategy. Given the cognitive costs incurred by such strategy change, participants tend to use the same strategy over two successive problems unless the benefits of using an alternative strategy outweigh the costs of strategy switching. The first goal of this study was to test whether elementary school children tend to repeat the same strategy over two successive problems when they should change strategies to obtain better performance. The second goal of the current study was to test the prediction that, as they grow older, children tend to repeat the same strategy less over two successive problems when they need to change strategies to obtain better performance. This is based on the fact that efficiency of executive control processes crucially involved in strategy selection (e.g., Ardiale & Lemaire, 2012, 2013a, 2013b; Hodzik & Lemaire, 2011; Lemaire & Lecacheur, 2010) increases with children’s age (e.g., Chevalier, 2015). The third goal of the current study was to investigate the effects of strategy repetitions during strategy execution so as to determine whether children obtain better performance when they execute a strategy on a problem after using that same strategy on the immediately preceding problem. Such strategy repetition benefits have been found in adults (e.g., Ardiale, Hodzik, & Lemaire, 2012; Lemaire & Lecacheur, 2010; Luwel et al., 2009; Schillemans et al., 2009, 2011, 2012). They are usually accounted for by assuming that having just executed a strategy on the immediately preceding problem makes this strategy more available to execute on the current problem. Of specific interest here was not only to test whether such strategy repetition benefits are found in children but also to determine whether and how they change with children’s age.

In this study, third and fifth graders (Experiment 1) and fifth and seventh graders (Experiment 2) accomplished computational estimation tasks in which they provided estimates to two-digit arithmetic problems (e.g., 34 + 68). On each problem, they were asked to select the better of the following strategies: rounding down (i.e., rounding both operands down to the nearest decades; e.g., 30 + 60 = 90) or rounding up (i.e., rounding both operands up to the nearest decades; e.g., 40 + 70 = 110). Previous works revealed that this was a good task to investigate strategic changes in children and that these two rounding strategies are well known by children aged 8 years or over (e.g., LeFevre, Greenham, & Waheed, 1993; Lemaire & Lecacheur, 2002; Lemaire, Lecacheur, &
Following Lemaire and Leclère (2014a, 2014b) studies in young and older adults, we asked children to solve series of three successive problems, on each of which they needed to select the better strategy (i.e., the strategy that yields the closest sum to the correct sum). We carefully selected the problems in each trial on the basis of the unit digits of both operands. Unit digits of both operands were either smaller or larger than 5 on the first two so-called prime problems (e.g., \(41 + 72\), \(37 + 49\)), so that the better strategy was easy to select on these prime problems. The unit of one operand was smaller than 5 and the other was larger than 5 on the last so-called target problems (e.g., \(47 + 84\), \(34 + 29\)). Previous studies (e.g., Dowker, 1997; Lemaire & Brun, 2014 b) established that children as young as 8 years can select the better of the two rounding (down/up) strategies on more than 95% of the problems when unit digits of both problems are either smaller or larger than 5 and that it is much harder for them to choose the better strategy on the other problems. Half of the trials were repeated strategy trials (i.e., the better strategy was the same for prime and target problems), and half were unrepeated strategy trials (i.e., the better strategy was different for prime and target problems).

Effects of strategy repetitions and changes in their magnitudes with increasing age were tested during both strategy selection and strategy execution. During strategy selection, we predicted more frequent strategy repetitions in younger children than in older children. During strategy execution, we tested the prediction that children would obtain better performance when executing a strategy on a problem immediately after executing it on a previous problem. We compared these benefits in young and older children. We tested these predictions in third and fifth graders in Experiment 1 and in fifth and seventh graders in Experiment 2 while children were solving prime problems. In Experiment 2, we also tested whether changes in executive control mechanisms with age mediate age-related changes in effects of strategy repetitions.

**Experiment 1**

**Method**

**Participants**

A total of 79 children were tested. They were divided into two groups: 39 third graders (20 boys; mean age = 8;9 [years;months], range = 7;10–9;2) and 40 fifth graders (21 boys; mean age = 10;7, range = 9;11–12.0). They were from French urban public schools. Parents provided written informed consent for their children’s participation in the study.

**Stimuli**

Each participant saw 28 trials. Each trial consisted of three consecutive two-digit addition problems followed by a series of four letters. Half of the four-letter series included four either only consonants or only vowels (e.g., eiua, htrs), and half included both types of letters (e.g., zaet). This letter judgment task was used to avoid contamination of strategy choices and strategy performance across trials.

Each trial included two prime problems followed by a target problem. The following are two examples of trials: (a) 24 + 41; 52 + 24; 39 + 42; eiua; (b) 16 + 28; 26 + 47; 19 + 34; htrs. Prime and target problems were selected so that they had comparable correct sums. More precisely, mean correct sums were 67.6 (range = 44–86) for prime problems and 67.9 (range = 42–83) for target problems (\(F < 1\)).

So-called homogeneous problems were used as prime problems, and heterogeneous problems were used as target problems. Homogeneous problems were problems with the unit digit of both operands smaller than 5 (e.g., \(42 + 51\)) or larger than 5 (e.g., \(48 + 56\)). Half of the homogeneous problems had their unit digits of both operands smaller than 5 so that participants would obtain the better estimates (e.g., closest sums to correct sums) on these problems when correctly executing the rounding-down strategy, and the other half had their unit digits of both operands larger than 5 so that the rounding-up strategy was the better strategy. Homogeneous rounding-down problems and homogeneous rounding-up problems had comparable mean correct sums. More precisely, mean sums were 67.0 (range = 46–77) and 68.1 (range = 44–86) for homogeneous rounding-down and homogeneous rounding-up problems, respectively (\(F < 1\)). Homogeneous problems were chosen because previous
works (e.g., Lemaire & Lecacheur, 2011) showed that children almost systematically select the rounding-down strategy on problems with the unit digit of both operands smaller than 5 and select the rounding-up strategy on problems with the unit digit of both operands larger than 5.

Heterogeneous problems were problems with the unit digit of one operand smaller than 5 and the unit digit of the other operand larger than 5 (e.g., 32 + 56, 38 + 54). Half of the target heterogeneous problems were best estimated with the rounding-down strategy (e.g., 36 + 52), and half were best estimated with the rounding-up strategy (e.g., 58 + 34). Heterogeneous rounding-down problems and heterogeneous rounding-up problems had comparable mean sums. More precisely, mean sums were 66.4 (range = 57–78) and 69.3 (range = 42–83) for heterogeneous rounding-down and heterogeneous rounding-up problems, respectively ($F < 1$). Heterogeneous problems were selected as target problems because it is harder to select the best strategy on these problems for children (e.g., Lemaire & Brun, 2014b; Lemaire & Lecacheur, 2011), thereby maximizing chances to observe age-related differences in strategy repetitions.

Finally, there were two types of trials: repeated and unrepeated. Repeated trials included three problems that were best estimated with the same rounding strategy. In unrepeated trials, the best strategy was different for the two prime and target problems. For example, a repeated trial included problems for which the better strategy was RD (round down), RD, and RD, and an unrepeated trial included problems for which the better strategy was RD, RD, and RU (round up). Target problems in repeated and unrepeated trials were matched on the size of correct sums and the type of strategy that yielded the best estimate. Thus, mean sums were 66.4 and 69.3 for repeated and unrepeated trials, respectively ($F < 1$).

Following previous findings in arithmetic (see Campbell, 2005, and Geary, 1994, for overviews), we controlled the following factors. First, no operands had a 0 unit digit (e.g., 20 + 63) or a 5 unit digit (e.g., 25 + 63). Second, no digits were repeated within operands, unit digit, or decade digit (e.g., 22 + 63, 23 + 63, or 24 + 26). Third, no reverse order of operands was used (e.g., 24 + 63 and 63 + 24). Fourth, the first operand was larger than the second operand in half of the problems and vice versa. Fifth, the first unit digit was larger than the second unit digit in half of the problems and vice versa. Sixth, no operands had their closest decades equal to 0, 10, or 100. Finally, rounded operands were never the same across two rounding problems in a given trial (e.g., if one problem in a trial was 32 + 64, the next problem could not be 31 + 62).

**Procedure and design**

Children were tested individually in one session that lasted approximately 45 min. Before encountering the experimental problems, children were told that they were going to do computational estimation. The computational estimation task was explained as giving an approximate answer to an arithmetic problem that is as close as possible to the correct answer without actually calculating the correct answer. Thus, children needed to estimate the sum of the problem displayed on the screen, trying to choose the best rounding strategy. The better strategy was the strategy that yielded the answer that was closest to the correct sum. Children were told to use only one of two rounding strategies, the rounding-down strategy (i.e., rounding both operands down to the nearest decades; e.g., doing 60 + 40 to estimate 62 + 47) or the rounding-up strategy (i.e., rounding both operands up to the nearest decades; e.g., doing 70 + 50 to estimate 63 + 48). An example was given to children, who were told the following:

“For example, if I have to estimate 26 + 54, I can do 20 + 50 and give 70 as an approximate solution to the problem. I can also do 30 + 60 or do anything else that yields an approximate sum. You will complete this computational estimation task in two blocks of 14 trials composed of three problems each. Hence, you will see 28 trials with three problems each for a total of 84 problems to solve, with a break in between each block. Your task is to tell me an approximate sum for each problem. To estimate the sum, you can use only two rounding strategies: the rounding-down strategy or the rounding-up strategy. Rounding down means that you round both operands down to the closest smaller decades, for instance, doing 20 + 50 to estimate 26 + 54. Rounding up means that you round both operands up to the closest larger decades, for instance, doing 30 + 60 to estimate 26 + 54. For each problem, try to choose the better of the two rounding strategies. The better strategy is the strategy that yields the answer that is closest to the correct sum.”
Instructions also emphasized that children should do only the initial rounding up or down and nothing more (i.e., adding or subtracting small amounts after calculating the sum of rounded operands). After an initial practice period including 10 problems (5 with each rounding strategy), during which children were told whether their answers were correct and estimated with the best strategy, all children had no difficulties with either rounding strategy; none of them tried to calculate the exact sum. Then, they practiced the experimental task on 4 trials (each involving 3 addition problems and a series of four letters) for them to get familiarized with the procedure and the structure of each trial. Finally, in the experimental part, participants solved 28 trials (i.e., 84 addition problems and 28 series of letters), with a break in between each block of 14 trials.

The experimental problems were presented in 48-point bold Courier New font (black color) in the center of a 14-inch computer screen. E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) controlled the experiment, generating problem display and recording latencies.

Each problem was preceded by a blank screen for 500 ms and a warning signal (‘‘‘‘’) presented for 400 ms in the center of the screen. Then, the problem was displayed on the computer screen, where it remained until participants’ response. Participants were asked to calculate out loud so as to be sure of which strategy they used. On each trial, the experimenter recorded responses and choice of strategy. After the last addition problem of each trial, a blank screen followed participants’ response for 500 ms. Then, the warning signal appeared for 400 ms, followed by four letters. Letters were presented until participants gave their response. Participants were asked to press on the “L” key of the AZERTY keyboard when the four letters were all vowels or all consonants (e.g., oiea, gkcr) and to press on the “S” key when the four letters included both types of letters (e.g., ierg). Finally, a blank screen was displayed for 100 ms at the end of each trial and before the next trial started.

Results and discussion

Results are reported in two main parts. We analyzed effects of strategy repetitions first during strategy selection and then during strategy execution. In all results, unless otherwise noted, differences are significant to at least $p < .05$.

Effects of strategy repetitions during strategy selection

Before examining how third and fifth graders differed in effects of strategy repetitions during strategy selection, we looked at age-related differences in how often children were able to select the better strategy on prime problems.

Better strategy selection on prime problems. Mean percentages of better strategy selection on prime problems were analyzed (i.e., if participants used the better strategy on the two prime problems within one trial, better strategy selection was coded 1; otherwise, it was coded 0) with a mixed-design analysis of variance (ANOVA): 2 (Grade: third or fifth graders) × 2 (Problem Type: rounding down or rounding up), with repeated measures on the last factor.

All children selected the better strategy more often on rounding-down problems (95.7%) than on rounding-up problems (92.3%), $F(1, 77) = 4.80, MSe = 98.8, \eta^2_p = .06$. Fifth graders selected the better strategy more often than third graders (96.2% vs. 91.8%), $F(1, 77) = 3.88, MSe = 473.8, \eta^2_p = .05, p = .05$. The Grade × Problem Type interaction was not significant ($F = 1.96, ns$), with both third and fifth graders selecting the better strategy on rounding-down problems (94.7% and 96.8% in third and fifth graders, respectively) more equally often than on rounding-up problems (89.0% and 95.5% in third and fifth graders, respectively).

Strategy repetitions on target problems. To determine whether children tended to repeat the same strategy on prime and target problems, we analyzed mean percentages of strategy repetitions on target problems (i.e., if participants used the same strategy on prime and target problems, strategy repetition was coded 1; otherwise, it was coded 0). Trials on which participants used the poorer strategy on one or both prime problems were not included in these analyses.

ANOVAs were performed on the mean percentages of strategy repetitions with a 2 (Grade: third or fifth graders) × 2 (Trial: repeated or unrepeated) × 2 (Best Strategy on Prime Problems: rounding
Effects of strategy repetitions during strategy execution

Effects of strategy repetition during strategy execution were analyzed on prime problems solved with the better strategy. ANOVAs were performed on participants’ mean solution times and percentage errors (coded 1 if the selected strategy was executed correctly and 0 otherwise) with 2 (Grade: third or fifth graders) × 2 (Strategy: rounding down or rounding up) × 2 (Problem: first or second) mixed designs, with repeated measures on the last two factors (see Table 1 for means).

Fifth graders (6862 ms) were faster on prime problems than third graders (10,609 ms), \( F(2, 77) = 13.78, MSe = 80489205.8, \eta^2_p = .15 \). All children were faster with the rounding-down strategy than with the rounding-up strategy (8013 vs. 9457 ms), \( F(1, 77) = 45.79, MSe = 3595937.4, \eta^2_p = .37 \), but especially the youngest children as revealed by the Grade × Strategy interaction, \( F(1, 77) = 5.63, MSe = 3595937.4, \eta^2_p = .07 \). All children were faster on the second problem (8558 ms) than on the first problem (8913 ms), \( F(1, 77) = 13.39, MSe = 745420.7, \eta^2_p = .15 \). The Strategy × Problem interaction showed that this difference was significant only with the rounding-down strategy, \( F(1, 77) = 9.36, MSe = 561220.9, \eta^2_p = .11 \). No other interaction effects came out significant (\( Fs < 2.0, \text{ns} \)). Although the difference in latencies between first and second problems tended to be larger in third graders (474 ms) than in fifth graders (237 ms), the Grade × Problem interaction was not significant (\( F = 1.50 \)).

All children made more errors with the rounding-up strategy (5.4%) than with the rounding-down strategy (3.0%), \( F(1, 77) = 10.81, MSe = 43.6, \eta^2_p = .12 \). No other main or interaction effects came out significant on mean percentage errors (\( Fs < 3.0, \text{ns} \)).

In summary, this experiment revealed strategy repetition effects during both strategy execution (i.e., children were faster to execute a strategy on a problem immediately after executing it on a previous problem) and strategy selection (i.e., children repeated the same strategy over two successive problems even when they should have used two different strategies to respect the instructions to

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<td>Mean solution times (in ms) and mean percentage errors in each group of children on the first and second prime problems as a function of the strategy used (Experiment 1).</td>
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* \( p < .05 \).
choose the better strategy on each problem). In addition, and surprisingly, the current data revealed no differences between groups in effects of strategy repetitions either during strategy execution or during strategy selection. Indeed, we found that the third and fifth graders had strategy repetition benefits of comparable magnitudes when they executed strategies and that both groups tended to repeat the same strategy across two successive problems equally often. Effects of strategy repetitions of equal magnitudes in younger and older children are in contrast to our predictions. One possibility that Experiment 2 tested directly was that changes in effects of strategy repetitions do not occur between 8 and 10 years of age but may occur later in children's cognitive development. It is indeed possible that age-related differences in executive resources required to not repeat a strategy across successive problems were not large enough between third and fifth graders to result in decreased strategy repetitions with children's age. Before drawing any firm and definite conclusions regarding the lack of age-related changes in effects of strategy repetitions, we tested fifth and seventh graders in Experiment 2.

Experiment 2

The goal of Experiment 2 was threefold. First, we wanted to replicate effects of strategy repetition while children select and execute strategies. Second, we wanted to determine whether effects of strategy repetitions change with age when older children (seventh graders) are tested. Third, we aimed to further our understanding of mechanisms underlying effects of strategy repetitions. To achieve these ends, we tested fifth and seventh graders with the same method as in Experiment 1 and collected for each child two measures of executive functions, namely inhibition and flexibility known to influence strategy selection. These executive functions proved in past research to correlate with strategy choices in children and with age-related changes in children's strategy choices (e.g., Lemaire & Lecacheur, 2011). Flexibility is assumed to be crucial because being able to not rigidly use the same strategy across all trials and being able to switch strategies from trial to trial when the better strategy changes across trials are crucial to using the better strategy on each trial. In addition, to switch strategy from one trial to the next, being able to inhibit the just-executed strategy is crucial if the better strategy on the next problem is different from the strategy of the just-solved problem. Finally, we tested each child's arithmetic fluency with an independent paper-and-pencil test to determine whether age-related differences in strategy repetitions correlate with children's arithmetic skills.

Method

We used the same method as in Experiment 1, with the following differences. First, we tested a total of 56 children who were divided into two age groups: 28 fifth graders (15 girls; mean age = 10;7, range = 10;0–11;3) and 28 seventh graders (16 girls; mean age = 12;7, range = 12;0–13;3). We assessed children's arithmetic fluency with an independent paper-and-pencil test. In the test, 100 addition problems (e.g., 1 + 4, 51 + 8, 78 + 45) were presented with increasing difficulty, and children were asked to solve as many problems as possible in 10 min. Each child's arithmetic fluency score was the number of problems correctly solved. Seventh graders were able to solve more problems than fifth graders (78.5 vs. 69.2), \( F(1, 54) = 5.17, MSe = 233.4 \).

Children were also tested with the Stroop test (Stroop, 1935) and the Trail Making Test (TMT; Reitan & Wolfson, 1992) to assess inhibition and flexibility, respectively. We used three subtests of the Stroop color task. In the neutral subtest, 20 colored squares appeared on a sheet of paper. In the color-congruent subtest, children saw 20 color names written in matched color ink (e.g., the word "blue" written in blue color ink). In the color-incongruent subtest, color name and color of ink differed for the 20 words (e.g., the word “blue” written in red color ink). Participants were asked to name the color of the ink for each word and square as quickly as possible. If they made a mistake, they were asked to name the color again. We recorded the time taken to complete each subtest. We used interference scores (i.e., naming times for incongruent subtest and naming times for congruent subtest) as a measure of inhibition for each individual. Seventh graders obtained smaller interference scores than fifth graders (10.6 vs. 16.4 s), \( F(1, 56) = 20.52, MSe = 22.9 \).
The TMT consisted of two parts. In each part, children viewed 25 circles distributed over a sheet of paper. In Part A, the circles were numbered from 1 to 25, and participants needed to draw lines connecting the numbers in ascending order. In Part B, the circles included both numbers (1–13) and letters (A–L), and children needed to draw lines connecting the circles by alternating between numbers and letters in ascending order (i.e., 1–A–2–B–3–C, etc.). They needed to connect the circles as quickly as possible without lifting the pencil from the paper. We used flexibility scores (i.e., TMT B – TMT A) as a measure of flexibility for each child. Although seventh graders (57.3) obtained better flexibility scores than fifth graders (67.4), the difference between the two groups was not significant, \( F(1, 54) = 2.12, MSe = 676.6, ns. \)

Children first completed the paper-and-pencil arithmetic fluency test, then the computational estimation task, and finally the Stroop and TMT.

**Results**

**Age-related differences in effects of strategy repetitions during strategy selection**

**Better strategy selection on prime problems.** Mean percentages of better strategy selection were analyzed on prime problems\(^1\) (i.e., if participants used the better strategy on the two prime problems within one trial, strategy selection was coded 1; otherwise, it was coded 0) with a mixed-design ANOVA: 2 (Grade: fifth or seventh graders) \( \times \) 2 (Problem Type: rounding down or rounding up), with repeated measures on the last factor. Seventh graders selected the better strategy on each problem more often than fifth graders (99.0% vs. 96.4%), \( F(1, 54) = 6.68, MSe = 27.3, \eta^2_p = .11. \) No other effects came out significant (\( F_s < 1). \)

**Strategy repetitions on target problems.** ANOVAs were performed on the mean percentages of strategy repetitions with a mixed design: 2 (Grade: fifth or seventh graders) \( \times \) 2 (Trial: repeated or unrepeated) \( \times \) 2 (Best Strategy on Prime Problems: rounding down or rounding up), with repeated measures on the last two factors. Children of both groups repeated the same strategy more often on repeated trials than on unrepeated trials (78.8% vs. 29.5%), \( F(1, 53) = 187.23, MSe = 713.7, \eta^2_p = .78. \) The Grade \( \times \) Trial interaction, \( F(1, 54) = 4.89, MSe = 359.2, \eta^2_p = .08, \) revealed that this difference was larger for seventh graders (56.4%) than for fifth graders (42.2%). Separate analyses on repeated and unrepeated trials revealed that fifth and seventh graders repeated the same strategy across prime and target problems equally often on repeated trials (\( F = 1.51, ns \)), although seventh graders tended to repeat more often than fifth graders (81.1% vs. 76.4%). Moreover, the main effect of grade was significant on unrepeated trials, \( F(1, 53) = 4.46, MSe = 553.2, \eta^2_p = .08, \) revealing that fifth graders (34.2%) repeated the same strategy across prime and target problems more often than seventh graders (24.7%).

**Role of executive functions in age-related differences in strategy repetitions.** To further understand the relationships among age, inhibition, flexibility, and strategy repetitions, we ran two analyses. First, we found a significant correlation between mean percentages of strategy repetitions on unrepeated trials (where there was a significant effect of grade) and interference scores on the Stroop task (\( r = .52 \)). Mean percentages of strategy repetitions did not correlate with the TMT (\( r = .14, ns \)). In the second analysis, we assessed the mediational effect of grade-related differences in interference abilities on grade-related differences in strategy repetitions. This assessment was based on a comparison of the proportion of variance (as reflected in increments in \( R^2 \) corresponding to squared semi-partial correlations) associated with grade before and after the variance associated with Stroop interference scores was controlled. Results showed that the proportion of grade-related variance in mean percentages of strategy repetitions decreased significantly by 63% (from \( R^2 = .084 \) to \( R^2 = .031; \) Sobel Test = 2.00) after control of Stroop interference. Actually, grade-related difference on poorer strategy repetitions was no longer significant after statistical control of Stroop inhibition measures (\( F = 2.40, ns \)).

\(^1\) All ANOVAs in Experiment 2 were run with scores in arithmetic fluency as covariates. However, the same results came out. In addition, none of the correlations with arithmetic fluency was significant.
Age-related differences in effects of strategy repetitions during strategy execution

Effects of strategy repetition during strategy execution were analyzed on prime problems solved with the better strategy. Mixed-design ANOVAs were performed on participants’ mean solution times and percentage errors for the prime problems (only when the better strategy was selected on the first and second problems): 2 (Grade: fifth or seventh graders) × 2 (Strategy: rounding down or rounding up) × 2 (Problem: first or second), with repeated measures on the last two factors (see Table 2 for means).

There was a main effect of grade, $F(1, 54) = 16.69$, $MSe = 8408255.5$, $\eta^2_g = .24$, as seventh graders (4794 ms) were faster than fifth graders (6377 ms). All children were faster with the rounding-down strategy than with the rounding-up strategy (5214 vs. 5957 ms), $F(1, 54) = 71.16$, $MSe = 434108.8$, $\eta^2_g = .57$. Children executed strategies more quickly on the second problem (5512 ms) than on the first problem (5660 ms), $F(1, 54) = 4.93$, $MSe = 249662.3$, $\eta^2_g = .08$. The Strategy × Problem interaction showed that this difference was significant only with the rounding-down strategy, $F(1, 54) = 8.93$, $MSe = 56214$, $\eta^2_g = .06$. Although children made very few errors, seventh graders tended to err less than fifth graders (0.1% vs. 1.2%), $F(1, 54) = 3.83$, $MSe = 17.1$, $\eta^2_g = .07$, $p = .06$. No other effects came out significant either on estimation times ($Fs < 2.1$, ns) on percentage errors ($Fs < 3$, ns).

In the final analyses, to examine relationships between effects of strategy repetition during strategy execution and executive control, we calculated correlations between interference scores on the Stroop task and TMT and effects of strategy repetitions during strategy execution (i.e., [(mean solution times for first problems – mean solution times for second problems in a trial)/mean solution times for first problems in a trial] × 2 (Problem: first or second)). Both overall and in each group of children, these correlations were nonsignificant ($rs < .16$).

We compared mean percentages of better strategy selection on prime problems, mean percentages of strategy repetitions, and strategy performance of fifth graders tested in Experiments 1 and 2. We found no significant differences between fifth graders in Experiments 1 and 2 on mean percentages of best strategy selection on prime problems, on mean percentages of strategy repetitions, and on mean estimation times on prime problems ($Fs < 1.0$). The only difference that came out significant was on mean percentage errors on prime problems, with fifth graders in Experiment 2 erring less than fifth graders in Experiment 1 (1.2% vs. 3.3%), $F(1, 66) = 6.14$, $MSe = 45.4$, $p < .05$, although children made very few errors in both experiments.

General discussion

Decades of research have shown that children of all ages use a variety of strategies to accomplish cognitive tasks and that age-related changes in strategy repertoire, distribution, execution, and

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Problem</th>
<th>Fifth graders</th>
<th>Seventh graders</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounding down</td>
<td>First</td>
<td>6099 (1.2)</td>
<td>4530 (0.3)</td>
<td>5314 (0.7)</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>5898 (0.9)</td>
<td>4331 (0.0)</td>
<td>5114 (0.5)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>201 (0.3)</td>
<td>199 (0.3)</td>
<td>200 (0.3)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>5998 (1.0)</td>
<td>4430 (0.2)</td>
<td>5214 (0.6)</td>
</tr>
<tr>
<td>Rounding up</td>
<td>First</td>
<td>6850 (0.9)</td>
<td>5161 (0.3)</td>
<td>6005 (0.6)</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>6662 (2.0)</td>
<td>5156 (0.0)</td>
<td>5909 (1.0)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>188 (−1.1)</td>
<td>5 (0.3)</td>
<td>96 (−0.4)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>6756 (1.4)</td>
<td>5138 (0.1)</td>
<td>5957 (0.8)</td>
</tr>
<tr>
<td>Mean</td>
<td>First</td>
<td>6474 (1.0)</td>
<td>4845 (0.3)</td>
<td>5660 (0.7)</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>6280 (1.4)</td>
<td>4743 (0.0)</td>
<td>5512 (0.7)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>195 (−0.4)</td>
<td>102 (0.3)</td>
<td>148 (−0.1)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>6377 (1.2)</td>
<td>4794 (0.1)</td>
<td>5586 (0.7)</td>
</tr>
</tbody>
</table>

* $p < .05$.
† $p < .10$.  

Table 2
Mean solution times (in ms) and mean percentage errors in each group of children on the first and second problems as a function of the strategy used (Experiment 2).
selection underlie children’s cognitive development (e.g., Siegler, 1998). The current study documented one aspect of strategic changes in elementary school children, namely strategy repetition effects. In two experiments, we found effects of strategy repetition both during strategy execution (i.e., children were faster to execute a strategy on a problem immediately after executing it on a preceding problem) and during strategy selection (i.e., children tended to repeat the same strategy on two successive problems even when they should change strategies to obtain better performance). In addition, the current data showed comparable effects of strategy repetition during strategy execution in younger and older children and revealed that strategy repetitions during strategy selection were comparable in third and fifth graders (Experiment 1) but were smaller in seventh graders (Experiment 2).

Strategy repetition benefits (i.e., participants were faster to execute a strategy on the second problem than on the first problem of each trial) were found here and in comparable magnitudes in younger and older children. This is not consistent with our prediction of age-related changes in effects of strategy repetition during strategy execution. Because the better strategy was always the same on the first and second problems of each trial, although children were not informed of this, children may have quickly acquired this knowledge. This knowledge may have contributed to strategy repetition benefits and may have masked potential group differences in these benefits. Future studies could test this contribution by testing a condition in which the better strategy is the same on the first two prime problems and a condition in which the better strategy is different on these first two problems. Participants’ performance would indicate whether the differences in strategy repetition benefits across these two conditions change with children’s age. Note, however, that the current strategy repetition benefits were significant only for the easier rounding-down problems and not for the harder rounding-up problems. This Strategy × Problem interaction cannot be explained by explicitly knowing that the better strategy is the same on the first two problems. It is likely that the strategy used on the first problem is still activated on the second problem display. Children can retrieve and execute procedures of this just-executed strategy more quickly. On the first problem, the activation level of strategy is at baseline. Participants need to allocate more efforts to activate and execute this strategy. Moreover, the fact that effects of strategy repetition were found only for the easier strategy might result from an easier strategy remaining more strongly activated from one problem to the next. Alternatively, or additionally, lack of strategy repetition benefits on the harder strategy may result from strategy sequential difficulty effects (i.e., executing a strategy takes more time following a harder strategy than following an easier strategy) (Lemaire & Brun, 2014b; Uittenhove & Lemaire, 2012, 2013). Strategy sequential difficulty effects may have absorbed some of the strategy repetition benefits. Interestingly, strategy repetition benefits were of comparable magnitudes in younger and older children, suggesting that post-execution decay of strategy activation was not larger in younger children.

The current data also showed strategy repetition effects during strategy selection and age-related changes in these. We found that seventh graders repeated strategies less often than fifth graders (Experiment 2), who repeated strategies as often as third graders (Experiment 1). We also found that age-related similarities in strategy repetitions depended on the strategy in Experiment 1. Indeed, third graders repeated the easier strategy more often than the harder strategy in Experiment 1. Fifth graders in both experiments and seventh graders in Experiment 2 repeated both rounding strategies equally often. Third graders in Experiment 1 repeated the easier strategy more often than the harder strategy probably as a result of their having fewer resources and preferring to keep using the easier strategy after using it and to change to the easier rounding-down strategy after using the harder rounding-up strategy.

In both experiments, we found that group differences in strategy repetitions depended on whether the best strategy was the same (repeated trials) or different (unrepeated trials) on prime and target problems. We found no group differences on repeated trials where it was appropriate to repeat the same strategy to select the better strategy. Children of all grades repeated strategies on more than 90% of these repeated trials. Group differences were found on unrepeated trials where children should have not repeated strategies to select the better strategy. Our correlation and regression analyses examining relationships between strategy repetitions and executive control measures are consistent with the hypothesis that group differences in being able to resist strategy repetitions result in part from increased efficiency in executive functions with age. Many studies revealed that efficiency of
executive functions such as inhibition and shifting, crucially involved in best strategy selection (e.g., Hodzik & Lemaire, 2011; Lemaire & Lecacheur, 2011), increases with children's age. Such increased executive resources may have led seventh graders to have fewer difficulties in changing strategy from one problem to the next and to repeat the same strategies less often, especially when it was appropriate to change strategies. Age-related differences in executive resources between third and fifth graders in Experiment 1 might not be large enough to result in different rates of strategy repetitions. It was interesting to find in Experiment 2 that interference scores in the Stroop task were the only measure that correlated significantly with strategy repetitions on unrepeated trials and that it mediated age-related differences in strategy repetitions. This suggests that group differences in strategy repetitions resulted in part from increased inhibitory capacities. Note that we had only one measure of interference processing and one measure of flexibility here. The current findings in children suggest that strategy repetition previously reported in adults (Lemaire and Leclère, 2014a, 2014b; Luwel et al., 2009; Schillemans et al., 2009, 2012), and more generally Einstellung or problem set effects (Luchins, 1942; Luchins & Luchins, 1950), may originate from demands in executive processes made by the necessity to switch strategies from one trial to the next when the best strategies are not the same on consecutive problems. Future studies may assess more completely executive functions (e.g., testing inhibition with Simon tasks) with more tests and assess other executive functions (e.g., working memory updating) to determine whether inhibition is the only crucial executive function involved in strategy repetitions or if other executive functions contribute to children's being able to resist the temptation to repeat the same strategies across problems.

The current findings have important empirical and theoretical implications. Previous empirical studies have documented the crucial role of strategies in children's performance on a wide variety of cognitive domains as well as age-related differences in strategic variations (see Siegler, 2007, for an overview). These works also revealed that strategy, problem, situation, and participants' characteristics influence how participants select and execute strategies. The current findings showed that children's strategy choices and execution are also influenced by previous strategy choices. It would be interesting in future research to determine how the tendency to repeat the same strategy across problems interacts with other situation, strategy, problem, and participants' characteristics to influence participants' performance, how children obtain this performance, and age-related changes therein. Moreover, the phenomenon of strategy repetition, found here in arithmetic, may be found in other domains where strategic variations, and age-related differences in these, have been found. Finally, future studies may examine whether decreased strategy repetitions with increased age stem from age-related changes in adaptivity of strategy choices or from increased efficiency of executive processes enabling children to switch strategy on unrepeated trials. The current study could not examine age-related changes in strategy adaptivity and strategy repetitions independently. Strategy adaptivity and strategy repetitions can be investigated independently in future studies with different approaches. One approach is to make three strategies available. With three available strategies, children may change strategy on unrepeated trials without necessarily selecting the better strategy. In that case, they would switch strategy but would not be adapted in their strategy choices. In addition, relationships between adaptivity of strategy choices and strategy repetitions may be further examined by manipulating difficulty of prime problems and difficulty of best strategy selection on target problems.

Theoretically, none of the current computational models of strategies (Lovett & Anderson's (1996) ACT-R; Siegler & Shipley's (1995) ASCM; Lovett & Schunn's (1999) RCCL; Payne et al.'s (1993) adaptive decision maker; Rieskamp & Otto's (2006) SSL; and Siegler & Arraya's (2005) SCADS) assumes that children's strategy selection and execution on a given problem are biased by the strategy used on the immediately preceding problems. These models should be revised to account for the current strategy repetition phenomenon. This could be done within existing models by assuming that children are trying to minimize demands on executive functions to manage costs of changing strategy from one problem to the next. It would enable current models of strategy choices to computationally specify how children, especially younger children with lower executive control resources, repeat strategies on successive problems even when they would obtain better performance with different strategies.
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References


