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THE INFLUENCE OF PREVIOUS STRATEGY USE ON INDIVIDUALS' SUBSEQUENT STRATEGY CHOICE: FINDINGS FROM A NUMEROSITY JUDGEMENT TASK

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We conducted two experiments to test whether individuals' strategy choices in a numerosity judgement task are affected by the strategy that was used on the previous trials. Both experiments demonstrated that a previously used strategy indeed influences individuals' strategy choices. Individuals were more inclined to reuse the strategy that they had used on the previous trials. However, this study also demonstrated that this influence is limited to those items that do not have a strong association with a specific strategy. Possible underlying mechanisms for the observed effect are discussed.

During the last decades, many studies have shown that people use multiple strategies to solve a wide range of cognitive tasks. Although this variability in strategy use has been studied most extensively in the domain of arithmetic (e.g., Cooney, Swanson, & Ladd, 1988; Geary & Wiley, 1991; Lemaire, Arnaud, & Lecacheur, 2004), it has also been investigated in other domains of human cognition such as scientific reasoning (Kuhn, Schauble, & Garcia-Milla, 1992), spelling (Rittle-Johnson & Siegler, 1999), reading (Goldman & Saul, 1990), decision making (Payne, Bettman, & Johnson, 1988), time telling (Siegler & McGilly, 1989), serial recall (McGilly & Siegler, 1990), currency conversion (Lemaire & Lecacheur, 2001), etc. Besides the wide range of tasks in which this strategic variability has been found, it is also clear that it is not limited to one specific age group. Indeed, it has been found that infants (Adolph, 1995), preschoolers (Geary & Burlingham-Dubree, 1989), school-age children (Luwel, Verschaffel, Onghena, & De Corte, 2000), young adults (Schauble, Glaser, Raghavan, & Reiner, 1991), and older adults (Lemaire & Arnaud, 2008) employ several strategies to solve a particular task.

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This strategic variability implies that one always has to select a strategy for solving a particular problem. It has been found that, already from a young age on, people select their strategies quite adaptively, taking into account problem, subject, and context characteristics (Siegler, 1996; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009). This adaptivity has widely been documented in various task domains.

An example of the influence of problem characteristics on individuals' strategy choices can be found in the study of Luwel, Verschaffel, Onghena, and De Corte (2003a). Using a numerosity judgement task involving a 7 x 7 grid filled with different numerosities of coloured cells, they found that participants used two main strategies to determine the number of coloured cells in the grid: (a) an addition strategy, whereby participants added the (groups of) coloured cells, or (b) a subtraction strategy, in which the (groups of) empty cells were added and then subtracted from the total number of cells in the grid. The choice between those two strategies was heavily based on the ratio of coloured cells to empty cells in the grid. As a rational task analysis would predict, participants used the addition strategy more often on items with few coloured cells (and, thus, a lot of empty cells), while the subtraction strategy was used more often on items with many coloured cells and few empty cells. This was supported by a negative correlation ($r = -.92$) between the percentage use of the subtraction strategy and the number of coloured blocks and a positive correlation ($r = .92$) between the percentage use of the addition strategy and the number of coloured blocks. The role of subject variables is, for example, examined by Imbo and Vandierendonck (2007). Using a mental arithmetic task wherein participants had to solve simple addition problems, these authors found an influence of the subject characteristics processing speed (children with higher processing speed used retrieval more frequently than children with lower processing speed), arithmetic skill (children with good arithmetic skills chose the retrieval strategy more often than children with weaker skills), math anxiety (low-anxious children used retrieval more often than high-anxious children), and gender (boys used retrieval more frequently than girls) on participants' strategy choices. An example of a study in which the role of a context factor on participants' strategy choices was examined is one by Campbell and Austin (2002), who systematically varied the response deadline in a mental arithmetic task. These authors observed an increase in the use of the retrieval strategy for problems with a large problem size in the condition with a short response deadline compared to the condition with a long response deadline.

A context factor that has hitherto hardly been investigated in current strategy choice research is the effect of people's strategy use on previous items on their current strategy choice. The absence of this context variable in current theoretical and empirical research on strategy choice is remarkable, since there is an older line of research in the problem solving literature that has already shown that participants' choice of a solution method is affected by the method that was repeatedly used on a series of previous trials. This effect has been termed the *Einstellung* or *set effect*. In Luchins' (1942) famous study on this effect, two groups of participants solved a series of problems in which they had to fill a vessel with a certain amount of water using jars of three different sizes. The experimental group received a series of so-called 'set items' that could only be solved by means of the formula B – A – 2C. For example, if jar A has a size of 21 units, jar B of 127 units and jar C of 3 units and the vessel has to be filled with 100 units, then one can remove 21 units from jar B with jar A and two times 3 units with jar C (i.e., 127 – 21 – (2 x 3) = 100). After being presented with a series of such problems, participants in the experimental group received 'test items' which could either be solved with the formula B – A – 2C but also via a much simpler one (i.e., A – C). An example of such a problem is filling the vessel with 20 units when jar A contains 23 units, jar B 49 units and jar C 3 units. Participants in the control group, on the other hand, got the test items without being confronted with the series of set items. It was found that the experimental group solved this test items more often with the complex than with the simpler formula compared to the control group. This *Einstellung* effect has been replicated in an alphabet maze task (Cowen, Wiener, & Hess, 1953), consisting of items wherein participants had to move from one location to another in a square filled with letters by looking for the shortest path consisting of words. After a series of trials that could only be solved via a long path, mazes with both a long and a short path were offered. It was found that the majority of the participants in the experimental group kept on using the familiar long path. Also in other domains than problem solving it is found that human behaviour can be influenced by what has happened on the previous trials. Epstein and Rock (1960), for example, demonstrated that after a series of ambiguous figures in which one of the two possible interpretations was more clearly pronounced than the other, a following ambiguous figure was more likely to be perceived in line with the pronounced interpretation in the previous sequence of figures. Starting from the recurrent observation that individuals' behaviour is influenced by what has happened on previous trials, we wanted to test the hypothesis that the repeated use of a particular strategy on a series of items would have an effect on the following strategy choices.

The present study

The present study comprised of two related experiments in which we made use of Luwel et al.'s (2003a) experimental task wherein participants have to determine different numerosities of coloured cells that were presented in a rectangular grid. As explained above, participants mainly use two strategies for solving this task, namely the *addition* strategy and the *subtraction* strategy.

We distinguished between two kinds of items in this task: extreme items and test items. The extreme items were items which strongly elicited one of the two above-mentioned strategies, whereas for the test items it is assumed that both strategies are applicable on them. We constructed item sequences that consisted of five or six extreme items that all elicited one specific strategy and that were then followed by one test item. We hypothesized that participants will choose on the test item more often for the addition strategy when this item was preceded by a series of extreme items that all strongly elicited the addition strategy than when it was preceded by a series of extreme items that all strongly elicited the subtraction strategy. And vice versa, participants will more often choose for the subtraction strategy when the item was preceded by a series of extreme items that all strongly elicited the subtraction strategy than when it was preceded by items that strongly elicited the addition strategy. Furthermore, we expected that this effect would be largest in the middle part of the numerosity continuum and would gradually become smaller towards the extremes due to an increase in the associative strength between each of the two strategies and the numerosities located at both sides of this continuum (i.e., the smaller/larger the numerosities, the stronger they will elicit the addition/subtraction strategy) (Luwel et al., 2003a).

In Experiment 1, we wanted to determine the range in which the hypothesized effect of the previous strategy use on the subsequent strategy choice could occur. In Experiment 2, we examined this effect in greater detail by zooming in on the range of items to which this effect was restricted.

Experiment 1

Method

Participants

Thirty-one students (28 women and 3 men) in Educational Sciences from the Katholieke Universiteit Leuven participated in this study in exchange for course credits. Their mean age was 20.3 years (range: 17-48 yrs.).

Material and stimuli

The experiment was run on a portable computer, attached to a 15-inch screen with a resolution set to 800 x 600 pixels. Stimuli were rectangular grids containing five rows of ten cells each. The grids were presented on a black background and bounded by a red line. Each grid contained 50 cells of 1 x 1 cm each, which were separated by a thin red line. Each cell was either coloured green or remained empty (i.e., it had the same black colour as the background). The green cells were located randomly in the grid.

Two types of items were presented: extreme items and test items. There were two kinds of extreme items: (a) addition items that comprised the numerosities at the lower end of the numerosity continuum (i.e., 1 to 10) and which were known to strongly evoke the addition strategy in adult participants and, (b) subtraction items that consisted of numerosities at the upper end of the numerosity continuum (i.e., 40 to 49) and which strongly evoke the subtraction strategy (Luwel, Verschaffel, Onghena, & De Corte, 2003b). The test items were five numerosities that were selected at regular intervals from the range between the extreme items (i.e., 13, 19, 25, 31, and 37). Six different versions were created for each test item by randomly varying the position of the green cells in the grid. This was done to avoid that participants would answer on the basis of their recognition of a previous presentation of the same stimulus instead of actually determining the number of coloured cells.

We created sequences of items that always consisted of a series of five or six randomly chosen extreme items of the same kind, followed by one test item. This variation in the exact number of preceding extreme items was inserted to obscure to some extent the typical sequence pattern that arises in this type of experiment. Four different lists containing 30 such sequences were generated with the following restrictions: (a) each test item had to be included six times; (b) half of the sequences had addition items as extreme items, and the other half subtraction items; and (c) half of the sequences contained five preceding extreme items, the other half six. Thus, one list contained 195 trials in total.

Procedure

Participants were randomly allocated to one of the four lists and were then tested individually in a quiet room. Participants were seated about 40 cm from the screen. Before the start of the experiment five practice trials, which were representative for the whole numerosity range from 1 to 50 (i.e., 8, 17, 25, 34, and 45), were presented. Participants were instructed to determine the number of green cells in each grid as quickly and as accurately as possible. They were also asked to point on the computer screen at the type of cells they were counting (i.e., the green cells when they were using the addition strategy and the empty cells when they were using the subtraction strategy). This enabled the experimenter to determine participants' strategy use on each trial. After each practice trial, participants had to explain how they had solved that problem. These verbal reports revealed which terms the participants used to describe the addition and subtraction strategy; the experimenter noticed these terms and used them in the further communication about those strategies. Each trial started with the presentation of a fixation mark at the centre of the screen, which consisted of five white exclamation marks ("!!!!!") on a black background. After 750 ms, the fixation mark was replaced by the stimulus, which stayed on the screen until participants had made their numerosity judgement. As soon as participants started to pronounce their answer, the experimenter pressed the ENTER-key, which cleared the screen. Then the experimenter typed in the given answer as well as the type of strategy used, after which the next trial started. Before the start of the experimental trials, participants were instructed to use only the addition and the subtraction strategy. They were again asked to point on the computer screen at the elements they were counting. In contrast to the practice trials, they were not asked to describe the strategy they had used after every trial. Participants were allowed a short break at three fixed moments during the experiment.

Results

Before the analysis, we carried out a manipulation check to assure that the extreme items indeed evoked the intended strategy. For both the addition and the subtraction items, the intended strategy was used on 2554 of the 2557 presented items (i.e., on 99.88% of the trials).

The analyses were only conducted on the test items that were solved correctly. The following test items were removed from the analysis: (a) test items following an extreme item on which an inversion error (i.e., an item on which the participant responded with the complement of the actual numerosity plus or minus 5, e.g., the participant answered 7 when the correct answer was 43) occurred (since inversion errors indicate that a mixture of both strategies is used, it is impossible to decide whether the strategy on the test item is the same as the previous or not), (b) test items after a sequence in which more than one inversion error occurred (since then it cannot be guaranteed that participants have been influenced by solely one strategy during that sequence). Based upon these criteria, 2 trials were removed from the total of 823 correctly solved trials (i.e., 0.2%). Missing values were replaced by the mean of the other cells of that specific combination of test item and preceding strategy.

A 5 (numerosity: 13, 19, 25, 31, 37) x 2 (preceding strategy: addition vs. subtraction) repeated measures ANOVA was performed on the proportion subtraction strategy use. This analysis revealed a significant main effect of numerosity, $F(4, 120) = 446.40$, $p < .001$, partial $\eta^2 = .94$, revealing that the use of the subtraction strategy increased as a function of numerosity. There was also a significant main effect of the type of preceding strategy, $F(1, 30) = 9.54$, $p = .004$, partial $\eta^2 = .24$. As expected, the subtraction strategy was used more frequently when the preceding trials were also solved with this strategy ($M = .45$) than when these previous items were solved with the addition strategy ($M = .40$). Finally, we also found a significant two-way interaction between numerosity and preceding strategy, $F(4, 120) = 2.51$, $p = .045$, partial $\eta^2 = .08$ (see Figure 1). A Tukey test indicated that the effect of the preceding strategy use was restricted to numerosity 31 ($d = .14$, $p = .011$).

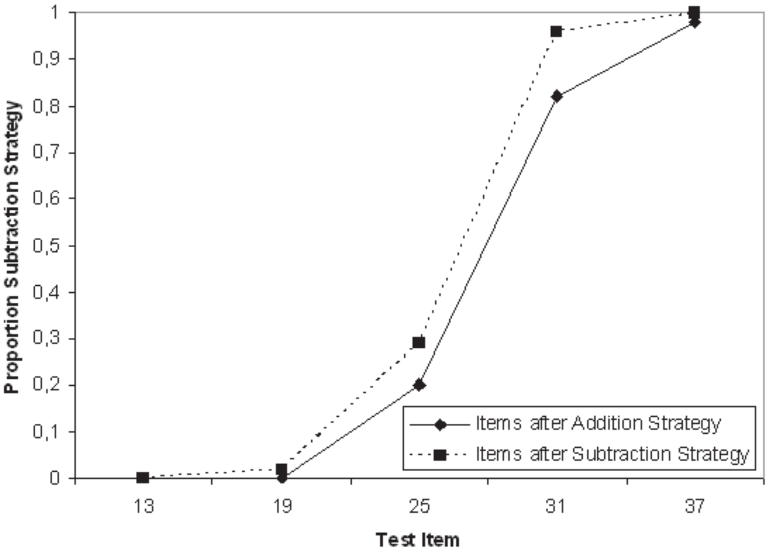

Figure 1
Proportion subtraction strategy use as a function of the test item and the preceding strategy in Experiment 1.

Discussion

The present experiment demonstrated that individuals' strategy choices are influenced by the repeated use of a particular strategy on the preceding items. However, this effect was restricted to numerosity 31. At first glance, it seems rather surprising to observe this effect on this numerosity and not on numerosity 25, the mathematical midpoint of the continuum. This can be due to the fact that the subtraction strategy is more complex than the addition strategy because it involves an additional step (i.e., subtracting the counted cells from the total number of cells) (Luwel et al., 2000), and therefore the numerosities around the midpoint of the continuum may still be somewhat more strongly associated with the addition than with the subtraction strategy. This is in agreement with the findings of Delvaux (2008) who found that most participants chose more often for the addition strategy on the mathematical midpoint 25, and only used both strategies to the same extent on a numerosity larger than 25. For all other items in this experiment, the associative strength between the problem features and the respective strategies may have been so overwhelming that the expected impact of the context factor "previous strategy" was negligible.

Experiment 2

Given the seemingly rather limited range of numerosities on which participants' strategy choices can be influenced as a function of their strategy use on the preceding trials, we decided to replicate Experiment 1 on a much narrower range of numerosities. This range consisted of the three numerosities preceding and following the item on which we observed the biggest influence on participants' strategy choices as a function of their preceding strategy use (i.e., 31). As such, this yielded seven test items: 28, 29, 30, 31, 32, 33, and 34.

Method

Participants

Twenty-four students (22 women and 2 men) in Educational Sciences from the Katholieke Universiteit Leuven participated in this study in exchange for course credits. None of them had participated in Experiment 1. Their mean age was 19.5 years (range: 17-25 yrs.).

Material and stimuli

The stimuli in this experiment were similar to those in Experiment 1 (i.e., coloured cells presented in a 5 x 10 grid). As explained before, the test items consisted, of the numerosities between 28 and 34. The extreme items differed somewhat from those in the previous experiment. At the lower end of the continuum, we now used the numerosities 5 to 14, and at the upper end the numerosities 36 to 45. By removing the most extreme items (1 to 4 and 46 to 49), we prevented that participants could solve some trials by subitizing the coloured or empty cells instead of actually counting them. Based on the results of Experiment 1 on the numerosities 13 and 37, we can assume that the chosen numerosities still strongly elicit either the addition or the subtraction strategy. Since each test item was presented eight times, eight different versions were created to avoid that participants could solve the items based on their recognition of a previous presentation of the same stimulus.

Following the same restrictions as in Experiment 1, we created four lists of item sequences that always consisted of a series of five or six randomly chosen extreme items of the same kind followed by one test item. Since each test item was now presented eight times instead of six times as in Experiment 1, each list contained 56 item sequences instead of 30. As such, each participant solved 364 trials.

Procedure

The procedure was exactly the same as in Experiment 1.

Results

As in Experiment 1, we executed a manipulation check to test if the extreme items indeed evoked the intended strategy. For the addition items, this was the case for 3692 of the 3696 presented items (i.e., 99.89% of the items), and for the subtraction items, this was the case for 3693 of the 3696 presented items (i.e., 99.91% of the items).

Only the test items that were solved correctly were included in the analyses. The same criteria for removing test items as mentioned in Experiment 1 were used, which led to a data reduction of 5 trials from a total of 1210 correctly solved trials (i.e., 0.4%). Missing values were replaced by the mean of the other cells of that specific combination of test item and preceding strategy.

A 7 (numerosity: 28, 29, 30, 31, 32, 33, 34) x 2 (preceding strategy: addition vs. subtraction) repeated measures ANOVA was performed on the proportion subtraction strategy use. This analysis revealed a significant main effect of numerosity, $F(6, 138) = 17.22$, $p < .001$, partial $\eta^2 = .43$, indicating an increase in the use of the subtraction strategy with increasing numerosity. There was also a significant main effect of preceding strategy, $F(1, 23) = 12.30$, $p = .002$, partial $\eta^2 = .35$: the proportion subtraction strategy use was higher following the use of the subtraction strategy on the preceding trials ($M = .97$) than following the use of the addition strategy ($M = .85$). Finally, the interaction between those two variables was significant, $F(6, 138) = 7.00$, $p < .001$, partial $\eta^2 = .23$ (see Figure 2). A Tukey test indicated that the difference in proportion subtraction strategy use was only significant for the numerosities 28 ($d = .32$, $p < .001$), 29 ($d = .15$, $p = .007$), and 30 ($d = .13$, $p = .05$).

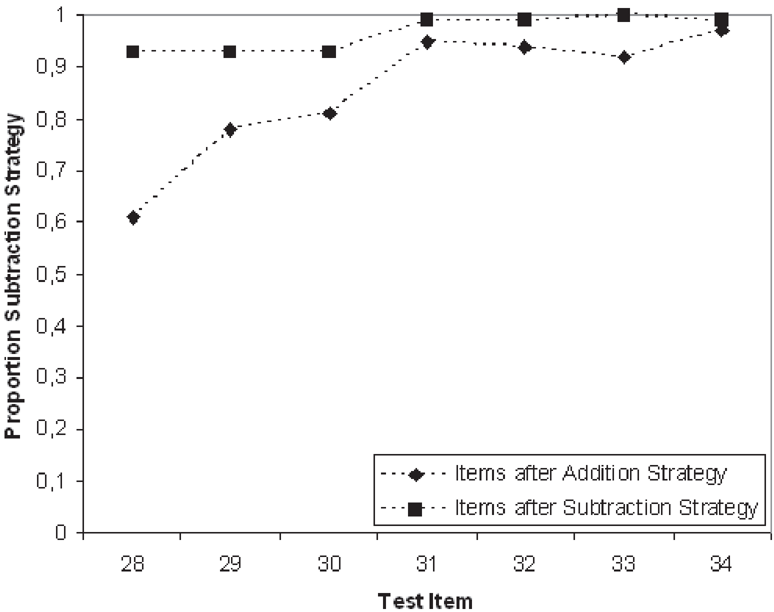

Figure 2
Proportion subtraction strategy use as a function of the test item and the preceding strategy in Experiment 2

Discussion

As in Experiment 1, we observed that the preceding repeated use of a particular strategy has an effect on participants' subsequent strategy choices. Again, this effect remained restricted to a small range of numerosities, namely the numerosities between 28 and 30. Given that the largest influence was found on the first numerosity of the tested range (i.e., 28), it cannot be excluded that there would also have been a significant influence on the numerosities just below the tested range, such as the numerosities 27 and 26.

General discussion

The present study tested whether individuals' strategy choices are influenced by their previous strategy use in the context of a numerosity judgement task. In both experiments test items that were assumed to be equally well solvable by means of an addition or subtraction strategy, were preceded by a series of five or six extreme items that were all solved either via the addition or subtraction strategy. In Experiment 1, the test items were drawn from a broad numerosity range. The results showed that there was indeed an influence of the previously used strategy, but the effect was restricted to only one of the five tested numerosities. Interestingly, the effect was not observed on the test item located in the mathematical middle of the numerosity range (i.e., 25) but on the first test item larger than this midpoint, namely 31. In Experiment 2, we focused on the range surrounding this numerosity, namely 28 to 34. The results revealed an influence of previous strategy use on the numerosities immediately preceding 31, namely 28 to 30. As such, our studies have provided convincing empirical evidence that the strategy used on previous items may bear an effect on the strategy choice on the current item. But, at the same time these results have shown that the influence of this context factor is restricted to problems with certain problem features, namely problems for which the association with both strategies is more or less the same. For the other numerosities, the impact of the proportion of coloured (vs. empty) cells is so overwhelming that the effect of the strategy being used on the previous items is negligible.

Although both experiments exhibited an influence of the previous strategy on a small range of test items, the exact results were somewhat different. Experiment 1 showed an effect on test item 31, while in Experiment 2 the effect was on test items 28 to 30. This slight difference might be attributed to differences in subject characteristics between the two samples tested. Verschaffel, De Corte, Lamote, and Dherdt (1998) and Delvaux (2008) already found large individual differences in associative strength between the different numerosities and the two strategies under consideration. Taking into account the rather small sample size for both experiments (i.e., 31 participants in Experiment 1 and 24 participants in Experiment 2), similar differences might have been present here as well. More specifically, if the same set of test items is used for all participants, and if there are (large) individual differences in associative strength, then it is possible to observe small differences with respect to the kind of items on which an influence of a previously used strategy can be observed.

Although we have demonstrated that the repeated application of a particular strategy has an effect on the subsequent strategy selection process for a limited set of items, little is known so far about the mechanism that is responsible for this effect. We propose three possible mechanisms that can account for the present results. A first mechanism is the occurrence of an *Einstellung* or *set effect*. The repeated application of one specific strategy might have caused a set effect which could have biased participants' strategy selections in the direction of the most recently used strategy. Stated differently, this set effect could have blinded participants for the possibility of applying the other strategy that might have been equally or even slightly more efficient for the item at hand. Interestingly, the results of the present study suggest that the occurrence of a possible set effect may be dependent on the associative strength between the problem at hand and each strategy. As such, this outcome could extend previous findings from the *Einstellung* literature. Indeed, to the best of our knowledge, it has never been reported that set effects might be moderated by the associative strength between the test item and a particular solution strategy (because associative strength was not addressed in earlier research on set effects). Take, for instance, Luchins' (1942) experiments with the water jar problem, where the associative strength between the test item and either the complex or the simpler solution method assumably remained constant across the different problems that were presented as a test item. For instance, consider a test item in which one has to arrive at an amount of 20 units with jar A = 23 units, jar B = 49 units and jar C = 3 units and another test item with an outcome of 6 units and jar A = 14 units, jar B = 36 and jar C = 8 units. Even though the short solution method (i.e., 20 – 3 and 14 – 8) is more straightforward than the longer one (i.e., 49 – 20 – (2 x 3) and 36 – 14 – (2 x 8)) for both items, there is no reason to assume that one problem would elicit the short solution method more strongly than the other one.

A second possible mechanism that could account for the present findings is priming. This priming mechanism can be conceived as a temporary increase in the strength of the last applied strategy, which in its turn will increase the probability that this strategy will be chosen on the following trial. Thus, on items with which the two strategies are more or less equally strongly associated, the primed strategy will slightly be favoured in the selection process at the expense of the other. However, on items that are more strongly associated with one of the two strategies, the boost in the strength of the weaker strategy due to the priming process might not be large enough to overcome the existing strength of the stronger strategy. The possibility of strategy priming has recently been suggested in Siegler and Arraya's (2005) SCADS* model, which tries to explain how individuals select and discover strategies.

A third possible explanatory mechanism is the so-called *strategy switch cost*. Only very recently, it has been demonstrated that switching from one strategy to another entails a cognitive cost that manifests itself in longer solution times immediately after having switched from one strategy towards another than when repeating the same strategy on two subsequent trials (Lemaire & Lecacheur, 2010; Luwel, Schillemans, Onghena, & Verschaffel, 2009). Maybe participants in the present study tried to avoid this strategy switch cost by continuing to apply the same strategy on the test items as on the previous sequence of extreme items, even if the problem characteristics suggest that another strategy would be somewhat more appropriate. Arguably, for an item with a very strong associative strength with either the addition or subtraction strategy, the cost of the strategy switch would be overwhelmed by the profit of choosing the strategy with the greatest associative strength. Further research is needed to test which of the aforementioned psychological mechanisms underlies the current findings.

Another issue for further research relates to the number and type of preceding trials that are necessary to evoke the observed influence of previous strategy use effect. In both experiments we administered five or six preceding highly extreme items before the test item. This raises two questions for further research. First, will this effect also occur if the test item is preceded by fewer extreme items, or even after the presentation of a single extreme item. And if so, will the effect be as strong as in the current study or will it become smaller with a decreasing number of preceding extreme items? Second, will we observe a similar effect if participants are presented less extreme items, or, stated differently, when they are confronted with a situation that comes closer to their more "natural" strategic behaviour?

A final question that arises from the present experiments pertains to the effect of age on the observed results. The present study included young adults as participants. As mentioned earlier, it is known that multiple strategy use is also observed in age groups other than (young) adults. However, this does not necessarily mean that the strategy choices in all age groups are influenced in the same way by a previously used strategy. Children, for example, are known to have less strong associations between specific problems and strategies (Siegler, 1996). Therefore, it is possible that they are more susceptible to these influences than (young) adults. And what about the elderly? It has been shown that people become more rigid as they grow older (Lemaire & Lecacheur, 2001), and this rigidity may further strengthen their tendency to stick to the strategy being used on previous items. Further research is needed to establish the extent to which the current findings are moderated by age effects.

To conclude, the present study has provided findings from a numerosity judgement task that document the influence of previous strategy use on young adults' subsequent strategy choices. These findings have implications for research on strategy choice in different domains. Indeed, for any study wherein individuals are allowed to make strategy choices, one must always bear in mind that at least some of these choices could be biased by the strategy that was used before.

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