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The Perseveration Effect in Individuals' Strategy Choices

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This doctoral dissertation consists of a series of four manuscripts in which we investigated the influence of the previously used strategy on the subsequent strategy choice (i.e., the so-called *perseveration effect*). Although sequential effects have already been widely studied in a variety of research domains, they have scarcely been investigated with respect to individuals' strategy choice behaviour. All reported experiments in this dissertation relied on the same experimental task, namely the numerosity judgement task. The goal of this task is to determine various numerosities of coloured cells in a rectangular 5 x 10 grids. Participants can choose between two strategies to solve the different problems: an *addition* strategy (i.e., adding the coloured cells individually or groupwise) and a *subtraction* strategy (i.e., adding the empty cells individually or groupwise and subtracting this number from the grid size).

The dissertation starts with a general introduction in which we provide a background about multiple strategy use, sequential effects in other research domains, and the numerosity judgement task. In ***Chapter 1,*** we report the first experiments that tested this perseveration effect in strategy choices. Therefore, sequences were built in which test items (that were assumed to elicit both strategies) were preceded by addition items or subtraction items that only elicited the addition or the subtraction strategy, respectively. We selected these test items from both a broad (first experiment) and a small numerosity range (second experiment). The results confirmed the hypothesized perseveration effect, that is, participants chose more often for the subtraction strategy after the multiple use of the subtraction strategy than after the multiple use of the addition strategy. However, it was also found that the effect was limited to these numerosities for which both strategies were more or less equally applicable.

The goal of the following experiment, reported in ***Chapter 2***, was to replicate the findings observed in the first two experiments with a different research paradigm. In this experiment, we manipulated the presentation order in which the different numerosities were presented (i.e., an ascending, a descending, and a random order). Also with this research paradigm, we were able to show the perseveration effect.

Common to the experiments of Chapter 1 and Chapter 2 is that they all showed the perseveration effect after a *repeated* use of the previous strategy. However, it is also important to know whether the perseveration effect would already show up after a single previous strategy application, and, if so, whether the strength of the effect would be different after a single versus a repeated application of a strategy. Therefore, we conducted an experiment (***Chapter 3***) with two different conditions, namely a repeat condition (i.e., the test item was presented after five strategy applications) and a single condition (i.e., the test item was presented after a single strategy application). This experiment revealed that a single previous strategy application was sufficient to elicit the perseveration effect. Moreover, the strength of the perseveration effect did not increase as a function of the number of previous strategy applications. Interestingly, an additional cluster analysis showed large individual differences in participants' strategy choices. Three groups could be distinguished: a group showing the perseveration effect (i.e., a group who used the addition strategy most often after addition items, and the subtraction strategy most often after subtraction items), and two groups who did not show the perseveration effect but who had a strong preference for either the addition strategy or the subtraction strategy (irrespective of the preceding strategy).

This latter finding led to a follow-up experiment (***Chapter 4***) in which we tried to find out how these individual differences in the perseveration effect could be explained. Five different subject characteristics (i.e., inhibition, switching, updating, arithmetic skills, and subtraction self-efficacy beliefs) were tested to further unravel this finding. The results showed that two of these subject characteristics could at least explain some of the individual differences, namely, inhibition and subtraction self-efficacy beliefs.

The dissertation ends with ***Chapter 5***, in which we provide a general discussion of some mechanisms that may underlie the observed perseveration effect, address some limitations of the reported studies of this dissertation, discuss some educational implications, and we will also give some directions for further research.

Viki Schillemans, Het Perseveratie-Effect in Strategiekeuzes
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Deze verhandeling bestaat uit een reeks van vier manuscripten waarin we de invloed van de voorgaande strategie op de daaropvolgende strategiekeuze zijn nagegaan (d.i., het zogenoemde *perseveratie effect*). Hoewel volgorde-effecten reeds veelvuldig bestudeerd werden in verschillende domeinen, zijn ze slechts zelden onderzocht bij strategiekeuzes. Alle gerapporteerde studies in deze verhandeling maakten gebruik van dezelfde experimentele taak, namelijk de *numerosity judgement* taak. Het doel van deze taak is om verschillende aantallen van gekleurde cellen te bepalen in rechthoekige roosters met een grootte van 5 x 10. Om de taak op te lossen kunnen proefpersonen kiezen uit twee mogelijke strategieën: een *optelstrategie* (d.i., het individueel of in groep optellen van de gekleurde cellen) en de *aftrekstrategie* (d.i., het individueel of in groep optellen van de lege cellen en dit aantal aftrekken van het totale aantal cellen in het rooster).

De verhandeling start met een algemene inleiding waarin we achtergrondinformatie geven over het gebruik van meerdere strategieën, volgorde-effecten in andere domeinen, en de *numerosity judgement* taak. In ***Hoofdstuk 1*** rapporteren we de eerste experimenten die het perseveratie-effect in strategiekeuzes onderzochten. Daarvoor werden itemreeksen opgesteld waarin test items (die verondersteld werden beide strategieën uit te lokken) werden voorafgegaan door optelitems of aftrekitems die respectievelijk enkel de optel- of de aftrekstrategie uitlokken. Deze test items werden zowel uit een breed (eerste experiment) als uit een smal bereik van aantallen geselecteerd. De resultaten bevestigden het voorspelde perseveratie-effect, dit wil zeggen, proefpersonen kozen vaker voor de aftrekstrategie na een herhaalde uitvoering van de aftrekstrategie dan na een herhaalde uitvoering van de optelstrategie. Dit effect was echter beperkt tot deze aantallen waarvoor de beide strategieën min of meer even goed toepasbaar waren.

Het doel van het volgende experiment, gerapporteerd in ***Hoofdstuk 2***, was om de bevindingen van de eerste twee experimenten te repliceren met een ander onderzoeksparadigma. In dit experiment manipuleerden we de volgorde waarin de verschillende aantallen gepresenteerd werden (d.i., een oplopende, een aflopende, en een willekeurige volgorde). Ook met dit onderzoeksparadigma konden we het perseveratie-effect vaststellen.

Gemeenschappelijk aan de experimenten uit Hoofdstuk 1 en 2 is dat ze het perseveratie-effect steeds aantoonden na een *herhaalde* aanbieding van de voorgaande strategie. Het is echter eveneens belangrijk om te weten of dit perseveratie-effect reeds optreedt na het eenmalig uitvoering van een strategie, en indien dit het geval is, of de sterkte van het effect verschillend is na een eenmalige versus een herhaalde uitvoering van de strategie. Om dit te onderzoeken werd een experiment (***Hoofdstuk 3***) opgesteld bestaande uit twee condities, namelijk een *herhaalde conditie* (d.i., het test item werd gepresenteerd na vijf voorgaande strategie-uitvoeringen), en een *eenmalige conditie* (d.i., het test item werd gepresenteerd na een eenmalige voorgaande strategie-uitvoering). Dit experiment toonde aan dat een eenmalige voorgaande strategie-uitvoering voldoende was om het perseveratie-effect uit te lokken. Daarenboven was het effect niet sterker na een herhaalde dan na een eenmalige strategie-uitvoering. Een extra clusteranalyse legde een interessant niet eerder geobserveerd fenomeen bloot, namelijk grote individuele verschillen in strategiekeuze. Drie groepen konden onderscheiden worden: een groep die het perseveratie-effect vertoonde (d.i., een groep die meestal de optelstrategie koos na optelitems en de aftrekstrategie na aftrekitems), en twee groepen met een sterke voorkeur voor respectievelijk de optelstrategie of de aftrekstrategie (onafhankelijk van de voorgaande strategie).

Deze bevinding leidde tot een volgend experiment (***Hoofdstuk 4***) waarin het doel was om na te gaan hoe deze individuele verschillen in het perseveratie-effect verklaard kunnen worden. Hiervoor werden vijf verschillende subjectkenmerken onderzocht (d.i., inhibitie, vaardigheid in wisselen, updating, rekenvaardigheden, en het geloof in de eigen aftrekvaardigheden). De resultaten toonden aan dat twee subjectkenmerken op zijn minst deels de individuele verschillen konden verklaren, namelijk inhibitie en het geloof in de eigen aftrekvaardigheden.

De verhandeling eindigt met ***Hoofdstuk 5*** waarin we een algemene discussie geven van enkele onderliggende mechanismen van het perseveratie-effect, enkele beperkingen van de studies gerapporteerd in deze verhandeling bespreken, enkele schoolse implicaties bediscussiëren, en waarin we eindigen met het toelichten van mogelijkheden tot vervolgonderzoek.

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General Introduction

The central topic of this doctoral dissertation concerns participants' tendency to repeat a previously-used strategy in a cognitive task. This tendency of repeating the preceding strategy is termed the *perseveration effect*. This doctoral dissertation consists of a collection of four manuscripts describing four related empirical studies concerning this perseveration effect, preceded by a general introduction and followed by a general discussion.

This introductory chapter starts with a brief overview of the research on multiple strategy use and strategy choices in cognitive tasks. In the second part, we will describe the aim of this doctoral dissertation in greater detail. Thereafter, this introduction gives an overview of studies from research domains other than strategy choices that have dealt with influences of preceding trials on participants' subsequent behaviour. In the fourth part of this introduction, we will describe the experimental task employed in all studies of this dissertation, namely a numerosity judgement task, and report some findings of earlier studies conducted using this task. This introduction ends with an overview of the different chapters (i.e., four empirical chapters and a discussion chapter) of this dissertation.

Multiple Strategy Use

A strategy can be defined as "any procedure that is non-obligatory and goal-directed" (Siegler & Jenkins, 1989, p. 11). This definition includes two important critical features of strategies; their non-obligatory and goal-directed natures. The first one, that a strategy is non-obligatory, distinguishes strategies from procedures in general. Essentially, procedures may represent the only way to achieve a goal, while adopting a strategy always implies a choice between different strategies. For example, the only way to let your car drive faster is to press harder on the accelerator. As this is the only way to achieve this goal, it is defined a procedure, not a strategy. On the other hand, if you wish to stop your car, you can choose between different possible strategies, for instance, you can press the brake pedal, you can pull the handbrake, or you can even drive into a wall… The second feature of a strategy is that it is goal-directed. Strategies are always selected and executed to achieve a predefined goal. This characteristic distinguishes strategies from activities that are not intended to accomplish a goal, or activities that accomplish other goals than the ones intended. A third characteristic which defines a strategy has been added by some authors (Lemaire & Reder, 1999: Siegler & Jenkins, 1989), namely that strategies do not necessarily require conscious awareness: they can also be selected and executed unconsciously. This possible unconscious use of a strategy has been shown in the study of Siegler and Stern (1998). The authors studied strategy use on inversion problems of the form a + b – b. These problems can be solved via a computation strategy (i.e., adding and subtracting all numbers), but can also be solved via a shortcut strategy (i.e., solving the problem by recognizing that adding and subtracting the same number does not change the result). Obviously, problems solved using this shortcut strategy are solved much faster than problems solved with the computation strategy. Siegler and Stern demonstrated that the use of this shortcut strategy was apparent in children's reaction times some trials before the children's verbal explanation reflected the use of this strategy. This points to the fact that children were already applying the shortcut strategy without being aware of it. However, both the conscious and the unconscious use of the shortcut strategy have the same predefined goal, namely solving the arithmetic problem. This feature distinguishes strategies from plans that are conceived as being inherently conscious.

The multiplicity of strategies has been presented at different levels (Siegler, 1996). At a first level, it has been shown that there is an inter-individual variability in strategy choices; that is, not all participants use the same strategy to solve a particular problem. For example, Siegler (1988) divided children into three groups, based on their strategy use and their performance, and observed that the group of children he called 'perfectionists' used the retrieval strategy less often than those in other groups. At a second level, there are also important intra-individual differences in strategy use. Individuals typically use several strategies to solve different kinds of problems within a task. For example, Lefevre, Sadesky, and Bisanz (1996) found that, in simple addition, retrieval is the most-often used strategy for solving small problems, while for the larger problems procedural-based strategies are more preferred. On a third level, participants sometimes use different strategies to solve exactly the same item at two different instances in time. For instance, Siegler and McGilly (1989) showed in a time telling task that children used different strategies to solve the same single problem presented twice close in time. For example, they used retrieval the first time a stimulus was presented, and then used a backup strategy the second time the same stimulus was presented. Finally, participants sometimes even use multiple strategies within a single trial. For example, Goldin-Meadow, Alibali, and Church (1993) showed that children sometimes articulate their opinion through both speech and gestures at the same time.

The use of different available strategies has been extensively shown in a wide variety of task domains, such as arithmetic (e.g., Cooney, Swanson, & Ladd, 1988; Geary & Wiley, 1991; Lemaire, Arnoud, & Lecacheur, 2004; Peters, De Smedt, Torbeyns, Ghesquière, & Verschaffel, 2010a; Torbeyns, Verschaffel, & Ghesquière, 2005), scientific reasoning (Kuhn, Schauble, & Garcia-Milla, 1992), spelling (e.g., Marsh, Friedman, Welch, & Desberg, 1980; Rittle-Johnson & Siegler, 1999), reading (e.g., Goldman & Saul, 1990; Lima & Castro, 2010; Sung, Chang, & Huang, 2008), decision making (e.g., Milkman, Chugh, & Bazerman, 2009; Payne, Bettman, & Johnson, 1988), time telling (Siegler & McGilly, 1989), serial recall (McGilly & Siegler, 1990), and currency conversion (Lemaire & Lecacheur, 2001). This strategic variability is also not limited to one specific age group, but appears to be present throughout the entire lifespan. Indeed, multiple strategy use has been found in infants (e.g., Adolph, 1995), preschoolers (e.g., Geary & Burlingham-Dubree, 1989), school-age children (e.g., Luwel, Verschaffel, Onghena, & De Corte, 2000), young adults (e.g., Schauble, Glaser, Raghavan, & Reiner, 1991), and older adults (e.g., Lemaire & Arnaud, 2008).

An advantage of this strategy variability is that people can always choose the best available strategy. By always applying the most optimal strategy, they can maximize their performance, both in terms of speed and in terms of accuracy. However, this strategy variability implies that individuals must determine – consciously or unconsciously – for every problem of a task which strategy from their strategy repertoire they will use to solve the problem at hand. There is ample evidence that individuals do not select these strategies at random, but that they take several factors into account. A distinction can be made between three main factors that are known to affect an individual's strategy choices (Siegler, 1996; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009). The first factor is subject characteristics; that is, people may differ in the strategies they select as a function of their knowledge and ability within a certain task, or based on their developmental level. Examples of subject characteristics that have an influence on the strategy choice can be found in the study of Imbo and Vandierendonck (2007). These authors found in a simple addition task an influence of the following subject characteristics; processing speed (children with higher processing speed used retrieval more frequently than children with lower processing speed), arithmetic skills (children with good arithmetic skills chose the retrieval strategy more often than children with weaker skills), math anxiety (low-anxiety children used retrieval more often than high-anxiety children), and gender (boys used retrieval more frequently than girls) on participants' strategy choices. The second factor which has an influence on strategy choice is problem characteristics. Individuals will vary their strategy use across the different problems in a task as a function of the type of problem. For example, Peters, De Smedt, Torbeyns, Ghesquière, and Verschaffel (2010b) have found that in two-digit subtractions, strategy choice was determined by the relative size of the subtrahend. If the subtrahend was smaller than the difference (e.g., 63 – 4) direct subtraction (i.e., solving the problem by directly subtracting the subtrahend from the minuend) was the dominant strategy, while if the subtrahend was larger than the difference (e.g., 74 – 68) subtraction by addition (i.e., using an addition to solve the subtraction, e.g., 68 + 6 = 74, so the answer is 6) was most often used. When the subtrahend and the difference were almost of the same size (e.g., 72 – 34), the size of the subtrahend did not predict participants' strategy choice between direct subtraction and subtraction by addition. The third factor involves contextual characteristics; that is, the strategies being selected may differ as a function of the demands of the context, such as need for speed or accuracy. An example of an influence of the context on the strategy choice can be found in Campbell and Austin (2002). The authors demonstrated in a mental addition task that strategy choice on large problems (i.e., problems for which at least one of the addends is larger than 5) is dependent on the time available to solve the problem; that is, participants used retrieval more often when they had less time to answer.

Aim of the Doctoral Dissertation

The goal of this doctoral dissertation is to test, in detail, one specific contextual characteristic, namely the possible influence of a previously-used strategy on the subsequent strategy choice process. Several research questions were tested: (a) Does the influence of the previously-used strategy have an effect upon all items or rather upon a limited subset of items, (b) Does such influence already appear after a single application of a strategy, or only after a repeated one, (c) Are all participants influenced by the previously-used strategy, or only some of them, and, consequently, (d) Which subject characteristics can account for such individual differences? The immediate reason for raising and investigating this question is the presence of some anecdotal findings observed in the studies of Luwel and colleagues on people's strategic behaviour in the domain of numerosity judgement. These anecdotal findings will be described in greater detail below (see section 'Numerosity Judgement Task'), but, generally speaking, they refer to the observation that people sometimes persist in using a particular strategy even if, from an objective point of view, a different strategy would have been slightly – or even considerably – more appropriate for solving the problem at hand. However, besides this anecdotal evidence no studies had tested the influence of the previously-used strategy on the strategy choice before the start of this PhD research. The lack of research investigating the effect of the previous strategy on the subsequent strategy choice is remarkable, given the number of studies which have investigated sequential effects in domains other than strategy choice. Hereafter, a short overview of some of these studies in which such sequential effects have already been demonstrated is given.

Sequential Effects in Other Domains

One of the oldest study domains in which sequential effects are observed is psychophysics (e.g., Garner, 1953; Lacouture, 1997; McGill, 1957; Staddon, King, & Lockhead, 1980; Ward & Lockhead, 1970; 1971). In the studies of this domain, participants were presented with stimuli that varied along a continuum (e.g., lines of different lengths, tones that vary in volume) and whereby each stimulus was associated with a unique response. For example, when ten different line lengths were presented, ten different response keys were associated with them. When the line had a length of 1, participants had to respond with "1", when the line had a length of 2, participants' response should be "2", and so forth. The participants' task was to correctly identify each of these stimuli by selecting the appropriate response for each stimulus. A crucial finding of these studies was that the response given to a stimulus was assimilated to the immediately preceding stimulus. This means that participants had a tendency to respond as if the stimulus was nearer to the previous stimulus than it actually was (e.g., when the first line had a length of 9, and the second line a length of 5, this latter line would be rather regarded as having a length of 6).

Sequential effects have also been investigated in two studies in the domain of decision making, more specifically in base-rate problems. Ginossar and Trope (1987, Experiment 1) tested participants' choice of solution methods on the base-rate lawyer-engineer problem, originally used by Kahneman and Tversky (1973). This problem reads as follows:

> Several psychologists interviewed a group of people. The group included 30% engineers and 70% lawyers. The psychologists prepared a brief summary of their impression of each interviewee. The following description was drawn randomly from the set of descriptions:
>
> Dan is 45 years old. He is married and has four children. He is generally conservative, careful, and ambitious. He shows no interest in political and social issues and spends most of his free time on his many hobbies, which include home carpentry, sailing, and mathematical puzzles.
>
> The chances that Dan is an engineer are ___ out of 100.
>
> The chances that Dan is a lawyer are ___ out of 100.

In this particular problem, the information given in the description (i.e., a stereotype of an engineer) is incongruent with the information of the base-rates (i.e., there are only 30% engineers in the group). The correct way to solve this problem is to rely on the information of the group composition. However, it is known that participants tend to neglect this base-rate information and base their judgement solely on the descriptive information provided. Ginossar and Trope (1987) let this Kahneman and Tversky problem be preceded by two problems containing diagnostic information, that is, a description of a stereotype (e.g., Zev is 39 years old. He is married and has two children. He is politically active. Zev's favourite hobby is collecting rare books. He is competitive, argumentative, and highly articulate in his oral expression), two problems that contained no diagnostic information, but only very general information that did not refer to a particular profession and that could therefore only be solved using the base-rate information (e.g., Joseph is 30 years old. He is married with no children. A man of high ability and high motivation, he promises to be quite successful in his field. He is well liked by his colleagues.), or no prior problems. They demonstrated that participants were more inclined to use the base-rate information in the Kahneman and Tversky problem if it was preceded by the non-diagnostic problems than when it was preceded by one of the other problem types. Ferreira, Garcia-Marques, Sherman, and Sherman (2006, Experiment 3) had base-rate problems similar to the lawyer-engineer problem be preceded by six problems that could only be solved correctly by relying on the description and neglecting the base-rates (e.g., consider a population that consists of 80 men and 20 women. One person is randomly chosen. This person likes modern art, is fashion aware, breast-fed the children, and a DNA test shows the presence of XX chromosomes). They showed that, when they compared this condition in which the preceding problems can only be solved based on the description with a condition in which the base-rate problems were preceded by unrelated neutral items, participants even more frequently based their judgements on the descriptions. As such, both studies demonstrated a sequential effect in decision making.

A third domain in which sequential effects have been observed, is in the task switching literature, and more specifically, in voluntary task switching (e.g., Arrington & Logan, 2004; 2005; Arrington, Weaver, & Pauker, 2010; Mayr & Bell, 2006). In this type of task switching experiments, participants are free to choose which task they will undertake, with the restriction that they have to execute both tasks approximately equally often, and in a random order during the experiment. As in other task switching studies, a switch cost (i.e., switching between two tasks is slower and more error prone than repeating the task on two successive trials) was observed. However, it was also observed that participants were more inclined to repeat the previously performed task than to switch to the other task (e.g., Arrington & Logan, 2004; Arrington & Yates, 2009; Mayr & Bell, 2006; Vandamme, Szmalec, Liefooghe, & Vandierendonck, 2010). In other words, a sequential effect has also been observed in the domain of task switching.

A fourth domain in which an influence of the preceding problem(s) has been demonstrated is the perception of ambiguous figures. Epstein and Rock (1960) presented participants with a series of ambiguous figures that could be interpreted in two different ways. They tested in four experiments the influence of expectancy, recency, and frequency on participants' interpretation of the ambiguous figure. This was achieved by constructing three different versions of the ambiguous figures; namely the ambiguous figure itself and two unambiguous versions that clearly represented one of both possible interpretations. The results showed that participants interpreted the ambiguous figure as the most recently observed unambiguous figure, even when the other figure was presented more frequently, or when an expectancy towards the other figure was created.

The last example of a sequential effect that we will discuss, and that is the most relevant for the present dissertation – as it concerns a sequential effect in strategy use – is the *Einstellung effect*. The first study of this effect was undertaken by Luchins (1942) using the water jar task. In this task, participants have to fill a vessel with a certain amount of water using jars of three different sizes. Luchins divided the participants into two groups; an experimental group and a control group. 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 a participant 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 a series of 'test items', which could 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. Contrary to the experimental group, participants in the control group received the test items without being confronted first with a series of set items. It was found that the experimental group solved these test items more often with the complex than the simpler formula when compared to the control group. This effect has since been frequently replicated with the water jar task (e.g., Cunningham, 1965; McKelvie, 1984), but also with other tasks, for instance an alphabet maze task (Cowen, Wiener, & Hess, 1953; Cunningham, 1965). In this task, participants are presented with grids of letters and are instructed to move from the upper right-hand corner to the lower left-hand corner, spelling out words on the way. They are allowed to move one letter at a time in any direction, as long as this move helps to spell a word. They were told that, as multiple paths were available, the correct answer was the shortest path. The ‘set items’ could only be solved via a long path, whereas the ‘test items’ could be solved both via this long path but also via a much shorter *alternative* path (i.e., the correct path according to the instructions that stated that the shortest path was the correct one). 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. However, an important characteristic of these studies upon the Einstellung effect is that participants are typically not aware of the easier alternative strategy before they encounter the critical test item. As such, participants still had to detect (the usefulness of) the alternative strategy for the task at hand. This repeated use of one strategy could have placed participants in a state of “blindness” or “mindlessness”, in which they based their problem solving behaviour solely on their past behaviour without noticing new aspects of the problem at hand (Langer, 2000) and/or considering alternative strategies. This differs greatly from most tasks in which multiple strategies are applicable, such as the earlier described cognitive tasks (e.g., arithmetic, spelling, time telling, ...), in which participants are most often aware that different available strategies can be used to solve the problems. This raises the question whether participants' strategy choices will also be influenced by the previously-used strategy under conditions in which all strategies are already available in their strategy repertoire.

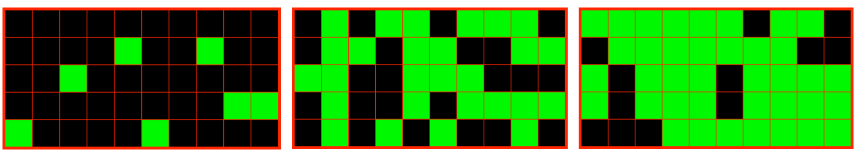
To summarize, sequential effects have already been observed in a variety of domains. This supports the idea that in strategy choices between multiple known strategies such effects may also be found. The study of this possible sequential effect in strategy choices is the topic of this dissertation. Because these kinds of sequential effects have not yet been studied in the domain of strategy choice, the main focus of this dissertation was on gathering empirical evidence for this effect and on determining the conditions under which they would occur. However, in the different chapters and the general discussion, some attempts are made to provide a theoretical account for this effect.

The Numerosity Judgement Task

To study the effect of the previous strategy on the subsequent strategy choice, we have chosen a numerosity judgement task which has already been extensively used in previous studies of Luwel and colleagues (e.g., Luwel, Foustana, Papadatos, & Verschaffel, 2011; Luwel, Lemaire, & Verschaffel, 2005; Luwel, Siegler, & Verschaffel, 2008; Luwel, Verschaffel, Onghena, & De Corte, 2003a; 2003b; 2003c; Verschaffel, De Corte, Lamote, & Dherdt, 1998). This task has been demonstrated to be very useful to study different aspects of individuals' strategy choice and execution. The goal of this task is to determine different numerosities of coloured cells that are presented in a grid. Previous research (Luwel et al., 2003a; 2003b) has shown that adults use two main strategies to solve this task; namely an addition strategy and a subtraction strategy. When using the addition strategy, participants determine the number of coloured cells by adding the coloured cells individually or groupwise, whereas when using the subtraction strategy, participants count the number of empty cells individually or groupwise, and subtract this number from the total number of cells in the grid. The two strategies are not of equal difficulty: the subtraction strategy is more difficult than the addition strategy, first, because, when compared to the addition strategy, the subtraction strategy contains an additional step, namely subtracting the number of counted empty cells from the total number of cells in the grid, and, second, because subtracting is harder than counting or adding up. (Luwel et al., 2005; Verschaffel et al., 1998).[1] The choice between these two strategies depends heavily on the ratio of coloured versus empty cells (e.g., Luwel et al., 2003c). When there are only few coloured cells and many empty cells (see Figure 0.1a), the addition strategy is most appropriate to solve the trial and therefore this strategy is almost exclusively selected by the participants when confronted with such trials. For this

[1] A second additional step that needs to be taken in executing the subtraction strategy compared to the addition strategy is determining the total number of cells in the grid. However, in all experiments reported in this dissertation, the size of the grid remains the same and the total numbers of cells is mentioned to the participants at the beginning of the experiment. As such, participants did not have to execute this step when applying the subtraction strategy.

reason, we will call this type of item *addition items*. Conversely, when there are many coloured cells and only few empty cells (see Figure 0.1c), the subtraction strategy is the most appropriate for solving the problem, and participants almost exclusively select this strategy. For this reason, we will call this type of item *subtraction items*. This implies that at a certain numerosity, participants switch from the addition strategy to the subtraction strategy (i.e., the *change point*). Since, as explained above, the subtraction strategy is cognitively more demanding than the addition strategy, participants do not switch to the subtraction strategy at the mathematical midpoint of the numerosity range (e.g. 24.5 in a 7 x 7 grid), but postpone their switch to a somewhat larger numerosity (e.g., 32; see Luwel et al., 2005). For the items in the immediate neighbourhood of this change point, the strategy choice is less straightforward than for the addition or subtraction items, since both strategies are more or less equally applicable in solving these problems. Therefore, the items around the change point will be called *strategy-neutral items* (see Figure 0.1b).



(a) *Addition Item* (b) *Strategy - Neutral Item* (c) *Subtraction Item*

Figure 0.1. An example of an Addition Item, a Strategy-Neutral Item, and a Subtraction Item

As mentioned before, Luwel and colleagues had already found some anecdotal evidence for an influence of the previously-used strategy in the numerosity judgement task. Indeed, participants sometimes applied the subtraction strategy on a trial that was located (far) before their change point and/or the addition strategy on a trial that was located (far) beyond their change point. When they further analyzed those seemingly inadaptive strategy choices as a function of the presentation order of the items during the experiment, they noticed that these specific trials often came after an – accidentally randomly generated – row of trials that all had been solved with the same strategy. This means participants continue to apply the same strategy on these specific trials as they had been using in previous trials instead of switching to a somewhat more optimal strategy.

Overview of the Different Studies

This final part of the introduction, gives a brief overview of the different studies of this dissertation, and explains the logic that connects them. As mentioned above, all studies are conducted with the numerosity judgement task. To keep all studies as comparable as possible, we always used the same grid size for the trials; rectangular grids containing five rows with ten cells each. As such, every grid had a total of 50 cells.

In ***Chapter 1,*** the first two experiments regarding the influence of the previously-used strategy on the subsequent strategy choice are described. In a first experiment, we tested this influence in a broad numerosity range. We created two kinds of items, namely extreme items and test items. The extreme items were subdivided into addition and subtraction items. The test items were items at regular intervals between the extreme addition and the extreme subtraction items (i.e., the numerosities 13, 19, 25, 31, & 37). With these item types, we created sequences with five or six extreme items (series with all addition items or all subtraction items), followed by one test item. The results showed an effect of the previous strategy on the subsequent strategy choice, in that participants more often applied the subtraction strategy after a series of subtraction items than after a series of addition items. However, it was also found that this influence of the previous extreme addition or subtraction items was limited to only one of the tested numerosity, namely 31. Apparently, the other test items were not strategy-neutral enough to elicit an influence of the previously-used strategy. In the second experiment, we created the sequences in the same way as in the first experiment, but we narrowed the set of test items to the small range around numerosity 31, using the numerosities 28 to 34 as test items. This experiment also showed an influence of the previous strategy, but it was again limited to a restricted range of numerosities, i.e. the numerosities 28 to 30. As such, both experiments demonstrated that participants are influenced by the previously-used strategy, but this influence is limited to a small range of numerosities.[2] Apparently, participants are only influenced by the previously-used strategy on the numerosities for which both strategies are more or less equally applicable (i.e., the above-mentioned strategy-neutral numerosities). Generally speaking, this pair of experiments provided the first empirical evidence that sequential effects also occur in the domain of strategy choice. We called this sequential effect the *perseveration effect*.

The goal of the next study, reported in ***Chapter 2***, was to replicate the findings of Chapter 1 with a different research paradigm. Therefore, we presented the numerosities in three possible presentation orders, namely, an ascending order, a random order, and a descending order. In the ascending order, participants started with solving addition items (e.g., 16, 18), and we gradually increased the numerosity of the cells in the grid so as to arrive at subtraction items (e.g., 36, 38). In the descending order, the items were presented in the opposite order compared to the ascending order: Participants started with solving subtraction items and we gradually decreased the numerosity of the cells in the grid towards addition items. In the random order, the different numerosities were presented randomly. As such, this study did not make an explicit distinction between (extreme) addition and subtraction items on the one hand, and test items on the other hand as in Chapter 1. Instead, the difference between the different types of items was more gradual. With this research paradigm, we were again able to demonstrate the perseveration effect. Taking the studies of Chapter 1 and Chapter 2 together, we were able to show the perseveration effect both in a situation in which there was a large discrepancy between the preceding and the strategy-neutral items, and in a situation in which there was a small discrepancy between the preceding and the strategy-neutral items.

Common to the studies of Chapter 1 and Chapter 2 is the fact that they all showed the perseveration effect after the *repeated* use of the previous strategy. In the following study reported in ***Chapter 3***, we attempted to investigate whether the perseveration effect would already show up after a single previous strategy

[2] A possible explanation for the small but reliable difference between the two experiments is provided in Chapter 1.

application, and, if so, whether the strength of the effect would be different after a single application than after a repeated application of a strategy.[3]

To answer these research questions, we created an experiment with two different conditions; a repeat condition and a single condition. The *repeat condition* was very similar to the sequences used in the experiments reported in Chapter 1, in that this condition consisted of sequences of five extreme addition items or five extreme subtraction items followed by one test item. The *single condition* was constructed in the same way as the repeat condition, but this time the test item was inserted already after the first extreme item. The other four extreme items were placed after the test item, to make both experimental conditions equal in terms of overall cognitive load. This study again yielded a perseveration effect, but we did not find evidence for a differential effect after a single versus a repeated previous strategy application. However, another interesting finding was observed. A cluster analysis showed large individual differences in participants' strategy choices. Three groups could be distinguished: a group showing the perseveration effect (i.e., a group who used the addition strategy most often after addition items, and the subtraction strategy most often after subtraction items), and two groups which did not show the perseveration effect - one with a strong preference for the addition strategy (irrespective of the preceding strategy), and a group with a strong preference for the subtraction strategy (irrespective of the preceding strategy).[4]

A final question which we addressed in this doctoral dissertation was how these individual differences in the perseveration effect could be explained. Therefore, a follow-up study (***Chapter 4***) was set up to further elucidate upon this finding. The goal of this study was twofold: first, we tried to replicate the individual differences in the perseveration effect observed in Chapter 3; and second, we tried to relate these differences in strategy choices to a set of five different subject characteristics that we hypothesized to be related to participants' strategy choice behaviour in the present

[3] After having conducted this study, we noticed that the research team of Patrick Lemaire from the University of Provence (France) had also started studying the perseveration effect. Therefore, the research goals of this study were, during the writing of the manuscript (as reported in Chapter 3), slightly changed in the light of the study of Lemaire and Lecacheur (2010).
[4] The studies of the Chapters 1 to 3 have been summarized in an article wherein we have reviewed all the available evidence on the perseveration effect but which we have not included in the dissertation because of the overlap with the reports presented in these three chapters (Schillemans, Luwel, Onghena, & Verschaffel, 2011).

task. These five subject characteristics consists of three executive functions which can be assumed to play a role in strategy choice behaviour in general, namely inhibition, switching, and updating, and two more task-specific characteristics, namely arithmetic skills, and subtraction self-efficacy beliefs. The results showed that two of these subject characteristics could at least explain some of the individual differences, namely, inhibition, and subtraction self-efficacy beliefs.

A general discussion of this dissertation is provided in ***Chapter 5***. This discussion begins by summarizing the results of the different studies. Next, we will discuss some remaining questions for further research. Thereafter, we will talk about the extent to which a number of underlying mechanisms can account for the observed perseveration effects. Next, we will address some educational implications, and we will end with a general conclusion.

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Chapter 1

The First Evidence for a Perseveration Effect in Strategy Choices[1]

Abstract

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.

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1.1. Introduction

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, Arnoud, & 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.

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: (1) an addition strategy, whereby participants added the (groups of) coloured cells, or (2) 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, many 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 cells and a positive correlation (r = .92) between the percentage use of the addition strategy and the number of coloured cells. 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-anxiety children used retrieval more often than high-anxiety 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.

1.2. 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 was 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.

1.3. Experiment 1

1.3.1. 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.

1.3.2. 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 1.1). A Tukey test indicated that the effect of the preceding strategy use was restricted to numerosity 31 (d= .14, $p = .011$).

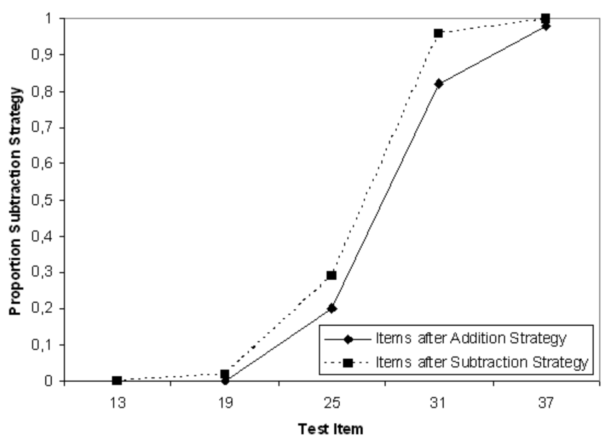

Figure 1.1. Proportion subtraction strategy use as a function of the test item and the preceding strategy in Experiment 1.

1.3.3. 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.

1.4. 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.

1.4.1. 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.

1.4.2. 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 ($M = .97$) 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 1.2). 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 ($d = .13$, $p = .05$).

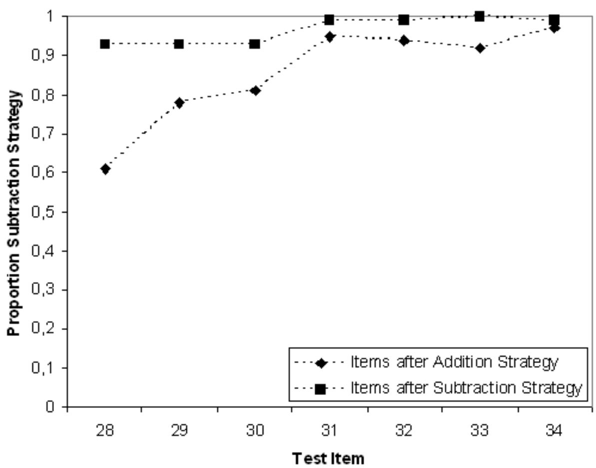

Figure 1.2. Proportion subtraction strategy use as a function of the test item and the preceding strategy in Experiment 2.

1.4.3. 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.

1.5. 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 choice 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 choices 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 the previously-used strategy. 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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Chapter 2

Replication of the Perseveration Effect with a Different Paradigm[1]

Abstract

The present study provides additional evidence for the recently described perseveration effect (i.e., participants repeat the previous strategy more often than to switch to another strategy). Participants' task was to determine the number of coloured cells in grids by using two possible strategies: an addition strategy (whereby participants add the coloured cells) or a subtraction strategy (whereby they add the number of empty cells and subtract this number from the total grid size). We used a paradigm in which the different numerosities were presented in three different orders: an ascending order, which started with low-numerosity items (which are known to be solved with the addition strategy) and gradually increased to high-numerosity items (which are known to be solved with the subtraction strategy), a descending order (with the reverse order) and a random order. The hypothesis that participants' change point (i.e., the numerosity on which they switch from the addition strategy to the subtraction strategy) would be largest in the ascending order and smallest in the descending order, is confirmed.

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[1] This Chapter has been accepted for publication as Schillemans, V., Luwel, K., Onghena, P., & Verschaffel, L. (in press). The influence of the previous strategy on individuals' strategy choices. *Studia Psychologica.*

2.1. Introduction

A growing body of research has shown that individuals exhibit a remarkable variability in their strategies for solving various 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). Strategy diversity is advantageous since it offers the potential to adapt one's problem-solving behaviour to inherent problem characteristics, such as the difficulty of the problem at hand, but also to changing contextual demands, such as the need to answer quickly or accurately, and to subject features, such as people's knowledge and mastery of particular solution strategies (Siegler, 1996; Siegler & Lemaire, 1997; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009).

Having multiple strategies at one's disposal, however, requires making adaptive choices among the different available strategies. The better one can adapt one's strategy choice to the demands of the task and context as well as to one's own competences, the better the resulting performance in a specific task will be. Being adaptive, however, implies also that one can flexibly switch between strategies when appropriate. This involves, among other things, that one is able to disengage from the last activated strategy and select and execute another strategy that is more appropriate to solve the current problem.

The literature contains various models of how people select and use cognitive strategies, such as ACT-R (Lovett & Anderson, 1996), the adaptive decision maker (Payne, Bettman, & Johnson, 1993), RCCL (Lovett & Schunn, 1999), or Rieskamp and Otto's (2006) SSL model. Although these models can account for a large number of findings about people's strategic behaviour, none of them does take into account the possibility that the use of a strategy on a trial may affect people's strategy choices on the following trial.[2] So, they cannot account for people's persistence in using a strategy when an alternative is faster and/or more accurate for the item at hand.

[2] A model that takes the influence of the most recently used strategy on individuals' strategy chocies into account is SCADS* (Siegler & Araya, 2005). We refer to section 2.5 for more information about this model and the way in which it accounts for this influence.

However, before pleading for having such a theoretical account, there is a need of convincing empirical evidence coming from various cognitive tasks and research paradigms that show that people indeed keep on using a particular strategy even if, from an objective point of view, a different strategy would have been slightly or even considerably more appropriate for solving the problem at hand. If so, then a revision of the available models of how people select and use cognitive strategies would be needed.

Interestingly, this empirical evidence is starting to show up. Very recently, Lemaire and Lecacheur (2010, Experiment 3) and Schillemans, Luwel, Bulté, Onghena, and Verschaffel (2009) have--simultaneously but independently--demonstrated that individuals' strategy choices are to some extent affected by the most recently used strategy. Lemaire and Lecacheur studied the influence of the previous strategy with a two-digit addition task. This task can be solved with two different strategies that are of equal complexity, namely full- and partial-decomposition. In the *full-decomposition* strategy, participants start with decomposing both addends into tens and units, first they add 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 only decompose the second addend into tens and units, then add the tens of the second addend to the first, and thereafter they add the units of the second addend to this running total (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 the second problem of each pair could be solved freely by either of the two strategies. To prevent carry-over effects from one problem pair to the following, 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. Using this task, Lemaire and Lecacheur 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.

Schillemans et al. (2009) used a numerosity judgement task to test for the influence of the previous strategy. In this task, participants have to determine the number of coloured cells in a grid. To do so, two main strategies can be used; an addition strategy wherein the different (groups of) coloured cells are added to arrive at the total number of coloured cells in the grid, and a subtraction strategy wherein the (groups of) empty cells are added and then subtracted from the total grid size. Verschaffel, De Corte, Lamote and Dherdt (1998) demonstrated that the choice between these two strategies is highly determined by the ratio of coloured versus empty cells in the grid. More specifically, participants typically choose for the addition strategy on items with few coloured and many empty cells, whereas they adopt the subtraction strategy on items with many coloured and few empty cells. To test for the influence of the previously-used strategy on the subsequent strategy choice, Schillemans et al. (2009) created 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 strategy (i.e., addition items) or the subtraction strategy (i.e., subtraction items). The test items, however, were not so exclusively associated with either of the two strategies, but were assumed to elicit both strategies. Participants received 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 sequence of extreme items. As expected, participants were more inclined to use 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 are known to elicit 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 (as for the extreme items) the effect of the contextual factor “previously-used strategy” was negligible.

These two studies (Lemaire & Lechacheur, 2010; Schillemans et al., 2009) have given the first evidence for a perseveration effect in individuals’ strategy choices, but more evidence is needed from different tasks and paradigms to obtain a clearer picture of the circumstances under which this recently discovered contextual factor operates.

2.2. The Present Study

The goal of the present study was to present additional evidence for the perseveration effect by replicating the previous studies with the aforementioned numerosity judgement task with a different paradigm. In studies in which the different numerosities of the numerosity judgement task were presented randomly, it has been observed that participants who use both the addition and subtraction strategy show a typical two-phase reaction-time pattern when the reaction times (RTs) are plotted as a function of numerosity (Luwel, Verschaffel, Onghena, & De Corte, 2003a; 2003b; 2003c). This pattern is characterized by a linear increase in RTs, followed by a linear decrease (see Figure 2.1). This typical RT-pattern can be explained on the basis of participants' strategy use. The use of the addition strategy leads to linearly increasing RTs with an increasing number of coloured cells, since the larger the number of coloured cells, the more time is needed to count them. In contrast, the use of the subtraction strategy leads to linearly decreasing RTs with augmenting numerosity, because the larger the number of coloured cells, the smaller the number of empty cells and, thus, the less time one needs to count the latter ones. The numerosity on which participants switch from the addition strategy towards the subtraction strategy is called the change point.

We tested the perseveration effect in the present study by presenting the trials in three different orders, namely an ascending, a random and a descending presentation order. If participants are more inclined to repeat the last executed strategy, one can expect that the average change point of a group of participants would be located on a larger numerosity when the different numerosities are presented in an ascending order than when presented in a random order. Conversely, the average change point is expected to be located on a smaller numerosity when the different numerosities are presented in a descending order than when presented randomly. These predictions were based on the following reasoning. In all studies that determined the change point in the numerosity judgement task so far (Luwel et al., 2003a; 2003b; 2003c; Luwel, Lemaire, & Verschaffel, 2005; Luwel & Verschaffel, 2003), the different numerosities were presented randomly. As a consequence, it can be assumed that the average change point in such a situation would be located on the most strategy-neutral item. When the numerosities are presented in an ascending order, participants are expected to solve the first item of the series (i.e., the item with the smallest number of coloured cells) with the addition strategy and to continue using this strategy to solve the other low-numerosity items. If participants are influenced by the previously-used strategy, they will also solve the strategy-neutral numerosities around the change point with the addition strategy. Indeed, they will only switch towards the subtraction strategy on a numerosity for which the latter strategy clearly outweighs the former one in terms of cognitive demands. As a consequence, the average change point will be located on a larger numerosity compared to an experimental setting in which the different numerosities would be presented randomly. Conversely, when the numerosities are presented in a descending order, participants are expected to solve the first item (i.e., the item with the largest number of coloured cells) with the subtraction strategy and to continue using this strategy on the same strategy-neutral numerosities and keep on using it until they encounter an item for which the addition strategy is clearly more beneficial and a switch towards that strategy is made. Consequently, the average change point will be located on a smaller numerosity than when the items are presented randomly.

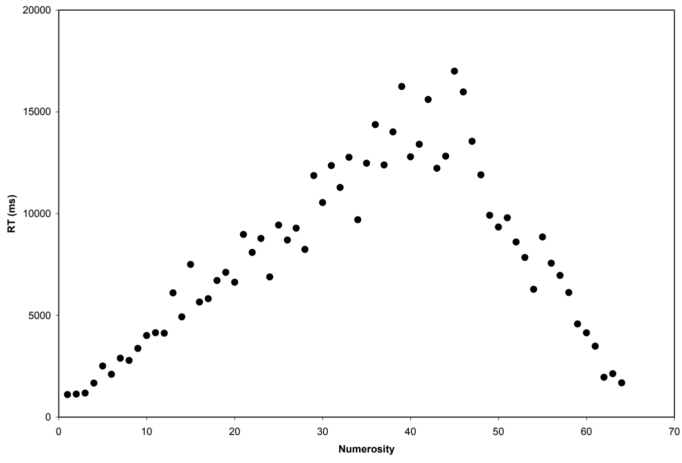

Figure 2.1. Example of an individual RT-pattern from an 8 x 8 grid (from Luwel, Verschaffel Onghena, & De Corte, 2001).

If participants' strategy choices are affected by the most recently used strategy, then one can expect to observe this effect on two closely related dependent variables, namely the frequency of strategy use and the location of the average change point. Concerning the frequency of strategy use, we expected that, compared to the situation in which the items were presented in a random order, participants would use the addition strategy more often when the items were presented in an ascending order and less often when they were presented in a descending order. With respect to the location of the average change point, we expected that, as outlined above, compared to the random order, the average change point would be located on a larger numerosity in the ascending order and on a smaller numerosity in the descending order.

2.3. Method

2.3.1. Participants

Fifty-seven students (53 women and 4 men)[3] in Educational Sciences from the Katholieke Universiteit Leuven participated in this study in exchange for course credits. Their mean age was 18.72 years (range: 18 – 23 years).

2.3.2. 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 x 1024 pixels. Stimuli were rectangular grids containing five rows with ten cells each. As such, each grid contained 50 cells of 1 x 1 cm each, and which 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.

During the experiment, grids with 16 to 38 coloured cells were presented. Two sets of numerosities were created. The first set included the numerosities 16, 18, 19, 22, 24, 26, 27, 28, 29, 31, 34, 35, and 37, while the second set comprised of the numerosities 17, 20, 21, 23, 25, 26, 27, 28, 30, 32, 33, 36, and 38. We included

[3] This unequal distribution of women and men in the sample is due to students' enrolment patterns.

irregular intervals between consecutive numerosities in each set to prevent that participants in the ascending and the descending order would be able to determine the numerosity of the following trial on the basis of a prefixed algorithm (e.g., n = (n - 1) + 3) instead of actually counting it. The numerosities 26, 27, and 28 were common to both sequences since it has been demonstrated that 27 is the most neutral numerosity in a 5 x 10 grid (Schillemans, Luwel, Onghena, & Verschaffel, 2010) and therefore we wanted to maximise the opportunity to detect a possible change point in this numerosity range. All participants received both numerosity sets in the three possible presentation orders, namely an ascending order (= A), a random order (= R), and a descending order (= D). These three presentation orders were in its turn administered in two possible sequences, namely, A – R – D – D – R – A or D – R – A – A – R – D, with a short break halfway the sequence. We have chosen sequences in which the random order was always in between the two other presentation orders to mask the typical patterns of the ascending and the descending order as much as possible. In each sequence, the two numerosity sets were counterbalanced across the different presentation orders. That is, for half of the participants the first presentation order in the sequence was tested with numerosity set 1 and the second with numerosity set 2, the third again with set 1, the fourth with set 2, and so on, and the other half of the participants started with numerosity set 2 and subsequently switched between the two. This resulted in four different sequences of presentation orders, namely

- $A_1 – R_2 – D_1 – D_2 – R_1 – A_2$
- $A_2 – R_1 – D_2 – D_1 – R_2 – A_1$
- $D_1 – R_2 – A_1 – A_2 – R_1 – D_2$
- $D_2 – R_1 – A_2 – A_1 – R_2 – D_1$

Participants were randomly assigned to one of these four possible sequences. As such, each participant solved 78 items in total (i.e., 6 presentation orders witch 13 items each). An intermediate task (i.e., a numerical comparison task, see below) was administered between every two successive presentation orders, to prevent possible carry-over effects from one presentation order to the next one.

2.3.3. Procedure

Participants were tested individually in a quiet room and were seated at about 40 cm from the screen. Next they were allocated to one of the four possible sequences.

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, the experimenter explained him/her this strategy. 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 currently counting. This pointing behaviour enabled the experimenter to identify the strategy used on every trial easily and reliably. If participants were pointing at the coloured cells, the strategy was classified as the addition strategy, while if they were pointing at the empty cells, it was classified as the subtraction strategy. 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 stopped the computer timer and 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, an intermediate task was administered after every presentation order to prevent carry-over effects from one presentation order to the next one. Participants were randomly presented ten problems (five addition and five subtraction problems) for which they had to determine whether the result was smaller or larger than 50 (e.g., 34 + 12) as fast and as accurately as possible. The transition between the two tasks was guided by a small text which reminded the participant of the goal of the upcoming task.

2.4. Results

The analyses included only the data of the numerosity judgement task. Before analysing these data, we removed all trials on which an inversion error was made. Inversion errors were defined as the trials on which the participant responded with the complement of the correct answer plus or minus five (e.g., responding 13 on a trial with 37 coloured cells). We removed this kind of errors because on these trials participants used a mixture of both available strategies. We did not remove the inversion errors in the middle one third of the numerosity range (for example responding 24 when the correct answer was 26) when it was not obvious from participant's overt behaviour whether he or she made an inversion error, because for this range it is impossible to distinguish between inversion errors and counting errors. Using these criteria, we removed 73 out of 4368 trials (i.e., 1.7% of the trials). In addition, one participant was discarded from the analyses because she made inversion errors on all trials being solved by the addition strategy. This reduced the number of participants to 56. An alpha level of .05 was used for all statistical tests. Exact p-values are reported, but very small values are rounded to $p < .0001$.

2.4.1. Frequency of Strategy Use

The first analysis tested the influence of presentation order on the frequency of strategy use. This frequency was derived from participants' pointing behaviour while solving the different items and constitutes a direct measure of individuals' strategy use. A 3 (order: ascending, random, and descending) x 2 (numerosity set: 1 vs. 2) repeated-measures ANOVA with proportion addition strategy use as the dependent variable was conducted. Because neither the effect of numerosity set, nor the interaction between this variable and order was significant, we removed this variable from the analysis. As such, we conducted an analysis with order as the only independent variable. This analysis showed a significant main effect of order, $F(2, 110) = 20.13$, $p < .0001$, partial $\eta^2 = .27$. In line with our predictions, a post-hoc Tukey test revealed that, compared to the random presentation order (*M* = .48), the addition strategy was used on a significantly larger proportion of trials when they were presented ascendingly (*M* = .53, *p* = .03), and on a significantly smaller proportion of trials when presented descendingly (*M* = .42, *p* = .001).

2.4.2. Location of the Change Point

Before doing the analysis on the location of the change point, we additionally removed the data of all participants who showed no change point at all in one or more presentation orders (this occurred when a participant only used one of both strategies to solve one of the presentation orders), or did not solve the first item of the ascending or descending order with the intended strategy (i.e., the addition or the subtraction strategy, respectively). This led to an additional removal of five participants, which further reduced the number of participants included in this analysis to 51.

To test for differences in participants' change point, we used a RT-approach because the previous studies that determined change points in the numerosity judgement task have revealed some unexpected strategy choices around the change point. That is, participants sometimes used the subtraction strategy on items before the change point, and the addition strategy on items after the change point. Hence, participants' change points cannot be determined unambiguously on the basis of their overt behaviour. To estimate participants' change point, we applied a two-phased segmented linear regression model on the individual RT-patterns (Beem, 1993, 1995). This model looks for a change point in the RT-pattern and accordingly computes two different linear regression equations. The first regression equation holds for the values before the change point, while the second regression equation holds for the values after the change point. For each participant, the observations for the different types of presentation orders were collapsed over the two numerosity sets. By doing so, we increased the number of observations for the regression analysis, which improved the reliability of the estimate of the location of the individual change point in the three orders. Outliers were removed by means of the Cook's D statistic (Myers, 1990; Neter, Kutner, Nachtsheim, & Wasserman, 1996). By doing so, 39 influential outliers were removed (i.e., 1.1% of all remaining data points).

The numerosities on which the individual change points were located were entered as the dependent variable in a repeated-measures ANOVA, with presentation order (ascending, random, and descending) as the only independent variable. This analysis showed a main effect of order, $F(2, 100) = 4.71$, $p = .01$, partial $\eta^2 = .09$. The average change points for the different presentation orders were in the hypothesized directions (*M*s: 27.88, 26.67, and 25.90 for respectively the ascending, random, and descending presentation order). A post-hoc Tukey test revealed that the difference between the average change point for the ascending presentation order was significantly larger than for the descending presentation order ($p = .008$). However, there was no significant difference between the location of the change point for the random presentation order on the one hand and the locations of the change points for either the ascending or descending presentation order on the other hand.

2.5. Discussion

The goal of the present study was to provide additional evidence for the existence of the perseveration effect in individuals' strategy use which indicates that participants are more inclined to repeat the previously-used strategy than to switch to another one (Lemaire & Lechacheur, 2010, Experiment 3; Schillemans et al., 2009). This finding is important because the existing theoretical models about strategy choice do not take the possibility of an influence of the most recently used strategy on participants' subsequent strategy choice into account. However, before adapting the existing models, it is important to have convincing evidence from different tasks and different paradigms about the existence of the perseveration effect. The present study therefore wanted to replicate the earlier findings with a different paradigm. More specifically, we made use of a numerosity judgement task in which the different numerosities are presented in three different presentation orders: an ascending, a random, and a descending order. We looked at the effect of these presentation orders on two variables, namely the frequency of strategy use and the numerosity on which participants switched from the addition to the subtraction strategy (i.e., the change point). As expected, participants used the addition strategy more often with an ascending order than with a random order and less often with a descending order than with a random order. Additionally, the change points differed between the conditions. However, we only observed a significant difference between the location of the change point in the ascending order and the descending order but not between these two orders and the random order. These findings replicated the earlier findings of the perseveration effect in the strategy choice process with a different paradigm.

Although these findings give additional support for the perseveration effect in strategy choice, the underlying mechanism that can explain these findings is still unclear. Schillemans et al. (2009) discussed three different underlying mechanisms that can possibly account for the perseveration effect. Hereafter, we will briefly discuss each explanatory mechanism and argue whether and how it may also help to theoretically explain the results observed in the present study. A first possible explanation is that the repeated application of one strategy "blinded" participants for another strategy. This explanation is inspired by Luchins' (1942) research on the *Einstellung effect* with the water jar task. He presented participants with series of problems that could all be solved via the same complex solution method. Thereafter they were presented a test item that could be solved with this complex solution method, but also with a much easier one. It was shown that participants made more use of the complex method, compared to a group of participants who had not seen the previous series of problems. Although this explanation is possible for the perseveration effect observed in the study of Schillemans et al. (2009), it cannot fully explain the current findings. If participants are blinded for an alternative strategy, they simply will never switch to that strategy. By contrast, in the present study, participants always switched to the more appropriate strategy; so, they only postponed their strategy switch in the ascending and the descending order. A second possible explanation concerns *the avoidance of a so-called strategy switch cost*. Both Lemaire and Lecacheur (2010) and Luwel, Schillemans, Onghena, and Verschaffel (2009) recently showed that switching from one strategy to another leads to longer RTs on the item immediately after a strategy switch than after a strategy repetition. From this point of view, it is beneficial not to switch towards another strategy if the difference between both strategies in terms of RTs is rather small. Conversely, if this difference is large, it is more favourable to switch to the fastest strategy since the gains that can be made by switching to the other strategy are larger than the cost of a strategy switch. The occurrence of a strategy switch cost can also explain the findings of the present study. If a participant starts using a strategy, it is, because of the switch cost, not beneficial for him or her to switch already towards the other strategy when confronted with strategy-neutral items for which both strategies are equally applicable. It becomes only beneficial to switch to the other strategy when the gains of using that other strategy are larger than the switch cost. A third possible framework to explain the perseveration effect is related to *priming*. Siegler and Araya (2005) incorporated this possibility in their latest version of the SCADS model (Shrager & Siegler, 1998), namely SCADS*. In this update of the SCADS model, they added a priming component, which enables a temporary increase in the strength of the latest applied strategy, which in turn increases the probability that this strategy will be selected again on the following trial. This explanation in terms of priming can also explain why participants in the ascending and descending presentation orders did not switch to the other strategy when they arrived at the items around the change point, which are assumed to be equally strongly associated with the two strategies. For those items, the priming mechanism may have increased the probability of the most recently executed strategy to be selected on the following trial. Contrary, for items with numerosities that are strongly associated with one strategy, priming of the other strategy may not be sufficient for that strategy to be selected, which explains why individuals switched towards the other strategy when they encountered an item for which one of both strategies clearly outweighs the other one in terms of cognitive demands. Further research is needed to determine which theoretical framework provides the best explanation for the observed perseveration effect.

As discussed above, the present findings can be explained by the SCADS* model (Siegler & Araya, 2005). To the best of our knowledge, none of the other theoretical models of strategy choice take the influence of the previous strategy on the subsequent strategy choice into account (see section 2.1). However, the repeated observation of the perseveration effect in the present study and in past research (Lemaire & Lecacheur, 2010; Schillemans et al., 2009) pleads for an extension of the existing models to somehow account for these findings.

This perseveration effect may also have implications for more naturalistic (e.g., educational) contexts. Indeed, strategy adaptivity is seen as an important characteristic in most reform-based approaches of mathematical education

(Verschaffel, Greer, & De Corte, 2007). It has been argued by many authors that one has to conceive and operationalize adaptivity in function of subject, item and contextual characteristics, and the research literature contains examples of studies that have revealed how each of these three types of characteristics can be taken into account in adaptive strategy choices (Verschaffel et al., 2009). However, the observed perseveration effect indicates that there is a contextual characteristic that has hitherto not been taken into account in educational practice, namely the influence of the previous problem. Since mathematical exercises are often not presented isolated but in series, it is important to pay attention to the exact order in which the exercises are presented. As such, if children are expected to use a wide range of different strategies to solve the problems at hand, curriculum developers, textbook authors, and teachers should be aware of this contextual bias and should try to design proper series of mathematical exercises and/or to give feedback about the adaptive nature of learners' strategy choices.

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Chapter 3

The Effect of Single versus Repeated Previous Strategy Use[1]

Abstract

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 and 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.

[1] This Chapter is currently under revision as Schillemans, V., Luwel, K., Ceulemans, E., Onghena, P., & Verschaffel, L. (under revision). *The effect of single versus repeated previous strategy use on individuals' subsequent strategy choice.* Manuscript under revision.

3.1. 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 individuals select, already from a young age on, their strategies relatively adaptively by taking problem, subject, and/or contextual characteristics into account (Siegler, 1996; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009).

A contextual 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 choice 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 choice 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 x 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' 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), wherein people have to detect and use an *alternative* strategy that is obviously more efficient than the one having repeatedly used before. But, until recently, 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 x 10 grid. 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 different (groups of) coloured cells to arrive at the total number of coloured cells, and a *subtraction* strategy, wherein they added (groups of) empty cells 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 many empty cells in the grid, whereas they adopted the subtraction strategy when there were many 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. 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 contextual 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 of equal difficulty (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.

An important difference between the study of Schillemans et al. (2009) and the one of Lemaire and Lecacheur (2010) is the number of problems in a sequence preceding a test item. Schillemans et al. always presented five or six problems before the test item, whereas Lemaire and Lecacheur's design involved only one preceding problem. Given that the perseveration effect has not only been observed after repeated previous strategy uses (Schillemans et al.), but also after a single previous strategy use (Lemaire & Lecacheur), the question is 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.

3.2. Method

3.2.1. 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 Katholieke Universiteit Leuven. Their mean age was 19.72 yrs. (range: 17 yrs. – 22 yrs.) and they received two film tickets as a reward for their participation.

3.2.2. 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 x 1024 pixels. Stimuli were rectangular grids containing five rows with ten cells each. As such, each grid contained 50 cells, which were sized 1 x 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.

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 choices. These test items were selected on the basis of a preparatory study (see Appendix) which yielded the numerosities 25 to 29 as being 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)[2]. 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). The 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 typical pattern of the 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.

To neutralise influences from a previous sequence to the next one, the different sequences were separated by an intermediate task. This intermediate task was a lexical decision task whereby participants were presented a series of six letter strings. For each string they had to judge whether it was a word or a non-word. To make this task somewhat harder, we selected pseudo-words (i.e., pronounceable non-words) as non-words.

3.2.3. 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.

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

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[2] 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.

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 judgements 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 experimental task and the intermediate task) was guided by a cue that stayed on the screen for 750 ms. If the upcoming task was the experimental 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.

3.3. 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 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 cells 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) x 2 (preceding strategy: addition vs. subtraction) x 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 analysis revealed a main effect of preceding strategy, $F(1, 56) = 57.96$, $p < .0001$, partial $\eta^2 = .51$. 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 $\eta^2 = .37$, indicating an increase in the proportion of subtraction strategy use with increasing numerosity. There was also a significant interaction between preceding strategy and numerosity, $F(4, 224) = 7.37$, $p < .0001$, partial $\eta^2 = .12$, 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 >.05, partial $\eta^2 = .05$, indicating that the perseveration effect occurred both in the single and the repeat condition, but without a significant difference in magnitude between the two conditions. All other effects were not significant.

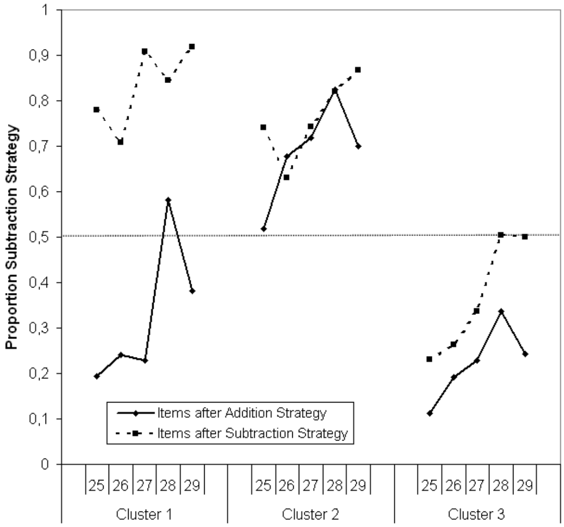

Figure 3.1. Three clusters solution.

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 x 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[3], the three-cluster solution was

[3] 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.

selected. These three clusters correspond with three clearly different response patterns on the test items (see Figure 3.1). Members of Cluster 1 (n = 22) showed a strong perseveration 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.

3.4. 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 replicate the earlier finding of Lemaire and Lechacheur with 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 from the repeat condition 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 evidence for a differential perseveration effect after a single or a repeated application of the previous strategy. Thus, one previous strategy application is apparently already sufficient to elicit the perseveration effect and the impact of a repeated previous strategy use (up to five times) is negligible. 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.

3.4.1. 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 its 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* 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 does not have to switch between strategies. 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). Further research is needed to unravel which mechanism, i.e., priming or strategy switch cost, provides the best explanation for the present results.

3.4.2. 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. This 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. Therefore, it can be that these two groups are also influenced by the previous strategy but within a different numerosity range than the one tested in this study. 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. A second explanation could be that the individuals in these two groups were simply not influenced by their previous strategy use. Evidence for individual differences in strategy preferences was already found in the data of the preparatory 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. Additionally, the possibility for individual differences in strategy preferences has also been suggested by Hickendorff, van Putten, Verhelst, and Heiser (2010) in the task domain of complex division. These authors showed that some sixth graders had a preference for a written solution strategy, others preferred a mental solution strategy, and still others preferred to use both strategies. Further research is needed to unravel these two possible explanations.

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 hypothesized 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.

3.4.3. Theoretical, Methodological, and Practical Implications

From a theoretical point of view, the present study has revealed an additional (contextual) factor that plays a role in people's strategy choices. As a consequence, this factor has to be taken into account in our theorizing 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 (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 need to be extended to account for the perseveration effect.

The present study has also some methodological implications, for instance, for the use of the choice/no-choice method (Siegler & Lemaire, 1997). This method involves the administration of two types of conditions, a choice condition and two or more no-choice conditions. In the choice condition the participants can choose (out of a list of available strategies) which strategy they will use to solve each problem, whereas in the no-choice conditions they are forced to use one particular strategy to solve all problems. According to Siegler and Lemaire (1997), these no-choice conditions provide unbiased estimates of the performance of all available strategies. As such, it becomes possible to determine for each problem whether participants in the choice condition chose the most adaptive strategy as evidenced by the no-choice strategy performance data. The present study, however, shows that this may not always be the case, since participants' strategy choices on certain items in the choice condition may be co-determined by their strategy choices on the previous item(s), a factor that is not taken into account in the logic underlying this choice/no-choice methodology. Indeed, when participants exhibit the perseveration effect on these particular items, one may wrongly conclude that they are not making adaptive strategy choices, whereas they are very adaptive just because they take the previously-used strategy into account.

Finally, these results have also educational implications. 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. This may help curriculum developers, textbook authors, and teachers to design proper series of mathematical exercises and/or to give feedback about the adaptive nature of learners' strategy choices.

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Appendix: Preparatory 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 maximize the neutrality of the test items in the present study, we conducted a preparatory 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 Katholieke Universiteit Leuven 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 x 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 with 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 3.2, 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.

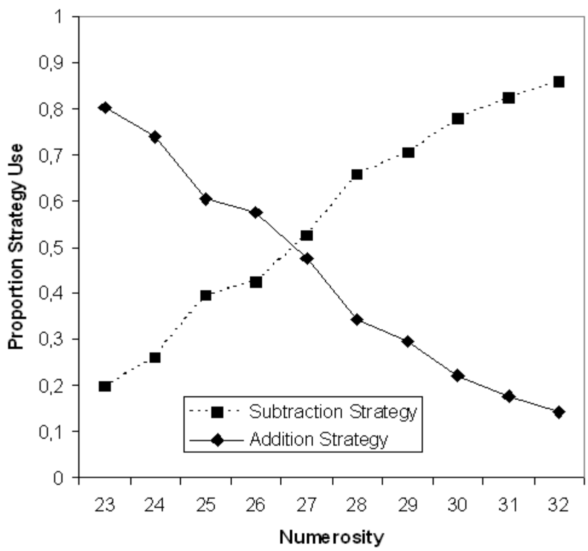

Figure 3.2. Proportion addition and subtraction strategy use for each numerosity.

Chapter 4

Individual Differences in the Perseveration Effect

Abstract

Studies concerning strategy choice have demonstrated that participants are more inclined to repeat the previously-used strategy than to switch to another one (e.g., Schillemans, Luwel, Bulté, Onghena, & Verschaffel, 2009). However, it has recently been shown that not all participants are influenced by this perseveration effect (Schillemans, Luwel, Ceulemans, Onghena, & Verschaffel, under revision). Only about one third of the participants showed the perseveration effect, whereas the others showed a preference for one strategy or another. The goal of the present study was to investigate a number of subject characteristics, namely inhibition, switching, updating, arithmetic skills, and subtraction self-efficacy beliefs, that could underlie these individual differences in perseveration. The current study replicated the earlier observed individual differences in the perseveration effect and revealed that the participants of the different groups differed partly in terms of inhibition and subtraction self-efficacy beliefs.

4.1. Introduction

Many cognitive tasks that we encounter in daily life like, for instance, arithmetic (e.g., Peters, De Smedt, Torbeyns, Ghesquière, & Verschaffel, 2010), reading (e.g., Lima & Castro, 2010), and decision making (e.g., Milkman, Chugh, & Bazerman, 2009), can be solved with multiple strategies. Having several strategies at one's disposal allows people to choose the most appropriate strategy for the problem at hand in a specific context. However, this strategic variability implies that a choice between the different available strategies needs to be made (more or less consciously) for every problem one wants to solve. Several studies have demonstrated that individuals' strategy choices are influenced by subject, problem, and contextual characteristics (Siegler, 1996; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009). An example of how subject characteristics can affect individuals' strategy choices has been provided by Imbo and Vandierendonck (2007), who observed that the choice for the retrieval strategy in a mental arithmetic task is co-determined by participants' gender; that is, boys use this strategy more often than girls. An example of how problem characteristics determine participants' choices can be found in Lefevre, Sadesky, and Bisanz (1996), who found that the retrieval strategy is for example more often used on easy than on hard problems in mental arithmetic. Finally, researchers have argued and shown that people's strategy choices are also influenced by contextual characteristics, for instance whether the problem is given in or out of a school context (Ellis, 1997; Nunes, Schliemann, & Carraher, 1993). Recently researchers have started to investigate a contextual characteristic which has not been described earlier, namely the influence of the previously-used strategy on the subsequent strategy choice (Lemaire & Lecacheur, 2010; Schillemans, Luwel, Bulté, Onghena, & Verschaffel, 2009; Schillemans, Luwel, Ceulemans, Onghena, & Verschaffel, under revision; Schillemans, Luwel, Onghena, & Verschaffel, in press). These studies have revealed that participants more often have a tendency to reuse the strategy that was used on one or more previous problems than to switch to another strategy. This influence of the previous strategy is called, the *perseveration effect*. However, not all participants were found to be equally susceptible to this influence (Schillemans et al., under revision; see further). The goal of the present study is to test which subject characteristics underlie these individual differences in the perseveration effect.

4.2. The Perseveration Effect

Lemaire and Lecacheur (2010, Experiment 3) studied the perseveration effect with a two-digit addition task that can be solved by two strategies of equal complexity (e.g., Beishuizen, 1993; Lemaire & Arnaud, 2008; Lucangeli, Tressoldi, Bendotti, Bonanomi, & Siegel, 2003). 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 continue with adding the units of the second operand (e.g., 27 + 38; 27 + 30 = 57; 57 + 8 = 65). Lemaire and Lecacheur presented the problems in pairs: the first problem of each pair was accompanied with a cue that indicated which strategy to use, while on the second problem of the pair participants could freely choose between the two strategies. The perseveration effect was measured as the proportion of pairs for which the second problem was solved with the same strategy as the first problem of that pair. The results indicated that participants repeated the strategy used on the first problem of the pair more often than that they switched to the other strategy.

Schillemans et al. (2009) studied the perseveration effect with a different task and a different method. The task they used was a numerosity judgement task in which participants had to determine several numerosities of coloured cells presented in a 5 x 10 grid. In line with previous studies (e.g., Luwel, Verschaffel, Onghena, & De Corte, 2003; Verschaffel, De Corte, Lamote, & Dherdt, 1998), adult participants were found to rely on two main strategies for solving this task namely an *addition* strategy, wherein they add the different (groups of) coloured cells to arrive at the total number of coloured cells, and a *subtraction* strategy, wherein they add the different (groups of) empty cells and then subtract this number from the total grid size. These previous studies (e.g., Luwel et al., 2003; Verschaffel et al., 1998) also demonstrated that participants' choice between these two strategies was mainly determined by the ratio of coloured versus empty cells in the grid. That is, participants typically choose the addition strategy when there are only few coloured and many empty cells in the grid, whereas they adopt the subtraction strategy when there are many coloured and only few empty cells. When neither the coloured nor the empty cells clearly outnumber the other ones, individuals use either of the two strategies. In their investigation, Schillemans et al. used two kinds of items: extreme items which were meant to evoke a certain strategy and test items which were used to test participants' strategy choices. Extreme items were items with either a very small or a very large number of coloured cells, which were known to almost exclusively elicit the addition (i.e., addition items) or the subtraction strategy (i.e., subtraction items), respectively. The test items, however, were assumed not to be so clearly associated with either of the two types of strategies, but to elicit both strategies more or less equally strongly. Participants received several sequences of items, always consisting of a series of five or six extreme items all aimed at evoking the same strategy (i.e., the addition strategy or the subtraction strategy), followed by one test item. These sequences differed in two important ways from the sequences used by Lemaire and Lecacheur (2010): (a) instead of *cueing* the intended strategy, it was *evoked* by the specific nature of the preceding trials, which made the whole task less artificial for the participants, and (b) multiple items preceded the test item instead of a single one. In line with the study of Lemaire and Lecacheur, the results of this study showed that individuals' strategy choices on the test items were indeed influenced by the type of strategy being repeatedly executed on the preceding series of extreme items. As expected, participants were more inclined to use the subtraction strategy on the test item when it was preceded by a series of subtraction items than when it was preceded by a series of addition items. Furthermore, it was found that this perseveration effect was not observed for all test items, but remained limited to the so-called *strategy-neutral* items (i.e., a rather small range of test items, located after the mathematical midpoint of the continuum of the numerosity range, for which the addition and the subtraction strategy were almost equally attractive or – stated differently – which elicited the two strategies about equally strongly).

In a follow-up study, Schillemans et al. (under revision) observed large individual differences in the perseveration effect. A cluster analysis revealed three groups of participants: (a) an *addition group* (28% of the participants) consisting of participants who chose most often for the addition strategy, both after an addition sequence and a subtraction sequence, (b) a *subtraction group* (34% of the participants) in which participants chose most often for the subtraction strategy, both after an addition sequence and a subtraction sequence, and (c) a *perseveration group* (38% of the participants) containing participants who showed a clear perseveration effect: they used the addition strategy more often after an addition sequence, and the subtraction strategy more often after a subtraction sequence. As such, this study demonstrated that the earlier observed perseveration effect (i.e., Lemaire & Lecacheur, 2010; Schillemans et al., 2009; in press) was only present in a subset of about one third of the participants. Since it was not clear which subject characteristics gave rise to these individual differences in strategy choice behaviour, the aim of the present study was to characterize these three groups by testing a number of candidate variables that could underlie the individual differences observed in Schillemans et al. (submitted).

4.3. The Present Study

Because the perseveration effect is a recently studied topic in strategy choice research, it is not established yet which subject characteristics could be associated with individual differences in this perseveration effect. Based on the literature, it seems plausible to assume that differences in executive functioning (i.e., inhibition, strategy shifting, and updating) could explain at least a part of these differences in strategy choice behaviour (Hodzik & Lemaire, 2011). In addition to this variable, which is assumed to underlie individuals' strategy choice behaviour in general, we tested two variables that were specifically related to the present numerosity judgement task and that might explain an additional part of the differences that have been previously observed, namely arithmetic skills and subtraction self-efficacy beliefs.

4.3.1. Executive Functions

One factor that may explain the observed individual differences in the perseveration effect are differences in executive functioning. Executive functions are considered higher order mental operations involved with the maintenance, manipulation, planning, monitoring and regulation of cognitive processes (Stuss &

Benson, 1986). Although there is no consensus on how to best define executive functions, abilities such as self-regulation, sequencing of behaviour, mental flexibility, inhibition, planning, organization, and the ability to initiate, maintain, switch and stop sequences of complex behaviour are generally included (Eslinger, 1996; Lezak, 1995). Miyake et al. (2000) demonstrated that executive functions can be divided into at least three abilities that are independent but conceptually related: the ability to inhibit dominant or prepotent responses, the ability to switch between different response sets, and the ability to update contents in working memory.

The first executive function, inhibition, refers to one's ability to deliberately inhibit dominant, automatic or prepotent behavioural or cognitive responses when necessary. In terms of strategy choice, this implies that inhibition of one of the strategies (e.g., the most activated one) may be needed to choose another strategy. After having used a particular strategy, this strategy will still have some remaining activation, and needs to be inhibited before another strategy can be selected. Although such a role of inhibition in individuals' strategy choices has not been shown yet, it has been suggested by Hodzik and Lemaire (2011). Therefore, it can be hypothesized that participants with better inhibition skills will be better able to suppress an activated strategy; that is, the previous strategy and will therefore be able to switch more often to another strategy. Stated differently, participants with better inhibition skills will be better able to resist the perseveration effect. Additionally, it can be hypothesized that inhibition of the previously-used strategy would be especially needed on these items that do not strongly activate one of the strategy themselves (i.e., the strategy-neutral items).

The second executive function, switching, involves the ability to disengage from an irrelevant strategy and to subsequently engage in a relevant strategy. Both Lemaire and Lecacheur (2010) and Schillemans et al. (2009) suggested a possible link between the perseveration effect and the strategy switch cost (see Lemaire & Lecacheur, 2010; Luwel, Schillemans, Onghena, & Verschaffel, 2009 for more information about strategy switch cost). They hypothesized that the perseveration effect could be the result of participants trying to avoid the cost of switching strategies. As such, it can be hypothesized that participants with weaker switching skills will demonstrate a larger perseveration effect because these participants will be less inclined to switch to another strategy.

A third executive function mentioned by Miyake et al. (2000) is updating, which refers to monitoring and coding incoming information for its relevance to the task at hand and then appropriately revising the items held in working memory by replacing old, no longer relevant information with newer, more relevant information (Morris & Jones, 1990). Hodzik and Lemaire (2011) suggest that updating capacities could be involved in strategy choices because participants have to update the available strategies after the execution of a strategy, to be able to select a (better) strategy on the following trial. This would imply that participants with weaker updating abilities are less able to update the available strategies after the execution of one of the strategies. Because of their reduced ability to update, these participants would be more inclined to repeat the previous strategy (i.e., the most recently activated strategy). In other words, participants with weaker updating skills are hypothesized to persevere more than participants with stronger skills.

4.3.2. Arithmetic Skills

Another subject characteristic that may have an influence on participants' strategy choice pattern in the numerosity judgement task are arithmetic skills. Although arithmetic skills are not thought to have an influence on the perseveration effect itself, we expect them to differ between participants with a preference for the addition or the subtraction strategy. Both strategies are not of equal difficulty; the subtraction strategy is harder than the addition strategy, not only because making subtractions is harder than doing additions, but also because, compared with the addition strategy, the subtraction strategy contains an additional step, namely subtracting the number of counted empty cells from the total number of cells in the grid (Luwel, Lemaire, & Verschaffel, 2005; Verschaffel et al., 1998). It can be hypothesized that participants with weaker arithmetic skills will choose more often for the easier addition strategy than participants with stronger arithmetic skills.

4.3.3. Subtraction Self-Efficacy Beliefs

It can further be hypothesized that not only participants' *actual* arithmetic skills can determine their strategy choices in the numerosity judgement task, but also their *perceived* skills, or stated differently, their epistemological beliefs in their skills (De Corte, Mason, Depaepe, & Verschaffel, 2011). Participants who believe that they cannot fluently execute the harder subtraction strategy (i.e., participants with lower *self-efficacy beliefs*) may choose less often for this strategy than participants who have more confidence in their subtraction abilities.

4.3.4. Task and Design

We used a design that consisted of two parts. In the first part, we used the above-mentioned numerosity judgement task to determine the extent to which the perseveration effect was present in the different participants. In the second part, the different subject characteristics (i.e., inhibition, switching, updating, arithmetic skills, and subtraction self-efficacy beliefs) were assessed, after which we related these subject characteristics to the individual differences in the perseveration effect.

4.4. Hypotheses

The following hypotheses can be put forward for the present study. First, we expected to replicate the perseveration effect as observed by Schillemans et al. (2009, under revision): participants were expected to use the subtraction strategy more often after a series of subtraction items than after a series of addition items (Hypothesis 1). Second, in line with Schillemans et al. (under revision), we expected to observe three groups of participants as a function of their strategy choices on the test items: one group that would show the perseveration effect (i.e., the perseveration group) and two groups of participants who would either show a strong preference for the addition strategy (i.e., the addition group), or for the subtraction strategy (i.e., the subtraction group) (Hypothesis 2). Third, we anticipated that individual differences in executive functioning would be a significant predictor for membership of one of these three groups. More specifically, it was expected that participants who are less able to inhibit would be more likely to belong to the perseveration group than to the addition or subtraction group (Hypothesis 3), as suggested by Hodzik and Lemaire (2011).

Furthermore, in line with the suggested link between strategy switch cost and perseveration effect (Lemaire & Lecacheur, 2010; Schillemans et al., 2009), individuals with a smaller switching capacity would have a higher probability to show the perseveration effect (Hypothesis 4). Finally, since it has been suggested that participants have to update their strategy repertoire after executing a strategy and before using another one (Hodzik & Lemaire, 2011), we predicted that participants with a weaker updating ability would be more likely to stick to the strategy in their repertoire and show the perseveration effect (Hypothesis 5). We also expected that arithmetic skills and self-efficacy beliefs would be significant predictors of strategy preference. More specifically, we anticipated that arithmetic skills would influence participants' choice for the harder subtraction strategy. The weaker participants' arithmetic skills, the less often this harder strategy would be used (Hypothesis 6). As such, participants with worse arithmetic skills would be more often in the addition group (i.e., participants who hardly use the subtraction strategy) than in the subtraction group (i.e., participants who use the subtraction strategy very often), or the perseveration group (i.e., participants who use the harder subtraction strategy after subtraction items but not after addition items). On the other hand, participants with good arithmetic skills will be more often in the subtraction group than in the addition, or the perseveration group. A similar effect can be expected for subtraction self-efficacy beliefs: the lower participants' beliefs, the less often the subtraction strategy would be used (Hypothesis 7). As such, participants with lower beliefs would be more often in the addition group than in the subtraction group or the perseveration group. Participants with higher beliefs would be more often in the subtraction group than in the addition or the perseveration group.

4.5. Method

4.5.1. Participants

Eighty students (69 women and 11 men) in Educational Sciences from the Katholieke Universiteit Leuven participated in this study in exchange for course credits. This unequal distribution of women and men in the sample is due to students' enrolment patterns. Their mean age was 21.98 years (range: 20 – 38 years).

4.5.2. Material, Stimuli, and Procedure

All participants were tested in three sessions: two individual sessions, and one group session. The order of the individual sessions was counterbalanced across participants: in a first session they accomplished the numerosity judgement task, and in a second session they were administered an arithmetic skills test, an inhibition test, a switching test, and an updating test. In the group session, they completed the Subtraction Self-Efficacy Beliefs (SSEB) questionnaire together with a number of questionnaires that were related to other studies. The link between the questionnaire and the other parts of the study was not mentioned to prevent that participants would adjust their response behaviour on this questionnaire in line with their believed goal of the study. The SSEB questionnaire and the arithmetic skills test were pencil-and-paper tests, whereas the other tests were taken on a PC with a Pentium 2 processor, attached to a 17” CRT screen. For the three executive functions (i.e., inhibition, switching, and updating), we specifically selected tests reported by Miyake et al. (2000) that did not include any arithmetic calculations. The reason for this choice was that using tests with arithmetic calculations can lead to overestimations of the effect of subject characteristics on the perseveration effect, because both tests would be tapping the same underlying arithmetic skills besides the hypothesized relations with executive functions.

Inhibition Test. The inhibition test was an adapted and computerised version of the Stroop task (Stroop, 1935). The goal of the task was to indicate in which colour the stimulus was printed. As test stimuli, participants received three different kinds of stimuli that were presented randomly, namely, (a) 72 neutral stimuli (i.e., five asterisks printed in a particular colour), (b) 60 incongruent stimuli (i.e., a colour word printed in a different colour; e.g., RED printed in blue), and (c) 12 congruent stimuli (i.e., a colour word printed in the same colour; e.g., RED printed in red). Participants' reaction times (RTs) were recorded by a sound-activated voice key. We subtracted the mean RT on the incongruent stimuli from the mean RT on the neutral stimuli to compute participants’ inhibition score. As such, higher scores (i.e., less negative scores) reflect better inhibition skills. Before the start of the experiment, participants got a number of practice trials to get used to the procedure and the task.

Switching Test. Participants' switching abilities are typically measured by means of a task-switching test. We chose the number-letter task originally used by Rogers and Monsell (1995) as task-switching test. The stimuli of this task were number-letter pairs (e.g., 6A) which were presented in one of the four quadrants of the computer screen. Participants had to regularly switch between two tasks: (a) determining whether the number was odd or even and (b) determining whether the letter was a consonant or a vowel. When the stimulus was presented in either of the two upper quadrants, participants had to do the odd-even task, and when it was presented in either of the two lower quadrants, they had to perform the consonant-vowel task. Participants responded by means of a key press on one of four possible keys (two for each task). The experiment started with two single task blocks (one for the odd-even task and one for the consonant-vowel task), and thereafter participants were presented a block with 128 experimental trials in which the number-letter pair rotated clockwise around all four quadrants so that participants always executed the same task for two trials before switching to the other task. As a score of switching ability, we subtracted the mean RT on the switch trials from the mean RT on the repeat trials, both taken from the last block. So, a higher score (i.e., a less negative score) referred to a better switching ability.

Updating Test. Updating ability was measured by means of the letter memory task (Miyake et al., 2000, adapted from Morris & Jones, 1990). In this task letters were serially presented for 2000 ms each and participants had to recall the last four letters presented. With every letter presented, participants had to update their memory; that is, dropping the fifth last letter and adding the last one, so that they always had the last four letters of the sequence in their working memory. To ensure that participants were continuously updating, they always had to rehearse the last four presented letters aloud. For example, if the letters "N, B, R, V, D, M, Z" were presented sequentially, participants should say aloud in reaction to each of these letters "N… NB… NBR… NBRV… BRVD… RVDM… VDMZ", and then recall and finally type in VDMZ. Three different letter sequence lengths (i.e., 5, 7, and 9) were presented three times each and the different lengths were presented randomly with the restriction that two subsequent sequences had a different length. The score on this test was the number of letters typed in correctly in the correct order.

Arithmetic Skills Test. To test for arithmetic skills, we used one of the arithmetic skills subtests of the French Kit (Ekstrom, French, & Harman, 1976). In the selected test, participants have to solve as much addition and subtraction verification problems as possible within two minutes. We have chosen for this subtest because addition and subtraction are the two arithmetic operations that are the most closely related to the two strategies to be used in the numerosity judgement task. The score on this test was the number of correctly solved problems minus the number of erroneously solved problems.

Subtraction Self-Efficacy Beliefs Questionnaire. Because no test was available to assess participants' SSEB, we constructed a ten-item questionnaire ourselves. This questionnaire consisted of questions such as "I become nervous when I have to solve a subtraction", and "I am good at solving subtractions". Participants were asked to indicate on a five-point Lickert scale, ranging from strongly disagree to strongly agree, the extent to which they agreed with these ten statements. On the basis of a reliability analysis, we removed one item that did not correlate significantly with the other items of the scale. The scale with the remaining nine items had a Cronbach's alpha of .92.

The Numerosity Judgement Task. To test for the perseveration effect, we made use of the above-mentioned numerosity judgement task. Stimuli of this task were rectangular grids containing five rows with ten cells each. As such, each grid contained 50 cells, which were sized 1 x 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 always located randomly in the grid and every item had a unique pattern of green cells to prevent participants from solving the trial based on their memory instead of actually counting the number of cells.

The paradigm we used for this study is very similar to the paradigm used in the studies of Schillemans et al. (2009, under revision). Stimuli were presented in sequences built with two types of items: every sequence started with three extreme items, followed by one strategy-neutral test item. The strategy-neutral test items were items that were assumed to elicit the two strategies about equally strongly and were used to assess participants' strategy choices. These test items consisted of the numerosities 25 to 29 and were the same as the test items used by Schillemans et al. (under revision). The extreme items were used to direct participants' strategy use before the test item in a non-obtrusive way. Two kind of extreme items were used, namely addition items, which strongly elicited the addition strategy and comprised numerosities at the lower end of the continuum (i.e., the numerosities 5 to 14) and 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]. Each test item was administered ten times, five times after an addition series and five times after a subtraction series. Thus, in total 50 sequences with four items each were administered. The sequences were constructed with three restrictions: (a) all extreme items in a sequence had a different numerosity, (b) all possible extreme items were administered equally often during the whole experiment, and (c) the sequences were constructed so that a given numerosity of a test item (e.g., 27) was immediately preceded by a given extreme item (e.g., 10 or 40) only once. To obscure the typical pattern of the sequences, we presented after each fifth sequence a filler sequence consisting of four randomly selected numerosities drawn from the whole numerosity range between 5 and 45. All grids used in the experiment had a unique configuration of coloured and empty cells to avoid that participants could answer on the basis of their recognition of a previous presentation of the same stimulus instead of actually determining the number of coloured cells.

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, and 40). The participants were instructed to determine the number of green cells in each grid as fast and as accurately as possible, and were asked to explain after each trial how they had solved the problem. If they had not spontaneously applied the subtraction strategy during these practice trials, the experimenter explained this strategy. Before the start of the experimental trials, the participants

[1] We did not select 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.

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 currently counting. If a participant was pointing at the coloured cells, the strategy was classified as the addition strategy; if he or she was pointing at the empty cells, it was classified as the subtraction strategy.

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. When participants' answer triggered a sound-activated voice key, the screen blanked and the experimenter typed in the given answer, the strategy used and whether the voice key was triggered at the right moment. Thereafter, the next trial started.

To neutralise influences from a previous sequence to the next one, the different sequences were separated by an intermediate task. This intermediate task was a lexical decision task whereby participants were presented a sequence of six letter strings consisting of five letters each. For each string, they had to judge whether it was a word or a non-word. To make this task somewhat harder, we selected pseudo-words (i.e., pronounceable non-words) as non-words.

The procedure of this intermediate task was similar to the one of the numerosity judgement task, and was also the same as for the intermediate task used by Schillemans et al. (under revision). 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 an icon of a grid; if the upcoming task was the intermediate task, the cue consisted of an icon with the letters a, b, c, and d arranged as a rhomb. The data of this intermediate task were not analysed.

4.6. Results

Seven participants were removed from the data set: three because of missing data on one or more tasks, two because of not following the instructions on the switching test, and two because they used other strategies than the intended ones in the numerosity judgement task. This reduced the number of participants in the analysis to 73.

We also had to exclude trials for some of the tests. In the inhibition test, we removed trials which were erroneously solved, and trials for which the RT deviated more than 2.5 standard deviations from the mean RT of that participant. This led to a data reduction of 659 of 10512 trials (i.e., 6.3%). For the task switching test, we applied the same criteria for removing trials as in the inhibition test, and we additionally removed the trials that were solved following a mistake. Based on these three criteria, 784 out of 9344 (i.e., 8.4%) experimental trials were removed. In the numerosity judgement task, we conducted the analyses on the test items only and the following test items were removed: (a) test items that were spoiled due to a voice key error, (b) test items in which participants suddenly switched between strategies during the trial, (c) test items that were immediately preceded by an extreme item that was not solved via the intended strategy, (d) test items that were preceded by an inversion error (i.e., an item for which the participants answered with the complement, such as answering '7' when the correct answer was '43'; these items were removed because this type of errors points to a mixture of the use of both strategies which makes it impossible to identify the strategy used on the test item) and (e) test items that were immediately preceded by an extreme item that was spoiled due to a voice key error. Although inversion errors were also possible on the test items, we did not exclude this type of errors because it is impossible to distinguish between counting errors and inversion errors on strategy-neutral items. Based upon these criteria, 102 out of 3650 test items were deleted (i.e., 2.8%).

4.6.1. The Perseveration Effect

As a first step, we tested whether we could replicate the general perseveration effect observed by Schillemans et al. (2009, under revision) and Lemaire and Lecacheur (2010). An ANOVA was conducted with the proportion subtraction strategy as the dependent variable, and numerosity (25 – 29) and preceding strategy (subtraction strategy versus addition strategy) as independent within-subject variables. This analysis demonstrated a significant main effect of numerosity, $F(4, 288) = 28.57$, $p < .0001$, partial $\eta^2 = .28$. Tukey tests indicated that participants used the subtraction strategy significantly less often (all *p*'s < .001) on the numerosities 25 to 27 (*M*s: .31, .32, and .34, respectively) than on the numerosities 28 and 29 (*M* = .45 and .47, respectively). More importantly, the analysis demonstrated a significant main effect of preceding strategy, $F(1, 72) = 38.96$, $p < .0001$, partial $\eta^2 = .35$. Participants chose more often the subtraction strategy after a series of subtraction items (*M* = .48) than after a series of addition items (*M* = .27). In other words, we replicated the earlier described perseveration effect (Lemaire & Lecacheur, 2010; Schillemans et al., 2009; under revision). The interaction between numerosity and preceding strategy did not reach significance.

4.6.2. Individual Differences in the Perseveration Effect

As a next step, we tested whether we could identify the same three groups on the basis of participants' strategy choice behaviour on the test items as found by Schillemans et al. (under revision). More specifically, we expected to find a group of participants showing a perseveration effect, a group with a preference for the addition strategy, and a group with a preference for the subtraction strategy. Therefore, we conducted a *K*-means cluster analysis with three clusters, using 1000 restarts. The dependent variable for this analysis was the proportion subtraction strategy use on each numerosity (i.e., 25 – 29) x preceding strategy (addition vs. subtraction) combination. The results of this cluster analysis are displayed in Figure 4.1. Cluster 1 corresponds with the hypothesized perseveration group. The 34 participants in this cluster chose most often for the subtraction strategy after a subtraction sequence and most often for the addition strategy after an addition sequence[2]. Cluster 2 matches the hypothesized addition group. These 23 participants chose the addition strategy on the test items most often, irrespective of the type of strategy used on the preceding extreme items. Cluster 3 corresponds with the hypothesized subtraction group. It comprises of 16 participants who chose the subtraction strategy on the test items most often, both after addition sequences as after subtraction sequences. We can conclude from this analysis that we were able to

[2] Since the proportion of addition strategy use is the complement of the proportion of subtraction strategy use, a low proportion of subtraction strategy use corresponds with a high proportion of addition strategy use.

distinguish the same three groups in terms of their strategy choice behaviour on the test items as observed in the study of Schillemans et al. (under revision).

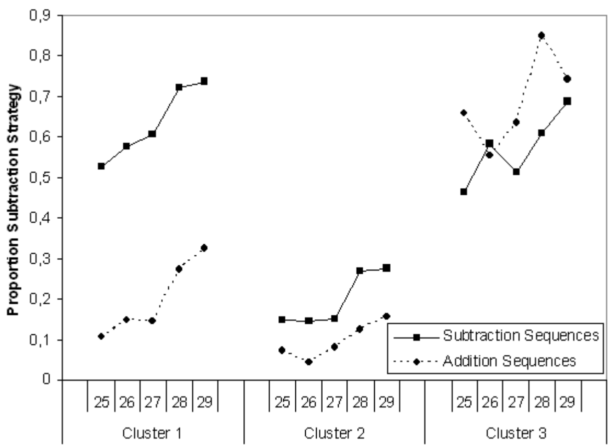

Figure 4.1 Three Cluster Solution of Participants' Strategy Choices on the Test Items

4.6.3.Subject Characteristics Underlying the Individual Differences

As a final step, we tried to relate the observed differences in strategy choice behaviour on the test items to the different subject characteristics under consideration by predicting cluster membership on the basis of the differences in these subject characteristics. This was accomplished by conducting a multinomial logistic regression analysis with cluster membership as the dependent variable and the different subject characteristics (inhibition, switching, updating, arithmetic skills, and SSEB) as predictors. Since we were specifically interested in the differences between participants showing a perseveration effect and participants showing no such effect, the perseveration group was taken as the reference group in this analysis. The results are summarized in Table 4.1. This analysis, yielded a statistically significant model, χ^2 (10) = 26.96, p < .01, which explained between 31% (Cox & Snell R^2) and

35% (Nagelkerke R^2) of the variance and made 58.9% correct classifications. The model had only two significant predictors, namely inhibition ability and SSEB.

Table 4.1

Results of Multinomial Logistic Regression, with the Perseveration Group as Reference Group

			95 % CI for Odds Ratio	
	B (SE)	Odds Ratio	Lower	Upper
the addition group vs the perseveration group				
intercept	-.627 (.335)			
arithmetic skills	-.122 (.380)	.885	.420	1.866
SSEB	-1.084 (.383) **	.338	.160	.716
inhibition	-.467 (.320)	.627	.335	1.174
switching	.579 (.415)	1.784	.791	4.023
updating	.524 (.385)	1.689	.793	3.594
the subtraction group vs the perseveration group				
intercept	-1.004 (.394) *			
arithmetic skills	-.122 (.431)	.885	.380	2.061
SSEB	-.451 (.397)	.637	.293	1.387
inhibition	.984 (.495) *	2.675	1.014	7.058
switching	-.527 (.378)	.590	.281	1.238
updating	.428 (.391)	1.534	.712	3.302

Note. CI = confidence interval; * $p < .05$, ** $p < .01$

First, we observed that the score on the inhibition task significantly predicted whether a participant belonged to the perseveration or the subtraction group, Wald $\chi^2(1) = 3.95$, $p < .05$. More specifically, as the score on the inhibition test increases by one unit, the odds of belonging to the subtraction group instead of the perseveration group change with a factor 2.68. That is, participants who scored one unit higher on inhibition are almost 2.7 times more likely of being in the subtraction than in the perseveration group. In other words, participants who are more able to inhibit, are more likely to be part of the subtraction group than of the perseveration group.

Second, we observed that the score on SSEB significantly predicted whether a participant belonged to the perseveration or the addition group, Wald $\chi^2(1) = 8.02$, $p < .01$. Thus, if the score on SSEB increases by one unit, the odds of belonging to the addition group instead of the perseveration group change with a factor .34. That is, participants who scored one unit higher on SSEB are almost 3.0 times less likely of being in the addition group than in the perseveration group. In other words, participants who rated their subtraction skills as higher, are more likely to be in the perseveration group (i.e., the group who used the addition strategy after the addition problems but the subtraction strategy after the subtraction problems) than in the addition group (i.e., the group that applied almost exclusively the addition strategy).

In a next analysis, we examined whether participants who belonged to the addition group differed from these who belonged to the subtraction group on the different subject characteristics under investigation. Therefore, we conducted a binary logistic regression analysis with cluster membership of these two groups as the dependent variable and the different subject characteristics as predictors (Table 4.2), $\chi^2\ (5) = 15.57$, $p < .01$, which explained between 33% (Cox & Snell R^2) and 44% (Nagelkerke R^2) of the variance and made 69.2% correct classifications. The addition group was used as the reference group for this analysis. The addition group differed significantly from the subtraction group on two subject characteristics, namely inhibition ability, Wald $\chi^2(1) = 5.47$, $p < .05$, and switching ability, Wald $\chi^2(1) = 4.16$, $p < .05$. With respect to inhibition ability, we observed that if the score on inhibition increases by one unit, the odds of belonging to the addition group change with a factor 3.46. Thus, participants scoring one unit higher on inhibition ability are almost 3.5 times more likely to belong to the subtraction than the addition group. In other words, participants who are better able to inhibit, are more likely to be part of the subtraction group than of the addition group. Regarding switching ability, we noticed that, if the score on the switching test increases by one unit, the odds of belonging to the subtraction group instead of the addition group change with a factor .34. Thus, participants with a higher score on switching are 2.9 times less likely being in the subtraction group than in the addition group. In other words, participants who are better at switching, are more likely to be in the addition group than in the subtraction group.

Table 4.2

Results of Binary Logistic Regression, with the Addition Group as Reference Group (Comparison with the Subtraction Group)

			95 % CI for Odds Ratio	
	B (SE)	Odds Ratio	Lower	Upper
intercept	-.294 (.439)			
arithmetic skills	-.003 (.467)	1.003	.402	2.504
SSEB	.796 (.502)	2.216	.828	5.931
inhibition	1.242 (.531) *	3.463	1.223	9.807
switching	-1.071 (.525) *	.342	.122	.959
updating	-.130 (.541)	.878	.304	2.535

Note. CI = confidence interval; * $p < .05$

4.7. Discussion

The main goals of this study were (a) to replicate the previously described perseveration effect (Lemaire & Lecacheur, 2010, Schillemans et al., 2009; in press; under revision), (b) to replicate the individual differences in the perseveration effect observed by Schillemans et al. (under revision), and (c) to look for subject characteristics that can explain these individual differences. Five different characteristics were tested, namely three executive functions (inhibition, switching, and updating), arithmetic skills, and subtraction self-efficacy beliefs. Hereafter, we discuss the results in relation to the three above-mentioned goals.

4.7.1. The Perseveration Effect

In line with the results of previous studies (Lemaire & Lecacheur, 2010; Schillemans et al., 2009, in press, under revision) and Hypothesis 1, a general perseveration effect was observed. Taken as a whole, participants chose significantly more often for the subtraction strategy after a series of subtraction items than after a series of addition items. In other words, the previously-used strategy has an influence on participants' strategy choices. However, a cluster analysis revealed that this effect is limited to a subset of participants. More specifically, as in Schillemans et al.'s study (under revision) and as predicted by Hypothesis 2, three groups emerged: one group of 47% of the participants who exhibited the perseveration effect, one group of 31% of the participants who showed a preference for the addition strategy, and one group of 22% of the participants with a preference for the subtraction strategy. These results stress the importance of looking at individual differences in general findings about people's strategy use because these results show that an overall effect can be elicited by less than half of the participants.

The third goal of this study was to look at subject characteristics that can explain these individual differences. Hereafter, we will discuss the different subject characteristics under consideration in relation to the hypotheses.

4.7.2. Executive Functions

A separate hypothesis was formulated for each of the three executive functions under consideration (i.e., inhibition, switching, and updating). Because of the suggested role of inhibition in strategy choices (Hodzik & Lemaire, 2011), we hypothesized that participants who are less able to inhibit would be more likely to belong to the perseveration group than to the addition or subtraction group (Hypothesis 3). This hypothesis is only partly confirmed: on the one hand, participants with a higher score on inhibition were more likely to be in the subtraction group than in the perseveration group. On the other hand, participants' score on inhibition did not predict whether they belonged to the addition or the perseveration group.

An influence of switching skills was also expected (Hypothesis 4). More particularly, it was hypothesized that participants with weaker switching skills would show a larger perseveration effect. This hypothesis was not confirmed: switching skills (measured as a task switching cost) could not predict membership of the perseveration group or one of the other groups. Stated differently, we did not find any evidence that switching skills would be related to the perseveration effect. Although such an effect had been assumed by both Schillemans et al. (2009) as by Lemaire and Lecacheur (2010), this result is, after all, not so surprising if one takes the literature on voluntary task switching into account. Mayr and Bell (2006) studied the relationship between task switching and the number of task switches and found only a weak correlation between switching cost and switch rate (i.e., the number of task switches), and Arrington and Yates (2009) even found no relation at all.

With respect to the third executive function, namely updating, it was hypothesized that participants with weaker updating skills would be more likely to show the perseveration effect (Hypothesis 5). However, updating skills did not significantly predict membership of the perseveration group or one of the two other groups. Stated differently, we did not find any evidence that updating skills would be related to the perseveration effect. It might be that the task we have used to measure updating skills in this study, was not appropriate to measure updating in strategy choices.

4.7.3. Arithmetic Skills

We predicted that arithmetic skills would be a significant predictor for strategy preference, and, more specifically, that participants with better arithmetic skills would use the more complex subtraction strategy more often. Stated differently, we expected that participants with weaker arithmetic skills would be found especially in the addition group (Hypothesis 6). However, no evidence for an influence of arithmetic skills on group membership was found. A possible reason may be that we measured arithmetic skills with a test that contained both addition and subtraction problems, but it might have been better to measure only subtraction skills to look for differences between the addition and the subtraction group. To explore this possibility, we calculated an arithmetic skills score by looking at the subtraction problems of the French Kit test only, and used this self-made ‘subtraction skills score’ (instead of arithmetic skills measured as a mix of addition and subtraction problems) as a predictor, but this did not alter the results. However, because the reliability of this self-made subtraction skills score is questionable, it is premature to draw strong conclusions based on the results of this adapted test only. Therefore, future studies should include a more specific, reliable and valid test of subtraction skills to further test this hypothesis. A second reason why no influence of arithmetic skills has been found may be the type of arithmetic skills test that we used. In the present study, we used a verification test, while our numerosity judgment task was a production task. Strategies for verification and production tasks may differ (e.g., Klein et al., 2010;

Zbrodoff & Logan, 1990) and therefore these two types of tasks may not necessarily measure the same abilities. So, future studies should not only include a test that specifically measures subtraction skills, but this test should preferably also be a production test instead of a verification test.

4.7.4. Subtraction Self-Efficacy Beliefs

Besides an influence of arithmetic skills, we also predicted an effect of subtraction self-efficacy beliefs: The lower participants' beliefs in their subtraction skills, the less often the subtraction strategy would be selected. So, participants in the addition group were expected to have lower subtraction self-efficacy beliefs than participants in the two other groups, and participants from the subtraction group would have higher beliefs than those from the other groups (Hypothesis 7). This prediction is only partly confirmed. Participants who rated their subtraction abilities as lower were more likely to be in the addition group than in the perseveration group. Apparently, participants in the former group were, due to their negative beliefs about their own subtraction skills, so reluctant to use the subtraction strategy that they hardly chose for it on the test items, even not after a series of items with high numerosities on which they had repeatedly applied that strategy.

However, contrary to the hypothesis, participants' beliefs did not differentiate between the addition and the subtraction group. The fact that participants in the subtraction group did not score higher on arithmetic skills nor rate their abilities in that strategy higher than participants in the addition group, suggests that neither one's actual skills in doing subtraction nor one's subjective belief about how good one is in subtraction is a decisive factor in the frequency with which the subtraction strategy is chosen or in the extent to which one is affected by the perseveration effect.

The result that the cluster to which participants belong is influenced by their self-efficacy beliefs and not by their actual skills vis-à-vis subtraction is not very surprising, since Bandura (1986) already described that people's behaviour is often better predicted by their beliefs in their capacities than in their actual capacities.

4.7.5. Conclusion

This study replicated the earlier observed perseveration effect (Lemaire & Lecacheur, 2010, Schillemans et al., 2009; in press; under revision), but also Schillemans et al.'s (under revision) finding that this effect is subject to individual differences: When confronted with the present numerosity judgement task, people can be divided into three groups, namely a perseveration group (participants who show the perseveration effect), an addition group (participants who choose most often for the addition strategy), and a subtraction group (participants who choose most often for the subtraction strategy). Therefore, the present study pointed to the importance of looking at differences between individuals. The current study represents a first attempt to try to further examine these individual differences in the perseveration effect and strategy preferences, and pointed to two characteristics that may partly explain these differences. A first characteristic is inhibition skill: Participants who were better at inhibition were more often in the subtraction group than in the perseveration group. A second characteristic is a rather task specific variable, namely people’s self-efficacy beliefs with respect to the more complex strategy in their strategy repertoire, namely the subtraction strategy. Participants with higher subtraction self-efficacy beliefs were more likely to be in the perseveration group than in the addition group.

Future studies should test the influence of inhibition further to see if its influence on the perseveration effect can be replicated with other tasks than this particular numerosity judgement task. Besides further investigating the role of these subject features on the perseveration effect in people’s strategy choices, it is also important to explore other subject characteristics that may determine participants’ strategy choices, for instance, working memory span, general intelligence,…

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Chapter 5

General Discussion

In the last chapter of this dissertation, we will start with briefly summarizing the results of the different studies. Next, we will discuss some remaining questions for further research. Thereafter, we will talk about the extent to which a number of underlying mechanisms that have already been proposed in the previous chapters could account for the observed perseveration effects. These mechanisms are related to Einstellung, strategy switch costs, and priming, respectively. Additionally, we will discuss a mechanism that was not mentioned before, namely, the response heuristic mechanism. Next, we will address some educational implications, and we will end with a general conclusion.

5.1. Overview of the Results

This dissertation reports about four different studies that have been conducted to investigate the perseveration effect in individuals' strategy choices. All these studies relied on the same experimental task, namely a numerosity judgement task. This task can be solved by two possible strategies, namely an addition strategy and a subtraction strategy.

In the first chapter, we described the first two experiments that tested the perseveration effect with the numerosity judgement task. Both experiments showed that participants were influenced by the strategy they had used on the previous trial.

More specifically, they were more inclined to repeat the previously-used strategy than to switch to the other one. This could be considered as the first evidence for a perseveration effect in individuals' strategy choices. However, these experiments also demonstrated that this perseveration effect was limited to these numerosities for which both strategies are more or less equally applicable.

Chapter 2 reported a study which replicated the aforementioned perseveration effect with a different paradigm. This was achieved by manipulating the presentation order of the different numerosities instead of presenting strategy-neutral numerosities after extreme numerosities. As such, we were able to demonstrate that the perseveration effect was not restricted to one specific paradigm but that it was a more general phenomenon.

The goal of the next study (Chapter 3) was to test whether the strength of the perseveration effect would differ after a single or a repeated previous strategy use. We observed that the perseveration effect already emerged after a single previous strategy application, and that its strength did not differ between a single and a repeated previous strategy application. This indicates that the perseveration effect is already present in its full strength after a single previous strategy application.

An additional finding of this study was that not all participants were influenced by the previously-used strategy. Only about one third of the participants showed a perseveration effect (i.e., the perseveration group), the others showed either a strong preference for the addition (i.e., the addition group) or the subtraction strategy (i.e., the subtraction group).

The last study (Chapter 4) replicated the emergence of the three groups observed in the previous study and tried to explain these individual differences by linking them to subject characteristics that were hypothesized to play a role in individuals' strategy choice in the numerosity judgement task. Two subject characteristics were found to be a significant predictor of the membership of one of the three participant groups (i.e., the perseveration group, the addition group and the subtraction group). The first one is inhibition skills: participants with higher inhibition skills were more often in the subtraction than in the perseveration group. Apparently, participants who were better at inhibiting dominant or prepotent responses were better able to inhibit the already activated strategy. The second is subtraction self-efficacy beliefs: participants who rated their subtraction skills as higher were more often in the perseveration than in the addition group. Participants in the addition group seemed to be so reluctant of using the subtraction strategy that they did not use it, even not when they had used it on several preceding trials. Although this study already found some subject characteristics that underlie the differences in strategy choices, they could not explain the whole picture yet.

5.2. Remaining Questions for Further Research

Although the perseveration effect has been extensively observed in the different studies of this dissertation, the contours of this effect are not entirely established yet. For instance, questions about the generalisability to other domains remain unanswered at the moment. Therefore, it is important to extend the current findings with further empirical studies. Hereafter, we propose two possible directions in which the present research can be extended, namely a replication in other task domains and a generalisation to other age groups.

5.2.1. Replications in other Task Domains

All studies in this dissertation are conducted with the same task, namely a numerosity judgement task. However, to draw more general conclusions, it is important to replicate the perseveration effect in other task domains. As already discussed in the previous chapters of this dissertation, the perseveration effect has already been observed in a different task, namely two-digit addition (Lemaire & Lecacheur, 2010, Experiment 3). However, this study has some limitations. First, these authors used a rather artificial design. They created pairs of stimuli, the first of which was accompanied with a cue to elicit one of the strategies, while the strategy choice on the second stimulus of the pair was free. This is a rather unusual and unnatural way of presenting the stimuli, which may have had an influence on the obtained results. A second limitation is that it only addressed the perseveration effect on a group level and not on an individual level. This means that this study did not look at individual differences in the perseveration effect. Looking at individual differences has been shown to be important, since both the studies in Chapter 3 and 4 have demonstrated that only a part of the participants exhibited the perseveration effect.

When searching for new task domains, it is important to note that they need to meet certain criteria. The most important criterion is that different kinds of stimuli can be created, namely stimuli that clearly elicit one of both strategies, and stimuli that elicit both strategies more or less to the same extent. Additionally, both strategies must generally be as equally difficult as possible, to minimize possible strategy preferences (as observed in Chapter 3 and 4) as good as possible.

A first example of a task that meets these requirements is a computational estimation task, previously-used by Hodzik and Lemaire (2011). In this task, participants have to give approximate answers to problems like 62 x 89, or 32 x 57 by essentially using one of the following two strategies: a rounding-down strategy or a rounding-up strategy. In the rounding-down strategy, they have to round down both operands to the smaller decade, for example rounding down 32 x 57 to 30 x 50. In the rounding-up strategy, they have to round up both decades to the closest decade, for example rounding up 32 x 57 to 40 x 60. Participants are instructed to always choose the best strategy; that is, the strategy that leads to the answer that is closest to the correct solution.

As in the numerosity judgement task, three types of items can be constructed in this computational estimation task, namely rounding-down items, rounding-up items, and neutral items. The rounding-down items have the units of both operands smaller than five and therefore, the rounding-down strategy leads obviously to the best answer. An example of such an item is 32 x 54. For this item, it is clear that rounding down to 30 x 50 provides a better approximation of the correct solution than rounding up to 40 x 60. The reverse is true for the rounding-up items. These items have the units of both operands larger than five and are therefore better solved with the rounding-up strategy than with the rounding-down strategy. An example of such an item is 48 x 69. It is clear that rounding up this item to 50 x 70 provides an answer closer to the correct solution than rounding down to 40 x 60. The neutral items are items with one operand with a unit smaller than five and one operand with a unit larger than five. For these items it is less clear which strategy is the most optimal. An example of such a neutral item is 53 x 48 (correct solution is 2494). Both the rounding-down and the rounding-up strategy lead to an answer that is approximately as far from the correct solution (i.e., 2000 for the rounding-down strategy and 3000 for the rounding-up strategy). Using these three kinds of items, it is possible to create sequences like those used in the studies of Chapter 1, 3, and 4 to test for the perseveration effect in another task domain than numerosity judgement.

A second example of a task is two-digit subtraction. This task can be solved by two different strategies, namely direct subtraction and indirect addition (e.g., Peters, De Smedt, Torbeyns, Ghesquière, & Verschaffel, 2010a; 2010b). Using the direct subtraction strategy, participants solve the problem by directly subtracting the subtrahend from the minuend. By using indirect addition, participants solve the problem by using an addition to solve the subtraction (e.g., 68 + 6 = 74, so the answer is 6). It has been shown (Peters et al., 2010b) that when the subtrahend was smaller than the difference (e.g., 63 – 4) direct subtraction was the dominant strategy, while if the subtrahend was larger than the difference (e.g., 74 – 68) subtraction by addition was most often used. When the subtrahend and the difference were almost of the same size (e.g., 72 – 34), the size of the subtrahend did not predict participants' strategy choice between direct subtraction versus subtraction by addition.

As in the numerosity judgement task and in the above-mentioned computational estimation task, three different types of items can also be created in this task, namely direct subtraction items, indirect addition items, and neutral items. The direct subtraction items are items for which the subtrahend is much smaller than the difference, the indirect addition items are items for which the subtrahend is much larger than the difference, and the neutral items are items for which the subtrahend and the difference are almost the same size. With these different types of items, it is also possible to create sequences like those used in the studies of Chapter 1, 3, and 4 to test for the perseveration effect in another task domain than numerosity judgement.

5.2.2. Generalisation to other Age Groups

A second important extension of the current findings is a generalisation to other age groups, for instance children and older adults. Indeed, all studies that investigated the perseveration effect so far have been conducted within the same age group, namely young adults. Chapter 4 demonstrated that an important subject characteristic that co-determines whether participants show a perseveration effect are inhibition skills. Since it is known that both children (e.g., McAuley & White, 2011; Prencipe, et al., 2011) and older adults (e.g., Verhaeghen & De Meersman, 1998) have weaker inhibition skills than young adults, it can be assumed that the perseveration effect will be larger for these age groups than for the already tested young adults. This larger perseveration effect can manifest itself in three possible ways: (a) an increase in the proportion strategy-neutral items that are solved via the previously-used strategy, (b) the numerosity range in which the perseveration effect occurs is larger; that is, the effect does not only occur on the most strategy-neutral items but also on less strategy-neutral items, and (c) the number of participants who show the perseveration effect is larger. All three possibilities may have implications for children's and older adults' strategy use.

The first possibility, namely an increase in the proportion strategy-neutral items that are influenced by the previously-used strategy is higher in children and older adults than in young adults, has the least severe implications for strategy use in these two groups. Indeed, when two strategies are almost equally applicable, performance is not seriously influenced when participants (almost) always stick to the previously-used strategy. However, performance will deteriorate when the perseveration effect also occurs on less strategy-neutral items for which one of the strategies is clearly beneficial (= the second possibility). Reusing the previous strategy on these items while the other strategy is somewhat or considerably more beneficial, might lead to slower and more error-prone responding. Finally, when a larger group of people show the perseveration effect, this implies that the perseveration effect is a more widespread phenomenon in children and older adults than in young adults.

5.3. Mechanisms Underlying the Perseveration Effect

After the first empirical documentations of the perseveration effect (Chapter 1), three possible underlying mechanisms for this effect were proposed, namely Einstellung, strategy switch cost avoidance, and (procedural) priming. Hereafter, we will briefly recapitulate these three mechanisms and provide an overall discussion of them in light of the findings of all studies. Additionally, we will discuss a mechanism that has not been mentioned before, namely the response heuristic mechanism.

5.3.1. Einstellung

As has already extensively been described in the introductory chapter, participants in the Einstellung studies (e.g., Luchins, 1942) reused a previous solution method even when a different one was clearly more beneficial. A typical characteristic of these Einstellung studies is that participants were not aware of any other solution method than the one they had repeatedly used on the preceding problems. Therefore, it is possible that this repeated use of one particular solution method rendered them into a state of “blindness” or “mindlessness”, in which they based their problem solving behaviour solely on their past behaviour without noticing new aspects of the problem at hand (Langer, 2000) and/or considering alternative strategies.

It might be that a similar kind of “blindness” for the other strategy was present in the experiments reported in Chapter 1. Indeed, it is possible that participants after five or six applications of the same strategy were blinded for the alternative strategy. However, it is important to note that participants did not demonstrate a perseveration effect on all test items in these first experiments. It only occurred on these items for which both strategies are more or less equally applicable. This means that the perseveration effect depends on the associative strength between the problem and a particular strategy. To the best of our knowledge, such dependency on the associative strength has not been tested or described in the Einstellung literature, possibly because the associative strength was the same for all problems in these experiments. Therefore, the Einstellung mechanism as described earlier cannot fully explain the results reported in Chapter 1. It would only be a plausible mechanism when it is demonstrated that the Einstellung effect can differ as a function of the associative strength between problems and strategies.

The Einstellung mechanism can also not properly explain the results reported in Chapter 2. The results of this study in which the numerosities were presented in three different presentation orders (i.e., an ascending, a descending, and a random order) demonstrated that participants *do* switch to the other strategy; they only *postpone* their switch to that other strategy. It is hard to explain how participants could switch to another strategy within a sequence of similar trials when they are blinded for that other strategy.

Since the Einstellung mechanism is not able to fully account for the results reported in Chapter 1 and in Chapter 2, this mechanism does not seem to be a plausible candidate to explain the perseveration effect.

5.3.2. Strategy Switch Cost

A second possible mechanism that has been put forward to explain the occurrence of the perseveration effect is the avoidance of a *strategy switch cost*. Recently, both Lemaire and Lecacheur (2010) and Luwel, Schillemans, Onghena, and Verschaffel (2009a) have demonstrated that switching from one strategy to another takes longer than repeating the same strategy on two successive problems. Participants may try to avoid this strategy switch cost, by repeating the previously-used strategy instead of switching to a different one. This repeating of the previously-used strategy would lead to a perseveration effect. Repeating the previously-used strategy by trying to avoid such a strategy switch cost may be beneficial if the difference in execution time between two strategies is rather small and especially so when this difference in execution time is smaller than the switch cost. Conversely, when the difference in execution time between the different strategies is large, switching towards the faster strategy is more favourable, especially when the difference in execution time between the strategies is (much) larger than the switch cost. Stated differently, it is only beneficial to switch from one strategy towards the other if the time gain due to this switch is (considerably) larger than the switch cost.

The findings reported in Chapter 1, namely that the perseveration effect is limited to the numerosities for which both strategies are more or less equally applicable, is in line with the strategy switch cost hypothesis. Indeed, for the strategy-neutral items on which both the addition and the subtraction strategy will be more or less equally fast and accurate, the switch cost will be larger than the difference in execution time between the two strategies. Thus, avoiding this switch cost by repeating the previously-used strategy can be considered as advantageous. In contrast, the difference in execution time between the two strategies is most probably larger than the switch cost for the more extreme items. Therefore, on this kind of items, it is most beneficial to switch to the most optimal strategy instead of repeating the previous one.

The results described in Chapter 2, namely that participants postpone their strategy switch when the numerosities were presented in an ascending or a descending order, are also in line with this strategy switch cost account. When participants in an ascending or descending order encounter the strategy-neutral items after having repeatedly used the addition or the subtraction strategy, respectively, the strategy switch cost will still be larger than the difference in execution time between the two strategies. Therefore, already switching to the other strategy is not beneficial yet on these strategy-neutral items. However, when participants go further in the ascending or the descending order to more extreme items, the difference in execution time between the two strategies becomes larger and will therefore, at a certain moment, become larger than the strategy switch cost. At this moment, switching to the other strategy becomes appropriate, and this was what we observed.

The strategy switch cost mechanism can also account for individual differences in the perseveration effect. Indeed, unpublished data (Luwel, Schillemans, Onghena, & Verschaffel, 2009b) demonstrated that participants differ in the size of their strategy switch cost. Stated differently, the time it takes to switch from one strategy to another is not the same for all participants. If participants only switch towards another strategy when the difference in execution times between the two strategies is larger than the switch cost, one can expect a positive relationship between the size of the switch cost and the size of the perseveration effect. That is, the larger the switch cost, the more frequently the cost will be larger than the difference between the two strategies, and the more often participants will stick to the previously-used strategy to avoid the large strategy switch cost. This can explain why some participants stuck to the previously-used strategy while others did not. However, this mechanism cannot explain why participants who do not display a perseveration effect differ in their strategy preferences for the addition or for the subtraction strategy.

It should be noted that one of the subject characteristics tested in the study reported in Chapter 4, was switching skills. It was hypothesized that participants in the perseveration group would have weaker switching skills than participants in the other groups. However, this characteristic did not predict whether participants belonged to the perseveration group or one of the other groups. As such, no relationship between switching skills and the perseveration effect was observed in this study. However, these switching skills were measured by calculating participants' *task* switch cost. As such, we did not measure participants' *strategy* switch cost.[1] At the moment, it is not clear how and to what extent these two kinds of switch costs are related. Therefore, it is not possible to derive strong conclusions based on this finding.

5.3.3. (Procedural) Priming

The third possible underlying mechanism is *(procedural) priming*. This mechanism can be conceived as a temporary increase in the strength of the last applied procedure (or, in our case, the last applied strategy), which in its turn will increase the probability that this procedure (or, in our case, this strategy) will be chosen again on the following trial (e.g., Kirmani, Lee, & Yoon, 2004). This increased probability of reusing the previous strategy will lead to the perseveration effect.

The priming hypothesis can also explain why the perseveration effect is limited to the more strategy-neutral items, as was observed in the study reported in Chapter 1. For the strategy-neutral items, it can be assumed that the associative strength between the items and both strategies is almost the same. If one of these almost equally activated strategies gets an extra boost in activation because of the priming effect, this strategy will be favoured in the selection process on the next trial at the expense of the other, which will lead to a perseveration effect. Conversely, for the more extreme items it can be assumed that the association between the item and one strategy (e.g., the addition strategy for the addition items) is much stronger than the association between that item and the other strategy (e.g., the subtraction strategy for the addition items). For these items, it can be assumed that a boost in activation from the previous trial will not be sufficient if this strategy is only weakly activated by

[1] We have chosen for a task switching test instead of a strategy switching test for practical reasons. Because we wanted to test several subject characteristics, the study was already very long and demanding for the participants. Since reaction times in task switching are on average more than ten times shorter compared to reaction times in strategy switching (measured with the numerosity judgement task), we opted for a task switching instead of a strategy switching test.

the problem characteristics of the next trial, which will lead to a switch to the strongly associated strategy.

This difference in associative strength can also explain why participants postpone their strategy switch in the ascending and the descending order in the study of Chapter 2. Since the priming mechanism temporarily increases the strength of the last applied strategy, this strategy is still the best option when participants encounter the strategy-neutral items. Only when participants encounter items which are much more strongly associated with the other strategy, the priming of the earlier strategy will no longer suffice to be selected on the next trial, and therefore a switch to the other strategy will be made.

Because priming has been shown to differ between participants (e.g., Tipper & Baylis, 1987; Woltz & Shute, 1993), the individual differences reported in Chapter 3 and Chapter 4 can also be explained in terms of this mechanism. It can be assumed that the stronger the effect of priming for a given individual, the stronger the increase of the strength of the last strategy will be, leading to a larger perseveration effect. Therefore, it can be hypothesized that participants who display a larger priming effect will be more inclined to repeat the previously-used strategy than participants with a smaller priming effect. Although priming can explain why some people show a perseveration effect and others do not, it cannot explain why some people prefer the addition strategy and others the subtraction strategy.

5.3.4. Response Heuristics

The three above-mentioned mechanisms have been proposed in our first manuscripts about the perseveration effect. However, during our quest on the nature and origin of the perseveration effect, another candidate mechanism emerged, namely a mechanism based on 'response heuristics'. DeCarlo and Cross (1990) argued, in the context of psychophysical studies, that participants' responses are not only determined by the stimulus itself, but also by a response heuristic. Applied to the sequential effects in psychophysics (see section 'Sequential Effects in Other Domains' in the General Introduction for more information about these kind of studies), this heuristic implies a tendency to choose an answer close to the previous response (e.g., DeCarlo, & Cross, 1990; Garner, 1953; Ward & Lockhead, 1971). This response heuristic is considered to be used when participants are uncertain about their classification of a stimulus (e.g., if they are uncertain about the length of a line). Although these authors found evidence for this kind of response heuristic in psychophysics, they explicitly state that other response heuristics might also be possible (DeCarlo, & Cross, 1990).

This mechanism based on response heuristics may also account for the different findings of the studies reported in this dissertation. That is, it can explain participants' tendency to repeat the previously-used strategy on the strategy-neutral items and to restrain from doing so on the more extreme items (Chapter 1). As noted by DeCarlo and Cross (1990) and Garner (1953), participants will use a response heuristic (only) when they are unsure about their answer. In terms of strategy choices, participants might rely on a response heuristic when the characteristics of an item do not allow a straightforward strategy choice. Since this is typically the case on the strategy-neutral items, the use of a response heuristic might lead participants to reuse the previous strategy. For the extreme items, the most optimal strategy is clear from the problem characteristics, and therefore the use of a response heuristic will not be evoked. Also the postponed switch in the ascending and descending order can be interpreted in terms of this mechanism (Chapter 2). Participants start in these presentation orders with items for which the most optimal strategy is clear from the problem characteristics; that is, the addition strategy in the ascending order and the subtraction strategy in the descending order. As the numerosity increases in the ascending order or decreases in the descending order, the most optimal strategy becomes less clear. On these items for which the strategy choice is less clear (i.e., the strategy-neutral items), participants will use a response heuristic (i.e., choosing the same strategy as on the preceding problems). However, when the numerosity further increase in the ascending order or further decreases in the descending order, it is again clear from the problem characteristics which strategy is the most optimal; that is, the subtraction strategy for the ascending order and the addition strategy for the descending order.

In line with the idea that different response heuristics might exist (DeCarlo, & Cross, 1990), the individual differences in the perseveration effect (Chapter 3) can be explained by assuming that participants differ in the kind of response heuristics they use. It can be assumed that participants in the perseveration group use a response heuristic in which they base their strategy choice on the previously-used strategy in case of uncertainty. Participants in the addition and subtraction group may use in such situations a different kind of heuristic, namely one in which they rely on a 'default strategy' (i.e., the addition and subtraction strategy, respectively) instead of relying on the most recently used strategy.

To summarize, four different underlying mechanisms for the perseveration effect are discussed. However, based on the current findings, it is not clear yet which mechanism is the most appropriate to explain the different findings. Therefore, further research is needed to clearly determine which underlying mechanism is the most suitable.

5.4. Methodological Considerations

Although the studies reported in this dissertation showed a robust perseveration effect (albeit on a limited range of items and in a limited group of participants), some methodological limitations remain.

A first limitation is that in all studies except the study reported in Chapter 2, a range of numerosities has been selected to be used as test items for all participants. However, it has been shown that the associative strength between the numerosities and the two strategies differs between participants (Verschaffel, De Corte, Lamote, & Dherdt, 1998). Therefore, it may be that all participants show a perseveration effect, but not in exactly the same numerosity range. This would imply that also participants in the addition and subtraction groups (Chapter 3 and 4) could possibly show a perseveration effect, but that we were not able to detect it due to the design of our study in which the same strategy-neutral items have been used for all participants. Stated differently, it is possible that participants in the addition group show a perseveration effect on numerosities larger than the test items (because their strategy-neutral items are on larger numerosities), and participants in the subtraction group show a perseveration effect on numerosities smaller than the test items (because their strategy-neutral items are on smaller numerosities). A solution to this problem would be to pretest all participants as to determine their individual range of strategy-neutral items, after which they are tested for the perseveration effect using a personalized set of neutral items. However, such a design is not without problems either, since it has been observed that the individual range of neutral items changes slightly between the pretest session and the actual experimental session (Delvaux, 2008). The reason for this shift in neutral items is still unclear. Therefore, and because this way of testing is very time consuming and demanding for the participants, such a design has not been used.

A second limitation of all studies is that to identify participants' strategy choices, we forced them to point to the cells they were currently counting. This obliged pointing behaviour was considered as annoying by some participants. Therefore, this pointing behaviour may have slightly influenced the strategy execution of some participants, that is, it may be that it influenced participants in how they determined the coloured or the empty cells. Additionally, it sometimes happened that participants' pointing behaviour was not clear enough to determine the strategy they had used on that trial. On these trials, the experimenter had to additionally question the participant about his or her strategy choice. Such questioning should be avoided, as it may influence participants' future behaviour due to the awareness of the importance of their strategy choices.

A third shortcoming of the studies is that it may be that not only the numerosity of the item plays a role, but also the configuration of the coloured and empty cells within the grid may have an influence on participants strategy choices. In the preparatory study reported in Chapter 3, we found that even for a certain numerosity (e.g., the numerosity 27), some configurations of cells more often elicited the addition strategy, while others more often elicited the subtraction strategy. To minimize this influence of configuration, we selected these grid configurations that were as strategy-neutral as possible in the preparatory study for all test items in the main study. However, this observation points to an additional characteristic that influences participants' strategy choice in the numerosity judgement task which has not been studied before.

5.5. Educational Implications

Because there are still numerous questions about the nature of the perseveration effect, its generalisability and its underlying mechanisms, it is premature to derive strong educational implications from the studies reported in this dissertation. Moreover, although the finding of the perseveration effect is robust and highly significant, it should be taken into account that it has so far only been observed on a small subset of items, for which both strategies are more or less equally applicable, and in only a part of the participants. Nevertheless, some tentative educational implications may already be raised. Specifically, since, as discussed in section 5.2.2, the perseveration effect may be larger for children than for the young adults who acted as participants in the studies about this effect so far.

First, because it has been shown that a single preceding strategy application is sufficient to elicit the perseveration effect in its full strength, this effect may play a decisive role in all kind of situations in which strategies need to be chosen on two or more successive problems. This is almost always the case in (mathematics) textbooks, educational computer programs, tests, and classrooms situations, in which children have to practise certain (mathematical) skills and, therefore, are confronted with series of problems of more or less the same type. When the perseveration effect is not taken into account in designing these learning and testing materials, this can hamper children's strategy development. For example, when all series of problems start with problems that are typically solved by a given strategy, children may also keep on using this strategy on other problems of the series for which another strategy is more optimal, and, therefore jeopardize the chances for developing strategy variability and flexibility, two important goals of current (reform-based) approaches to (elementary) mathematics education (Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009). Therefore teachers and designers of educational materials need to take serious care of the presentation order of the problems in practice and testing settings.

Second, even though variable and flexible strategy use has become more important as a (mathematics) educational goal during the last years (Verschaffel et al., 2009), it is not yet clear how this should be diagnosed in and taught to children. The finding of a perseveration effect shows that this may be even more complicated than it has so far been regarded, because it turns out that not only the features of the present problem plays an important role, but also the strategy used on the preceding one. Therefore, children need to take the perseveration effect (more or less consciously) into account in making flexible strategy choices. Children's alertness to this effect could be realized, for instance, by putting them in some kind of Einstellung situation, in which they repeatedly solve problems with the same strategy, and then suddenly encounter a problem that can also be solved via a much easier strategy. Thereafter, these children can be confronted with their inadaptive strategy choices, opening the possibility to discuss the perseveration effect with them. As such, they may become aware of this possible influence and somehow take it into account in their future strategy choices both in and out of school.

However, before children can be taught to take the influence of the previously-used strategy into account, teachers should also be aware of the perseveration effect, as part of their (pedagogical) content knowledge. Therefore, developing awareness of this effect and appropriate ways to handle it in their daily teaching activities (e.g., preparing practice sheets, developing test materials, diagnostic teaching…) should become part of teacher training programs.

5.6. General Conclusion

The different studies in this dissertation have provided substantial evidence for an effect in individuals' strategy choices that was so far not subjected to systematic empirical research, namely the perseveration effect. The lack of research about this effect was remarkable, given that similar sequential effects have already been studied in various other research areas. This dissertation demonstrated that the perseveration effect is a robust and significant finding that is, however, not apparent on all items, but only on those items for which both strategies are more or less equally applicable. The perseveration effect already appears after a single previous strategy application, and does not seem to increase after a repeated use of the previous strategy. It has also been shown that not all participants are influenced by this effect and that participants who are better at inhibiting information are more likely to be in the subtraction group than in the perseveration group. Additionally, participants with low confidence in their subtraction skills are more likely to be in the addition group than in the perseveration group. Although the perseveration effect has been showed to be a robust finding, it is still important to replicate these findings with other tasks, and to generalise them to other age groups. Additionally, the search for the underlying mechanisms of this effect needs to continue.

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