Psychologica Belgica
2012, 52/4, 307-325
DOI: http://dx.doi.org/10.5334/pb-52-4-307

THE EFFECT OF SINGLE VERSUS REPEATED PREVIOUS STRATEGY USE ON INDIVIDUALS' SUBSEQUENT STRATEGY CHOICE

Viki Schillemans[(1)], Koen Luwel[(1, 2)], Eva Ceulemans[(1)], Patrick Onghena[(1)], & Lieven Verschaffel[(1)]*
(1) KU Leuven & (2) Hogeschool-Universiteit Brussel

Previous research has shown that participants' strategy choices can be influenced by the previously-used strategy. This *perseveration effect* has been demonstrated both after a repeated use of the previous strategy (e.g., Schillemans, Luwel, Bulté, Onghena, & Verschaffel, 2009), but also after a single use of the previous strategy (Lemaire & Lecacheur, 2010). In the present study, we tested whether this perseveration effect would be stronger after a repeated than after a single previous strategy application. We were able to replicate the perseveration effect but we did not find evidence for an influence of the number of previous strategy applications on the strength of this effect. An additional cluster analysis revealed that only about one third of the participants was susceptible for the perseveration effect. The theoretical, methodological, and educational implications of these results are discussed.

Introduction

A growing body of research has shown that people use multiple strategies to solve a wide range of cognitive tasks, such as arithmetic (e.g., Torbeyns, Verschaffel, & Ghesquière, 2005), reading (e.g., Sung, Chang, & Huang, 2008), decision making (e.g., Milkman, Chugh, & Bazerman, 2009), and currency conversion (e.g., Lemaire & Lecacheur, 2001). This strategic variability implies that one always has to choose a strategy from his/her strategic repertoire when solving a particular problem. Several studies have demonstrated that problem, subject, and/or environmental characteristics bear an influence on participants' strategy choices (Siegler, 1996; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009).

* Viki Schillemans, and Lieven Verschaffel, Centre for Instructional Psychology and Technology, KU Leuven; Koen Luwel, Centre for Educational Research and Development, Hogeschool-Universiteit Brussel and Centre for Instructional Psychology and Technology, KU Leuven; Eva Ceulemans, and Patrick Onghena; Centre for Methodology of Educational Research, KU Leuven.
This study was funded by the grant G.0377.06 from the Fund of Scientific Research-Flanders (Belgium) and the GOA grant 2012/010 from the Research Fund KU Leuven to the Centre for Instructional Psychology and Technology.
Correspondence concerning this article should be addressed to Koen Luwel, Centre for Instructional Psychology and Technology, KU Leuven, Dekenstraat 2, B-3000 Leuven. E-mail: Koen.Luwel@ppw.kuleuven.be

An environmental factor that has hardly been studied in research on strategy choices so far is the influence of a previously executed strategy on the following strategy selection process. More particularly, it can be argued that having used a particular strategy on one or more problems will increase the chance that it will be used again on the following problem. Although the empirical evidence for this *perseveration effect* in strategy selection is still very scarce, the earlier Gestalt psychological work concerning the so-called *Einstellung* effect (Luchins, 1942) contains some indications of its existence. In Luchins' basic study, 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 × 3) = 100). After being presented with a series of such problems, participants in the experimental group received a number of '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 the test items more often with the complex than with the simpler formula compared to the control group. In other words, most of the participants in the experimental group did not come up with the much easier strategy but rather stuck to the complex solution method.

Since the publication of Luchins' (1942) well-known study, the Einstellung effect has been frequently replicated, both with the water jar task (e.g., Cunningham, 1965; McKelvie, 1984), but also with other tasks, like for instance an alphabet maze task (Cowen, Wiener, & Hess, 1953; Cunningham, 1965). In this task, participants are presented with a grid in which each cell contains a letter. They are instructed to move from the cell in the upper right corner to the one in the lower left corner in such a way that the path they follow spells out a word. The 'set items' could only be solved via a long path, whereas the 'test items' could be solved via this long path but also via a much shorter alternative path. Also in this task, participants were more inclined to persist in using the longer path on the test items after having solved the set items with the longer path. Until recently, however, such a perseveration effect had not been studied in situations in which participants have to choose between two strategies that are already available in their strategy repertoire, rather than having to detect an alternative strategy for solving a problem (as was the case in the above-mentioned studies).

Starting from the findings concerning the Einstellung effect, Schillemans, Luwel, Bulté, Onghena, and Verschaffel (2009) and Lemaire and Lecacheur (2010, Experiment 3) have – simultaneously but independently – started to collect evidence for the occurrence of a perseveration effect in situations in which people have to choose between two strategies available in their strategy repertoire. More specifically, they tested whether the previous use of a strategy could affect the subsequent strategy choice in two different domains of elementary arithmetic, respectively numerosity judgement and two-digit addition.

Schillemans et al. (2009) instructed participants to determine several numerosities of coloured cells presented in a 5 × 10 grid (see Figure 1). In line with previous studies involving the same task (Luwel, Verschaffel, Onghena, & De Corte, 2003a; Verschaffel, De Corte, Lamote, & Dherdt, 1998), participants relied on two main strategies namely an *addition* strategy, wherein participants added the different coloured cells individually or in groups to arrive at the total number of coloured cells, and a *subtraction* strategy, wherein they added the empty cells individually or in groups and then subtracted this number from the total number of cells. These studies demonstrated that the choice between these two strategies available in their strategy repertoire is highly influenced by the ratio of coloured versus empty cells in the grid. Participants typically chose the addition strategy when there were only few coloured and a lot of empty cells in the grid, whereas they adopted the subtraction strategy when there were a lot of coloured and only few empty cells. When neither the coloured nor the empty cells clearly outnumbered the other ones, individuals used either of the two strategies. In their investigation, Schillemans et al. (2009) used two kinds of items: extreme items and test items. Extreme items were items with either a very small or a very large number of coloured cells, which were known to exclusively elicit the addition (i.e., addition items) or the subtraction strategy (i.e., subtraction items). The test items, however, were assumed not to be so exclusively associated with either of the two types of strategies, but to elicit both strategies about equally strongly. Participants received several sequences of items, always consisting of a series of five or six extreme items all evoking the same strategy, followed by one test item. Results showed that individuals' strategy choices on the test items were indeed influenced by the type of strategy being repeatedly executed on the previous extreme trials. As expected, participants were more inclined to reuse the addition strategy on a test item when that item was preceded by a series of addition items than when it was preceded by a sequence of subtraction items and vice versa. Furthermore, it was found that this perseveration effect remained limited to the so-called *strategy-neutral* items (i.e., a rather small range of test items for which the addition and the subtraction strategy were almost equally attractive or – stated differently – that elicited the two strategies about equally strongly). For the other (not strategy-neutral) test items, the impact of the problem characteristic "ratio of coloured versus empty cells" was apparently so overwhelming that the effect of the environmental characteristic "previous strategy use" was negligible.

Lemaire and Lecacheur (2010, Experiment 3) studied the perseveration effect with a two-digit addition task. This task can be solved with two different strategies that are equally difficult (e.g., Beishuizen, 1993; Lemaire & Arnaud, 2008; Lucangeli, Tressoldi, Bendotti, Bonanomi, & Siegel, 2003), namely full- and partial-decomposition. In the *full-decomposition* strategy, participants start solving the addition problems by adding the tens, then the units, and finally they add the two results (e.g., 27 + 38; 20 + 30 = 50; 7 + 8 = 15; 50 + 15 = 65). In the *partial-decomposition* strategy, they first add the tens of the second operand to the first operand, and thereafter they add the units of the second operand (e.g., 27 + 38; 27 + 30 = 57; 57 + 8 = 65). Lemaire and Lecacheur created pairs of problems whereby participants had to solve the first problem of each pair with a strategy that was imposed by means of a cue, whereas they were free to choose either of the two strategies to solve the second problem of each pair. Each problem pair was always followed by a filler task in which participants had to judge whether a string of letters consisted of only vowels or consonants or both types of letters. Lemaire and Lecacheur also observed a perseveration effect on participants' strategy choices: participants were more inclined to reuse the previously executed strategy on the second problem of the pair than to switch to the other strategy.

The paradigm used by Lemaire and Lecacheur (2010) differs in two important ways from the one used by Schillemans et al. (2009). First, Lemaire and Lecacheur *cued* the intended strategy on the preceding items instead of having it being *evoked* by the specific nature of the preceding trials as was done by Schillemans et al. Second, and most important for the current study, Lemaire and Lecacheur (2010) let the test item precede by only one strategy application while the test items in the Schillemans et al. study were always preceded by several strategy applications.

As such, the perseveration effect has been demonstrated both after a single (Lemaire & Lechacheur, 2010, Experiment 3) and after a repeated previous strategy application (Schillemans et al., 2009). This raises the question whether the perseveration effect is equally strong in both situations, or whether its strength is affected by the number of strategy repetitions.

The present study had three goals. First, we wanted to replicate the study of Schillemans et al. (2009); that is, to replicate the perseveration effect after a repeated strategy use. Second, we wanted to replicate the perseveration effect after the single use of a strategy in another type of task than two-digit addition, namely numerosity judgement. Third, we wanted to examine whether the strength of this perseveration effect would be the same after a *repeated* than after a *single* previous strategy application. To achieve these goals, we conducted an experiment that consisted of two conditions: a *repeat* condition in which a strategy-neutral test item was preceded by five addition or five subtraction items, and a *single* condition in which only one addition or subtraction item preceded the strategy-neutral test item.

Method

Participants

An *a priori* power analysis suggested that at least 54 participants were needed for detecting a within-between interaction in a repeated measures ANOVA, for a medium effect (effect size = 0.25), a power of .95 and a level of significance equal to .05. We rounded this number up to 60 participants. All participants (5 men and 55 women) were students in Educational Sciences at the KU Leuven, Belgium. Their mean age was 19.72 yrs. (range: 17 yrs.-22 yrs.) and they received two film tickets as a reward for their participation.

Material and stimuli

The experiment was run on a PC with a Pentium D-processor, attached to a 17” screen with a resolution set to 1280 × 1024 pixels. Stimuli were rectangular grids containing five rows with ten cells each (see Figure 1). As such, each grid contained 50 cells, which were sized 1 × 1 cm each and were separated from each other by a thin red line. The grids were bounded by a thick red line and were presented on a black background. Each cell of the grid 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.

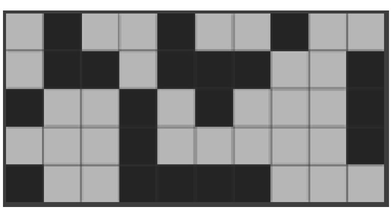

Figure 1

Example of a stimulus of the numerosity judgement task containing 30 coloured cells

Two types of items were presented: strategy-neutral test items and extreme items. The strategy-neutral test items were items that elicited the two strategies about equally strongly and were used to assess participants’ strategy selections. These test items were selected on the basis of a pilot study (see

Appendix) which revealed that the numerosities 25 to 29 were most strategy-neutral. The extreme items were used to manipulate participants' strategy use before the test item, and consisted of two types: (a) addition items, which strongly evoked the addition strategy and comprised numerosities at the lower end of the continuum (i.e., the numerosities 5 to 14), and (b) subtraction items, which strongly elicited the subtraction strategy and comprised numerosities at the higher end of the continuum (i.e., the numerosities 36 to 45)[1]. Fifty different series of five randomly chosen extreme items were built (i.e., series that always consisted of five addition items, or five subtraction items). These series were constructed with two restrictions: (a) a numerosity could not appear twice in a sequence, and (b) all possible extreme items were administered equally often during the whole experiment. In the single condition, the test item was always inserted between the first and the second extreme item in each sequence, whereas in the repeat condition the test item always occurred after the fifth extreme item in each sequence. To obscure the presentation order of the six trials within these (experimental) sequences, we presented after each fifth sequence a filler sequence consisting of six randomly selected numerosities drawn from the whole numerosity range between 5 and 45 (e.g., a sequence with the numerosities 30 – 21 – 18 – 24 – 31 – 10). As such, participants received 50 sequences of five extreme items and one test item, and nine sequences of six randomly selected numerosities. This sums up to a total of 354 trials.

To neutralise influences from a previous sequence to the next, an intermediate task was included after each sequence (i.e., both after the experimental sequences as well as after the filler sequences). This intermediate task allowed us to control for the number of preceding strategy applications. Otherwise, the number of preceding strategies could have been larger than the intended one or five (i.e., when the preceding sequence and its corresponding neutral item would all have been solved with the same strategy as the current one). This intermediate task was a lexical decision task whereby participants were presented a series of six letter strings of five letters each. For each string they had to judge whether it was a word (e.g., *tafel,* meaning table) or a non-word (e.g., *asban*, which has no meaning in Dutch). To make this task somewhat harder, we selected pseudo-words (i.e., pronounceable non-words) as non-words.

---

1. We did not use the even more extreme numerosities 1 to 4 (as addition items) and 46 to 49 (as subtraction items) for two reasons: first, these numerosities can be determined with subitizing instead of counting which would entail the use of a different strategy than the intended addition or subtraction strategy, and second, choosing for somewhat less extreme items obscured to some extent the distinction between test and extreme items, which made the design of the experiment less obvious for the participants.

Procedure

Participants were randomly allocated to either the repeat condition or the single condition and were tested individually in a quiet room. They were seated at about 40 cm from the screen. To make the design of the study less obvious for the participants, we told them that we would test their ability to switch between two different tasks, namely a numerosity judgement task and a lexical decision task. Afterwards, participants were debriefed about the actual goal of the study.

Numerosity judgement task

Before the start of the experiment, participants were presented five practice trials that were representative for the whole numerosity range (i.e., the numerosities 4, 13, 22, 31, 40). Participants were instructed to determine the number of green cells in each grid as fast and as accurately as possible. They were also asked to explain after each trial how they had solved the problem. This enabled the experimenter to discern which terms the participant spontaneously used to describe the addition and the subtraction strategy. The experimenter noticed these terms and applied them in her further communication with the participant about the strategies. If the participant had not applied the subtraction strategy spontaneously during these five practice trials, this strategy was explained to him/her by the experimenter. Before the start of the experimental trials, participants were told that they were only allowed to use the addition and the subtraction strategy and, for every trial, they were asked to point on the screen at the cells they were counting at that moment. This pointing behaviour enabled the experimenter to identify the strategy used on every trial easily and reliably. Each trial started with the presentation of a fixation mark in the centre of the screen, namely five white exclamation marks ('!!!!!') on a black background. After 750 ms, the fixation mark was replaced by the stimulus. As soon as participants had pronounced their answer, the experimenter pressed the SPACE-bar, which blanked the screen. Thereafter the experimenter typed in the given answer and the strategy used, which led to the start of a new trial.

Intermediate task

As mentioned above, a lexical decision task was administered after each sequence of six numerosity judgement trials to neutralise the influence of one sequence to the next one. Before the start of the experiment, participants also received five practice trials for this task. As in the numerosity judgement task, every trial started with a fixation mark in the centre of the screen (i.e., five white exclamation marks on a black background). After 750 ms this fixation mark was replaced by a letter string, presented in 24-point Courier New font (white colour on a black background). Participants had to say as fast as possible *woord* (meaning "word") when the letter string was an existing word, or *non-woord* (meaning "non-word") when the letter string was a non-existing word. After the participant had given his or her answer, the experimenter pressed the SPACE-bar which blanked the screen. After the experimenter had typed in the participant's answer, the next trial started. The transition between the two tasks (i.e., the numerosity judgement task and the intermediate task) was guided by a cue that stayed on the screen for 750 ms. If the upcoming task was the numerosity judgement task, the cue was a small grid, if the upcoming task was the intermediate task, the cue consisted of the letters a, b, c, and d arranged as a rhomb.

Results

Two participants were removed from the data set: one because she unexpectedly solved the subtraction items frequently with the addition strategy, and the other one because her pointing behaviour did not enable us to reliably identify her strategy use. The analyses were conducted on the test items only, and we removed from the analyses these test items that were: (a) immediately preceded by an inversion error (i.e., an item on which the participant responded with the complement of the actual numerosity plus or minus 5, for example, the participant answered 7 when 43 out of the 50 blocks were coloured; 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) preceded by a sequence in which more than one inversion error occurred, (c) immediately preceded by an extreme item which was not solved via the intended strategy, (d) preceded by a sequence in which more than one extreme item was not solved via the intended strategy, and (e) on which the participant switched during the solution process from one strategy to the other. Based upon these criteria 39 out of 2900 test items were removed from the analyses (i.e., 1.3%).

We conducted a 2 (condition: single vs. repeat) × 2 (preceding strategy: addition vs. subtraction) × 5 (numerosity: 25-29) ANOVA with repeated-measures on the last two variables and with the proportion subtraction strategy use on the test items as the dependent variable. The proportion subtraction strategy use in the various conditions can be found in Table 1. The analysis revealed a main effect of preceding strategy, $F(1, 56) = 57.96$, $p < .0001$, partial $\eta^2 = 0.51$. As expected on the basis of the perseveration hypothesis, participants applied the subtraction strategy significantly more frequently after having executed the subtraction strategy ($M = .68$) than after having used the addition strategy ($M = .42$). In line with previous research (e.g., Luwel, Verschaffel, Onghena, & De Corte, 2003b), this analysis also yielded a main effect of numerosity, $F(4, 224) = 32.96$, $p < .0001$, partial $\eta^2 = 0.37$, indicating an increase in the proportion of subtraction strategy use with increasing numerosity. A contrast analysis revealed a significant linear trend $F(1, 56) = 78.58$, $p < .001$. There was also a significant interaction between preceding strategy and numerosity, $F(4, 224) = 7.37$, $p < .0001$, partial $\eta^2 = 0.12$, which indicated that, although the perseveration effect was significant for all test items, it was somewhat smaller for the items with the numerosities 26 and 28. However, the crucial test for the main research question – namely, whether the strength of the perseveration effect would differ as a function of the number of previous strategy repetitions – was the interaction between condition and preceding strategy. This interaction failed to reach significance, $F(1, 56) = 3.22$, $p = .08$, partial $\eta^2 = 0.05$, indicating that the perseveration effect occurred both in the single and the repeat condition, but we did not find evidence for a significant difference in magnitude between the two conditions. All other effects were not significant.

Table 1

Mean proportion (and standard deviations) subtraction strategy use on the different strategy-neutral items as a function of preceding strategy and condition

Preceding Strategy	25	26	27	28	29
			Single condition		
Addition Strategy	.36 (.29)	.47 (.33)	.43 (.29)	.66 (.31)	.46 (.29
Subtraction Strategy	.61 (.32)	.57 (.31)	.69 (.31)	.75 (.26)	.76 (.27)
			Repeat condition		
Addition Strategy	.20 (.21)	.28 (.26)	.36 (.32)	.54 (.24)	.44 (.28)
Subtraction Strategy	.62 (.33)	.55 (.29)	.70 (.32)	.73 (.27)	.81 (.21)

During the experiment, clear differences in participants' response patterns were observed. Specifically, some students seemed to show a quite strong perseveration effect whereas it seemed absent in others. Therefore, we decided to conduct an additional *K*-means cluster analysis on the numerosity × preceding strategy data, to investigate whether groups of participants with different response patterns could be distinguished. *K*-means cluster solutions with two to ten clusters were fitted using 1000 restarts (for a discussion of the use of *K*-means cluster analysis, see Steinley, 2003) and, on the basis of a scree test[2], the three-cluster solution was selected. These three clusters correspond with three clearly different response patterns on the test items (see Figure 2). Members of Cluster 1 ($n = 22$) showed a strong perseveration

2. The sum of squared residuals for the solutions with two to ten clusters amounted to 31.20, 24.73, 21.11, 18.53, 17.13, 15.90, 14.83, 13.84, and 13.04, respectively

effect; that is, when previous items were solved via the subtraction strategy, the test items were also frequently solved via this subtraction strategy, and when the previous items were solved via the addition strategy, the test items were also frequently solved via this addition strategy. Members of Cluster 2 ($n = 20$) used the subtraction strategy very often and showed hardly any influence of the previously-used strategy, while members of Cluster 3 ($n = 16$) used the subtraction strategy very rarely (and thus used the addition strategy very often) and also showed hardly any influence of the previously-used strategy. An additional χ^2-test indicated that the number of participants in the different clusters did not differ as a function of condition (single vs. repeated exposure to extreme items), $\chi^2(2) = 3.62$, $p = .16$.

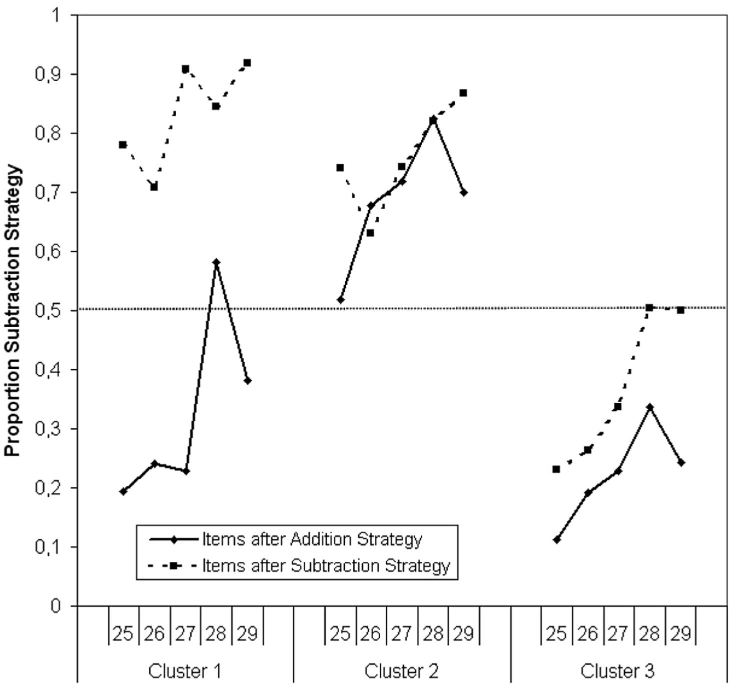

Figure 2
Three cluster solution of participants' strategy choices on the test items

Discussion

Recently, Schillemans et al. (2009) showed that the repeated application of a particular strategy affects an individual's subsequent strategy choice. More specifically, the repeated use of a particular strategy on previous problems was found to increase the probability that this strategy will be selected again on a problem that elicits the different strategies more or less equally strongly. In addition, Lemaire and Lecacheur (2010, Experiment 3) demonstrated that a perseveration effect already occurs after a single application of a strategy in a two-digit addition task. With the present study we tried to replicate the earlier finding of Schillemans et al. (2009), to generalise the earlier finding of Lemaire and Lechacheur to another task, and to extend these findings by testing whether the strength of the perseveration effect is affected by the number of strategy repetitions. We conducted an experiment in which we compared young adults' strategy choices on strategy-neutral test items in a numerosity judgement task under two conditions: a single condition and a repeat condition. In the single condition, the test items were always preceded by a single extreme item that strongly elicited one of both strategies, whereas in the repeat condition a series of five extreme items that all elicited the same strategy were solved before participants were presented the test item.

First, we were able to replicate the perseveration effect found by Schillemans et al. (2009) by showing that the *repeated* use of a strategy has an influence on the subsequent strategy choice in the domain of numerosity judgement. Indeed, participants chose on the test items more often the strategy they had used on the previous items. Second, this experiment generalised the perseveration effect after a single strategy application, as found by Lemaire and Lecacheur (2010) for two-digit addition problems, to a numerosity judgment task. Third, we did not find much evidence for a differential perseveration effect after a single or a repeated application of the previous strategy. Although there was a trend towards a stronger effect in the repeat condition, the interaction was not significant and the effect in the single condition was significant as well ($F(1, 27) = 60.21$, $p < .001$). Thus, one previous strategy application seems already sufficient to elicit the perseveration effect in its full strength. Finally, a cluster analysis revealed large individual differences in the occurrence of the perseveration effect. Only one third of the participants demonstrated this effect, whereas the others very often used either one of the two strategies to solve the problems. The number of participants in the different clusters did not differ as a function of condition (single vs. repeated exposure).

Towards an explanation of the perseveration effect

Although the present study replicated and generalised earlier findings on the perseveration effect, it still remains unclear which mechanism(s) can account for it. We propose two different mechanisms. A first possible underlying mechanism is procedural priming. This type of priming is described by Kirmani, Lee, and Yoon (2004, p. 860) as "... *[something which] arises when the* *frequent or recent use of certain cognitive procedures increases the propensity to use the same procedures on a subsequent task*". Applied to cognitive strategies, this type of priming can be conceived of as a temporary increase in the strength of the last applied strategy, which in turn will increase the probability that this strategy will be chosen again on the following problem. On items that can be solved about equally well with both strategies (as is the case for the strategy-neutral test items), the primed strategy will slightly be favoured in the selection process at the expense of the other strategy. This possibility of strategy priming has been suggested in Siegler and Arraya's (2005) SCADS* (Strategy Choice and Discovery Simulation) model, which tries to describe how individuals select and discover strategies.

A second mechanism that can account for the present results is the so-called *strategy switch cost.* Lemaire and Lecacheur (2010) as well as Luwel, Schillemans, Onghena, and Verschaffel (2009a) have recently shown that switching from one strategy to another leads to longer response times (and higher error rates) on the item immediately after a strategy switch than when one repeats the previous strategy. This phenomenon is called the strategy switch cost. The perseveration effect might be the result of participants avoiding such a switch cost. Indeed, in some cases, it can be more adaptive *not* to switch to another strategy but continue applying the same strategy. This is especially the case if two strategies are almost equally well applicable as in our test items. Switching to the other strategy would in this case entail a cost that may be larger than the possible gain that can be made by executing a somewhat more efficient strategy, and therefore participants may continue applying the same strategy on the test item as the one that they had applied on the preceding extreme item(s).

It should be noted that, although the priming and the switch cost mechanism are theoretically different, they overlap to some extent. Indeed, many authors consider priming itself as a possible underlying mechanism for explaining task switch costs (e.g., Allport, Styles, & Hsieh, 1994; Sohn & Anderson, 2003). For this reason, disentangling the two mechanisms may be very difficult and even impossible because evidence for the strategy switch cost mechanism does not exclude the priming mechanism. On the other hand, if the strategy switch cost mechanism could be ruled out, this does not rule out the priming mechanism.

Individual differences in the occurrence of the perseveration effect

As reported above, a cluster analysis revealed three groups, only one of them showed a substantial perseveration effect, whereas the other two relied strongly on either the addition or the subtraction strategy. The present study is the first to report such individual differences in the perseveration effect.

The strong reliance on one specific strategy in the last two groups can be explained in two different ways. First, despite our efforts in determining the most strategy-neutral items in a relatively large sample of participants (see Appendix), large individual differences in associative strength between the different numerosities and the two strategies (Verschaffel et al., 1998) may exist. More particularly, it may be that the strategy-neutral items were located on *smaller* numerosities than the ones being used here for the group with a strong tendency to choose the subtraction strategy and on *larger* numerosities for the group with a strong tendency to choose the addition strategy. Therefore, it may be that these two groups are also influenced by the previous strategy but in a different numerosity range than the one tested in this study. A way to test this possibility would be to use individualised neutral items instead of the same strategy-neutral items for all participants. However, Delvaux (2008) has shown that such a design also has some methodological problems (i.e., there appears to be a shift in participants' neutral items between two sessions), which casts some doubts on the usefulness of this approach. In our future work, we will develop a design to further test this explanation. A second explanation could be that the individuals in these two groups had a strong inclination to use one of the two strategies and thus were simply not influenced at all by their previous strategy use, irrespective of the neutrality of the test items. Subject characteristics such as rigidity or inhibition might make that some individuals are not influenced by the previous strategy, even not when confronted with the most strategy-neutral numerosities. Although this last possibility may account for why some participants are inclined to repeat the previous strategy and others do not, it cannot explain why some participants choose for the addition strategy and others for the subtraction strategy when they are not influenced by the preceding strategy. However, this finding is not new; it has already been observed in other studies (e.g., Hickendorff, van Putten, Verhelst, & Heiser, 2010). It was also found in the data of our own pilot study. Even with the wider range used in this study (range 23-32), some participants only used the addition strategy while others only used the subtraction strategy, but most participants used a mixture of both strategies.

The occurrence of individual differences in susceptibility to the perseveration effect does not rule out one of the explanations for the perseveration effect. In other words, both the above-mentioned priming mechanism and the strategy switch cost mechanism can explain individual differences in the effect. Concerning the first mechanism, namely priming, it has been shown that not all participants show this effect to the same extent (e.g., Tipper & Baylis, 1987; Woltz & Shute, 1993). Therefore, it can be hypothesised that people who display a larger priming effect will be more inclined to repeat the previously-used strategy because the stronger the priming, the stronger the increase in the strength of the last used strategy, and thus the higher the probability that this strategy will be selected again.

Also with respect to the second mechanism, the avoidance of a strategy switch cost, there exist large individual differences in switch costs (Luwel, Schillemans, Onghena, & Verschaffel, 2009b). In other words, the time it takes to switch from one strategy to another is not the same for all participants. The larger a participant's individual switch cost, the larger the advantage of one strategy over the other has to be before one can benefit from a strategy switch. In other words, the larger the costs for switching from one strategy to the other, the more inclined individuals will be to stick to the previously-used strategy.

Implications of the present study

From a theoretical point of view, the present study confirms the role of an additional environmental factor in people's strategy choices, namely the influence of the previously used strategy. As a consequence, this factor has to be taken into account in our theorising about the mechanism underlying people's strategy choices. However, most theoretical accounts of strategy choice such as the Adaptive Decision Maker (Payne, Bettman, & Johnson, 1993), RCCL[3] (Lovett & Schunn, 1999) and the Strategy Selection Learning (SSL) theory (Rieskamp & Otto, 2006) cannot explain this influence yet (neither in terms of priming nor in terms of the avoidance of a strategy switch cost), and hence, need to be extended. An exception is the SCADS* model (Siegler & Araya, 2005) that can explain this effect in terms of priming with its additional priming component. However, if the avoidance of a strategy switch cost is the correct explanation, also this model needs to be extended to account for the perseveration effect.

Additionally, some tentative educational implications may be drawn from the existence of the perseveration effect. Strategy adaptivity is seen as an important characteristic in most reform-based approaches to mathematical education (Verschaffel, Greer, & De Corte, 2007; Verschaffel, et al., 2009). It has been argued that one has to look at adaptivity as a function of problem, context, and subject characteristics. The present study points to an additional context characteristic that has previously not been taken into account in educational practice, namely the influence of the previous strategy. Because the current study showed that the perseveration effect is already apparent in its full strength after a single strategy application, this effect may play a role in

3. RCCL stands for: Represent the task, Construct a set of action strategies consistent with the task representation, Choose from among those strategies according to their success rates, and Learn new success rates for the strategies based on experience.

all kinds of situations where strategies need to be chosen on two or more consecutive problems. Therefore, it seems important that curriculum developers, textbook authors, and teachers design proper series of mathematical exercises to maximise learners' opportunities to use and practise all possible strategies.

References

Allport, A., Styles, E.A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 421-452). Cambridge, MA: MIT Press.

Beishuizen, M. (1993). Mental strategies and materials or models for addition and subtraction up to 100 in Dutch second grades. *Journal for Research in Mathematics Education, 24*, 295-323.

Cowen, E.L., Wiener, M., & Hess, J. (1953). Generalization of problem-solving rigidity. *Journal of Consulting Psychology, 17*, 100-103.

Cunningham, J.D. (1965). Einstellung rigidity in children. *Journal of Experimental Child Psychology, 16*, 237-247.

Delvaux, E. (2008). *De invloed van voorafgaand strategiegebruik op de actuele strategiekeuze* [The influence of preceding strategy use on the actual strategy choice]. Unpublished master's thesis, Katholieke Universiteit Leuven, Leuven, Belgium.

Hickendorff, M., van Putten, C.M., Verhelst, N.D., & Heiser, W.J. (2010). Individual differences in strategy use on division problems: Mental versus written computation. *Journal of Educational Psychology, 102*, 438-452. doi: 10.1037/a0018177

Kirmani, A., Lee, P.L., & Yoon, C. (2004). Procedural priming effects on spontaneous inference formation. *Journal of Economic Psychology, 25*, 859-875. doi: 10.1016/j.joep.2003.09.003

Lemaire, P., & Arnaud, L. (2008). Young and older adults' strategies in complex arithmetic. *American Journal of Psychology, 121*, 1-16.

Lemaire, P., & Lecacheur, M. (2001). Older and younger adults' strategy use and execution in currency conversion tasks: Insights from French franc to Euro and Euro to French franc conversions. *Journal of Experimental Psychology: Applied, 7*, 195-206. doi: 10.1037//1076-898X.7.3.195

Lemaire, P., & Lecacheur, M. (2010). Strategy switch costs in arithmetic problem solving. *Memory & Cognition, 38*, 322-332. doi: 10.3758/MC.38.3.322

Lovett, M.C., & Schunn, C.D. (1999). Task representation, strategy variability, and base-rate neglect. *Journal of Experimental Psychology: General, 128*, 107-130.

Lucangeli, D., Tressoldi, P.E., Bendotti, M., Bonanomi, M., & Siegel, L. (2003). Effective strategies for mental and written arithmetic calculation from the third to the fifth grade. *Educational Psychology, 23*, 507-521.

Luchins, A.S. (1942). Mechanization in problem solving – the Einstellung effect. *Psychological Monographs, 54* (Whole No. 248).

Luwel, K., Schillemans, V., Onghena, P., & Verschaffel, L. (2009a). Does switching between strategies within the same task involve a cost? *British Journal of Psychology, 100*, 753-771. doi: 10.1348/000712609X402801

Luwel, K., Schillemans, V., Onghena, P., & Verschaffel, L. (2009b). [Individual differences in strategy switch costs]. Unpublished data.

Luwel, K., Verschaffel, L., Onghena, P., & De Corte, E. (2003a). Flexibility in strategy use: Adaptation of numerosity judgement strategies to task characteristics. *European Journal of Cognitive Psychology, 15*, 247-266. doi: 10.1080/09541440244000139

Luwel, K., Verschaffel, L., Onghena, P., & De Corte, E. (2003b). Analyzing the adaptiveness of strategy choices using the choice/no-choice method: The case of numerosity judgement. *European Journal of Cognitive Psychology, 15*, 511-537. doi: 10.1080/09541440244000292

McKelvie, S.J. (1984). Relationship between set and functional fixedness: A replication. *Perceptual and Motor Skills, 58*, 996-998.

Milkman, K.L., Chugh, D., & Bazerman, M.H. (2009). How can decision making be improved? *Perspectives on Psychological Science, 4*, 379-383.

Payne, J., Bettman, J.R., & Johnson, E.J. (1993). *The adaptive decision maker.* New York: Cambridge University Press.

Rieskamp, J., & Otto, P.E. (2006). SSL: A theory of how people learn to select strategies. *Journal of Experimental Psychology: General, 135*, 207-236. doi: 10.1037/0096-3445.135.2.207

Schillemans, V., Luwel, K., Bulté, I., Onghena, P., & Verschaffel, L. (2009). The influence of previous strategy use on individuals' subsequent strategy choice: Findings from a numerosity judgement task. *Psychologica Belgica, 49*, 191-205.

Siegler, R.S. (1996). *Emerging minds: The process of change in children's thinking.* Oxford: University Press.

Siegler, R., & Araya, R. (2005). A computational model of conscious and unconscious strategy discovery. In R.V. Kail (Ed.), *Advances in child development and behavior. Vol. 33* (pp. 1-42). Oxford, UK: Elsevier.

Sohn, M.H., & Anderson, J.R. (2003). Stimulus-related priming during task switching. *Memory & Cognition, 31*, 775-780. doi: 10.3758/BF03196115

Steinley, D. (2003). Local optima in *K*-Means clustering: What you don't know may hurt you. *Psychological Methods, 8*, 294-304. doi: 10.1037/1082-989X.8.3.294

Sung, Y.-T., Chang, K.-E., & Huang, J.-S. (2008). Improving children's reading comprehension and use of strategies through computer-based strategy training. *Computers in Human Behavior, 24*, 1552-1571. doi: 10.1016/j.chb.2007.05.009

Tipper, S.P., & Baylis, G.C. (1987). Individual-differences in selective attention: The relation of priming and interference to cognitive failure. *Personality and individual differences, 8*, 667-675.

Torbeyns, J., Verschaffel, L., & Ghesquière, P. (2005). Simple addition strategies in a first-grade class with multiple strategy instruction. *Cognition and Instruction, 23*, 1-21.

Verschaffel, L., De Corte, E., Lamote, C., & Dherdt, N. (1998). The acquisition and use of an adaptive strategy for estimating numerosity. *European Journal of Psychology of Education, 13*, 347-370.

Verschaffel, L., Greer, B., & De Corte, E. (2007). Whole number concepts and operations. In F.K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 557-628). Greenwich, CT: information Age Publishing.
Verschaffel, L., Luwel, K., Torbeyns, J., & Van Dooren, W. (2009). Conceptualizing, investigating, and enhancing adaptive expertise in elementary mathematics education. *European Journal of Psychology of Education, 24*, 335-359.
Woltz, D.J., & Shute, V.J. (1993). Individual differences in repetition priming and its relationship to declarative knowledge acquisition. *Intelligence, 17*, 333-359.

Appendix: Pilot study

Goal

Schillemans et al. (2009) had observed a slight but significant difference between their two experiments with respect to the numerosities on which the perseveration effect occurred. To maximise the neutrality of the test items in the present study, we conducted a pilot study wherein we determined the most strategy-neutral test items in a new, more appropriate way.

Method

Participants

Fifty-seven students (9 men and 48 women) in Educational Sciences from the KU Leuven, Belgium participated in this study in exchange for course credits. Their mean age was 22.75 yrs. (range: 20 yrs.-50 yrs.). Three participants were removed from the analysis, one because she misinterpreted the instructions, the other two because they made an unacceptable number of errors.

Material and stimuli

The experiment was run simultaneously on different computers with a Pentium 4-processor, attached to a 17” screen with a resolution set to 1280 × 1024 pixels. The stimuli were the same kind of grids as used in the main study.

Based on a rational task analysis and the results of Schillemans et al. (2009), we selected the numerosities 23 to 32 as test items. For each numerosity, twenty different variants were constructed by changing the random configuration of the green cells in the grid. This yielded 200 different test items. Two stimulus lists were created, so that each list contained ten different variants of each numerosity and 100 different test items in total.

Procedure

Participants were randomly allocated to one of the two stimulus lists and were tested in groups of about 9 persons. The addition and the subtraction strategy were explained to the participants and they were asked to solve all trials as fast and as accurately as possible by solely relying on these two strategies. To encourage them to do the best they could, we promised two film tickets for the three participants with the smallest number of errors. Participants received four practice trials to get accustomed to the task and the procedure. Next, they received two blocks of 50 experimental trials each, separated by a brief pause. Each trial started with a fixation mark, which consisted of five white exclamation marks on a black background ('!!!!!'), that was presented in the middle of the screen. After 750 ms this fixation mark was replaced by the stimulus, which remained on the screen until the participants had typed in their answer. Hereafter, the word "*Strategie?*" (meaning "Strategy?") appeared on the screen and participants had to type '+' if they had used the addition strategy and '–' if they had used the subtraction strategy, after which the next trial started.

Results and discussion

We calculated, for each numerosity, the proportion of usage of the addition and the subtraction strategy. We defined the most strategy-neutral numerosity as the numerosity on which both strategies were most equally often applied. As can be seen in Figure A1, the most strategy-neutral numerosity was 27. Overall, on this numerosity, participants selected the addition strategy on 47% of the trials and the subtraction strategy on 53% of the trials. Based on the smallest differences in strategy usage on the other numerosities, we considered the numerosities 25 to 29 as the next "most strategy-neutral" numerosities. Interestingly, these were not the items in the precise middle range of the continuum, but these located somewhat more to the right of the mathematical midpoint. From an adaptivity point of view, this is not very surprising because the subtraction strategy always includes an additional step compared to the addition strategy, namely the subtraction of the number of empty cells from the total number of cells in the grid. Next, we looked at the strategy usage of both strategies on the twenty variants of each numerosity between 25 and 29 and selected for each numerosity the ten stimulus configurations for which both strategies were used most equally often.

Received May 17, 2011
Revision received March 6, 2012
Accepted March 23, 2012

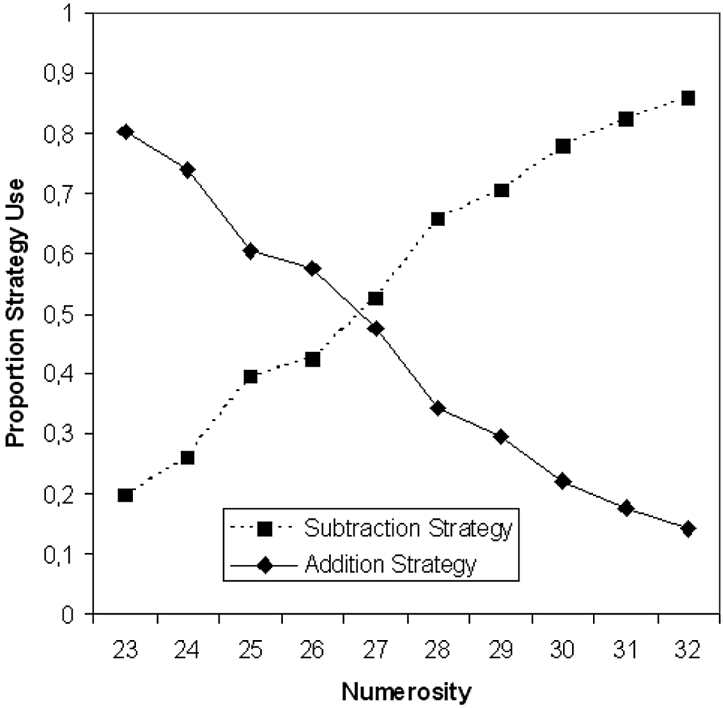

Figure A1

Proportion addition and subtraction strategy use for each numerosity