Back in control : the episodic retrieval of executive control

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CHAPTER 5: SEQUENTIAL MODULATIONS OF THE SIMON EFFECT DEPEND ON EPISODIC RETRIEVAL

Sequential modulations of conflict effects, like the reduction of the Simon effect after incompatible trials, have been taken to reflect the operation of adaptive control mechanisms. However, recent findings suggest that such modulations are often contaminated by prospective episodic effects like priming and stimulus-response feature integration. Here we replicate previous observations that the Simon effect is strongly reduced after incompatible trials. More importantly, however, we demonstrate that this sequential modulation is eliminated entirely under conditions that are likely to change the memory representation of stimuli between two trials without affecting the degree or likelihood of conflict. This suggests that control-relevant information is integrated into episodic structures or event files that are retrieved only if the current situation is sufficiently similar to the situation in which the files were created.

Introduction

The time it takes to act is strongly affected by the compatibility between the stimulus and response (Fitts & Seeger, 1953). Simon and Rudell (1967), for example, showed that processing the location of a stimulus automatically triggers a response towards the source of the stimulus, such that even though the location of a stimulus may be irrelevant to the task, having to respond with a left button-press to something appearing right wreaks havoc in terms of error and reaction latency. This effect later became known as the *Simon effect* (coined by Hedge & Marsh, 1975), and is one of the more popular effects amongst the range of stimulus-response compatibility phenomena (see Alluisi & Warm, 1990, for an overview). Like similar phenomena such as the Stroop effect (Stroop, 1935) or the flanker-compatibility effect (Eriksen & Eriksen, 1974), the Simon effect follows a more general rule: if a task-irrelevant dimension of a stimulus suggests a different response than the relevant dimension, this leads to a robust impairment of performance.

Conflict Control

Whether a location attracts a response in its direction, a flanker triggers an associated key-press, or a color word suggests reading it, people experience response conflict. How are they able to resolve this conflict and eventually carry out the correct action? According to some researchers, detecting conflict enhances the amount of cognitive control exerted by increasing the support for the correct response (e.g., Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Egner & Hirsch, 2005). Others have suggested that incorrectly triggered response alternatives are actively suppressed, thus eliminating the response competition (e.g. Band, Ridderinkhof, & Van der Molen, 2003; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Thus, both approaches assume that the cognitive system continuously monitors for output conflict and enhances cognitive control if conflict is detected.

The main empirical basis for conflict-control approaches is provided by the observation of sequential effects in conflict-inducing tasks. Using the flanker-compatibility task (Eriksen & Eriksen, 1974), Gratton, Coles, and Donchin (1992) showed that the impact of response-compatible and incompatible flankers on performance is reduced in trials that follow trials with incompatible flankers as compared to trials with compatible flankers. Comparable observations have been made with the Stroop task (e.g., Kerns et al., 2004) and the Simon task (e.g., Praamstra, Kleine, & Schnitzler, 1999), demonstrating that the Stroop effect and the Simon effect are reduced and sometimes even eliminated after incompatible trials. These observations have been taken to suggest that facing a conflict trial challenges and leads to an increase of cognitive control, which then facilitates the handling of conflict in the next trial. Given that flanker, Stroop, and Simon effects can be taken to reflect response conflict, reducing conflict necessarily reduces their size.

Event Files

Recent considerations and findings have, however, raised some doubts in the interpretation of sequential effects in flanker, Stroop, and Simon tasks in terms of conflict monitoring and resolution. As pointed out by Mayr, Awh, and Laurey (2003) and Hommel, Proctor, and Vu (2004), sequential relationships between compatibility and incompatibility are entirely confounded with particular patterns of stimulus and response repetitions and alternations. Decades of research (since Meyer & Schvaneveldt, 1971) on priming have shown that repeating (parts of) a stimulus affects reacting upon this stimulus, and during sequence modulations, such effects are always present. The same goes for response repetitions, which since research in the 1960s are known to affect performance (e.g., Bertelson, 1963). Interestingly, the combination of stimulus and response repetition has been reported to facilitate performance in a overadditive fashion, which has been attributed to a tendency to bypass response selection if everything repeats

(Bertelson, 1963). Given that the combinations of stimulus and response repetitions are not equally distributed across the possible transitions between compatibility conditions, it is possible that at least a part of sequential modulations goes back to repetition priming (Mayr et al., 2003).

But things are more complicated. Sequences of stimulus-response combinations do not only invite simple priming effects. Treisman and colleagues have claimed that processing the features of an object leads to a binding of the corresponding feature codes, that is, of the neural representations of these features (e.g., Treisman, 1996). Indeed, the priming effect obtained by repeating an object is strongly enhanced if this object also appears in the same location, suggesting that object features get bound to location codes (Kahneman, Treisman, & Gibbs, 1992). Hommel and colleagues have extended this approach to include action and suggested that object features and action features may be spontaneously integrated into what they call *event files* (Hommel, 1998; Hommel, Müsseler, Aschersleben & Prinz, 2001). If, for instance, a stimulus like a cup of coffee is accompanied by an action like grasping or drinking, the codes of the sensory features (BROWN, WARM, ROUND, etc.) become integrated with action features like moving the dominant hand towards an object, touching it with thumb and index finger, etc., resulting in an event file referring to the "grasping of a brown, warm cup of coffee". If one or more features are encountered again the whole event file, or at least parts of it, is retrieved automatically (cf., Logan, 1988) in a kind of pattern-completion process. This can lead to benefits and costs—depending on the circumstances. It can lead to benefits if the retrieved feature components are useful by further specifying the repeated features (e.g., if recognition is hampered by suboptimal visibility). And it can lead to costs if some but not all features are repeated but now combined with other features. For instance, repeating the mentioned cup-grasping action may lead to the prediction of tasting coffee and thus trigger surprise if what one is drinking is actually tea.

Costs induced by partial feature overlap between two successive stimulus-response conjunctions have been demonstrated under various circumstances. For instance, performance is as good if both the shape of a stimulus and the location of a corresponding action are repeated than if both are alternated, whereas worse performance is obtained if the shape repeats a response alternates, or vice versa (Hommel, 1998, 2004; Hommel & Colzato, 2004; Keizer, Colzato, & Hommel, 2008). Importantly for present purposes, Hommel, Proctor, and Vu (2004) pointed out that partial-overlap costs are commonly confounded with the sequence of compatible and incompatible trials in the Simon task (and other conflict tasks). For instance, if a participant responds with a *left* button-press to a stimulus appearing on the *right*, this implies stimulus-response incompatibility (IC), whereas responding with the same key to a *left* stimulus, this would imply compatibility (C). Consider the case that these trials are followed by a compatible trial, such as a right button-press to a right stimulus. In the IC-C case (left|right → right|right), the right location is repeated. According to event file logic, this should reactivate the left response, which creates response competition. In the C-C case (left|left → right|right), on the other hand, both features alternate and no retrieval takes place. Comparing these two conditions, C-C should yield better performance than IC-C for reasons that are entirely unrelated to executive control issues—episodic retrieval in the IC-C condition simply induces more selection conflict than in the C-C condition.

Given that conflict tasks rely on the interrelationship of stimulus and response features, the confound between feature repetitions and the repetitions of compatibility conditions is to some degree unavoidable—at least if the original tasks are left more or less intact. Recent workaround solutions have improved the situation by introducing relatively more complex design versions. For instance, some studies have considered only those conditions where no stimulus or response feature is repeated (e.g. Akçay & Hazeltine, 2007) and, given that sequential effects were still obtained, been taken to demonstrate purely executive effects. Even though this approach seems straightforward, it creates two somewhat related problems.

One problem is that excluding any feature overlap between two successive stimuli or stimulus-response episodes does not exclude proactive effects of episodic integration and retrieval (Dutzi & Hommel, in press). Consider stimuli that vary on two dimensions, such as the visual letters “X” and “O” appearing in red or green. According to available models of feature integration (e.g., Duncan & Humphreys, 1989; Treisman, 1988; Wolfe, 1992), processing a green “X”, for instance, would lead to the competition between codes of the colors GREEN and RED and between codes of the shapes X and O. Collecting sufficient visual evidence should provide sufficient support for GREEN and X, which helps them to outcompete the possible alternatives. Now consider that you process the green X after having seen a red O. If having processed the red O led to the integration of the codes RED and O (Kahneman et al., 1992), they can be assumed to act as a unit and engage in what Duncan and colleagues have called “integrated competition” (Duncan, 1996; Duncan, Humphreys & Ward, 1997). This has advantages for the integrated unit if the stimulus it encodes is repeated but a competitive disadvantage if the stimulus changes: having integrated RED and O makes it easier to reject them as a unit (Duncan & Humphreys, 1989). Any loss of RED in the competition with GREEN will propagate to and thus weaken O as well, and losses of O in the competition with X will propagate to and weaken RED. Empirical evidence for this mechanism has been obtained in search tasks, where nontargets can be more easily rejected if they share features that do not overlap with the target, so that they can be grouped together and rejected as a group (Duncan & Humphreys, 1989). Also in line with expectations from an integrated competition approach is the observation that alternating all features and aspects of a stimulus or stimulus-response episode leads to performance that is as good as (e.g., Hommel, 1998) and sometimes even better than performance with complete repetitions (e.g., Colzato, Fagioli, Erasmus & Hommel, 2005; Colzato, van Wouwe & Hommel, 2007a; Hommel & Colzato, 2004). In any case, it seems clear that avoiding feature overlap between successive trials does not allow one to exclude contributions from feature integration and episodic retrieval.

Another problem one runs into by restricting analyses to alternation trials is that this amounts to the selection of just one data point from what can be considered a least two-by-two interaction (repetition versus alternation of one feature and another). This implies the loss of statistical control over possible interactions between control processes and episodic effects. That this is a real problem is suggested by recent observations by Spapé and Hommel (2008). They had participants respond to high or low-pitched tones by saying “high” or “low”, respectively, and ignore the simultaneously presented auditory word “high” or “low”. Not surprisingly, this created a Stroop-like effect showing worse performance if the heard word was incompatible with the required response. The standard sequential modulation was also obtained, showing that the Stroop effect was reduced after incompatible trials. Importantly, however, this sequential modulation was only observed if the voice in the two successive trials was the same but not if the voice changed. This does not necessarily rule out that conflict control took place and affected successive trials if the speaker remained the same. Apparently, however, control information was integrated with the episodic context, of which the voice was a part of. If this episodic context was the same in the next trial, the previous event file including all the control adaptations was retrieved and could thus affect performance. If the context changed, however, episodic retrieval was prevented and so was the impact of previous adaptations on current control. Task-switching studies provide support for this interpretation. While switching to a new task is difficult in general (Allport, Styles & Hsieh, 1994), switching costs are particularly pronounced if the current stimulus was previously encountered in a competing task (Waszak, Hommel & Allport, 2003). This suggests that stimuli and task information are integrated into episodic bindings that are retrieved if the stimulus is encountered another time—which is beneficial if the task has remained the same (as is usual in everyday life) but problematic if the task is different. Further converging evidence is provided by observations from sequential studies. Some authors have obtained conflict-adaptation-like result patterns after a task-switch only if the tasks had at least some overlap in terms of stimuli and responses (e.g., Kiesel, Kunde & Hoffmann, 2006). In the absence of any similarity between tasks, Notebaert and Verguts (2008) found no sequential effects, suggesting to them that conflict-monitoring acts *locally* (see also Blais, Robidoux, Risko & Besner, 2007).

To summarize, there are reasons to assume that at least some of the effects that are commonly taken to reflect adaptive control actually reflect stimulus-response integration and that these effects cannot be avoided entirely by restricting one’s analyses to alternation trials. Moreover, even if adaptive control does take place, its proactive impact on subsequent behavior seems to depend on episodic retrieval, suggesting that control information is being integrated into episodic, context-sensitive event representations.

Aim of Study and Rationale

The aim of the present study was to investigate the relationship between adaptive control processes and episodic retrieval in producing sequential modulations in a conflict task, and to test the hypothesis that the former may depend on the latter. Instead of trying to get rid of episodic effects and see whether something is left to explain, the present study was based on the opposite logic. We used the standard Simon task, leaving its basic design and structure intact, and did not exclude conditions that may or may not be crucial for episodic retrieval. However, we did introduce a manipulation that arguably affects episodic retrieval without having any impact on control processes. If sequential effects would reflect adaptive control only, they should not be affected by these manipulations at all. If sequential effects would be due to a mixture of independently operating control and episodic processes, they should be weakened by our manipulation but still present. If, however, sequential effects would be entirely controlled by, or at least be contingent on episodic retrieval, we should be able to eliminate sequential modulations by manipulating retrieval. This is what we tried to do in the following two experiments, but let us first introduce our episodic manipulation.

In their classical study on feature integration, Kahneman et al. (1992) provided evidence that feature bindings can “move” with the object they represent. They presented participants with preview displays consisting of a number of letters appearing inside boxes and found that, as mentioned already, repeating one of those letters yielded particularly good performance if it also appeared in the same box. Interestingly for our purposes, this was the case even if all the boxes moved between the presentation of the preview letters and the eventual target, suggesting that the letters remained represented as part of the boxes and thus, cognitively speaking, moved with them. Letters and boxes were apparently bound into enduring object representations that were updated when the boxes moved, even if the letters were currently not visible, and retrieved as a unit when a letter reappeared. That object representations survive movements of the objects they represent is also suggested by the observation that multiple objects can be concurrently tracked (e.g., Blaser, Pylyshyn, & Holcombe, 2000). For instance, when a subset of a larger number of squares is briefly flashed to indicate their role as targets, participants are well able to track up to four of them through their rather complex movements across a display.

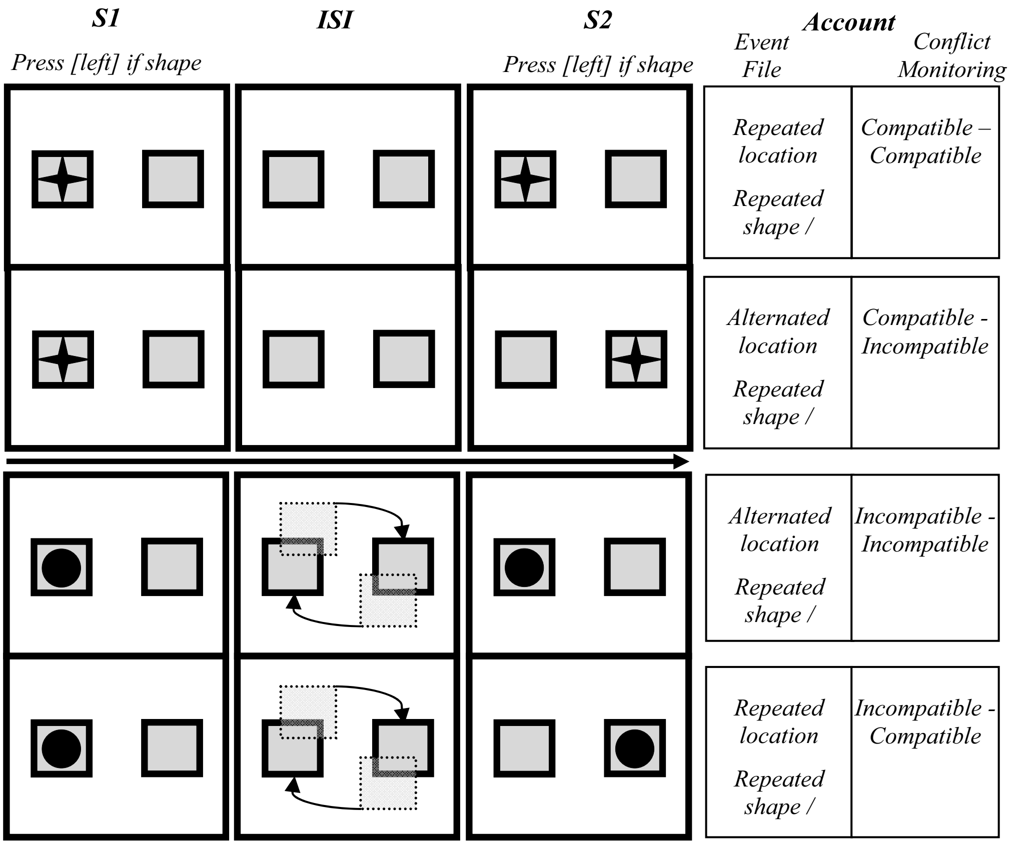

Figure 1: Sequence of events in a single trial and coding in terms of event files and conflict-monitoring.

In the present study, we made use of people's ability and spontaneous tendency to track objects across space and to update object-related feature bindings accordingly. Consider the situation depicted in the first row of Figure 1. In the first of a pair of trials the participant is presented with a star to signal a left-hand keypress. The star appears in the left of the two boxes displayed, which makes this a stimulus-response compatible trial. In the following trial, the star appears again to signal a left-hand keypress and it again appears in the left box. As this is also a compatible trial, the sequence of these two stimuli and responses (S1-

R1 and S2-R2) falls into the C-C category. In the next row, S1 and R1 are the same but they are followed by the star (still signaling a left-hand keypress) appearing in the right box. This makes the second member of the trial pair incompatible and the sequence falls into the C-I category. Other conditions can be easily constructed along the same lines (see rows 3 and 4 for more examples) and we in fact investigated all four types of sequences of compatible and incompatible trials. In all these conditions, predictions from control approaches and an event file approach are just as indistinguishable as in many other preceding studies. Accordingly, we would expect to find the standard pattern of a smaller Simon effect after incompatible than after compatible trials, but would not be certain whether this is due to adaptive control or episodic retrieval or both.

More interesting is the manipulation that is sketched in the two lower rows of Figure 1 (which again applied to all four types of sequences of compatible and incompatible trials). Stimulus presentation and response requirements were unchanged but the two boxes on the screen were rotated by 180° around the screen center in the inter-trial interval. There is no reason to assume that this would affect control processes: if registering conflict upon R1 selection suppresses or prevents the processing of stimulus location on S2 presentation, this should not be affected by the presence or absence of a rotation of actually task-irrelevant boxes in between two trials. From an episodic approach, one would expect rotation to have a strong impact on sequential effects. Let us consider the example depicted in the third row. In both parts of the double trial, a circle signals a right-hand key-press but appears in the left box, which makes both trials incompatible. From a control view, this implies that the sequence falls into the category I-I, which leads us to predict a smaller Simon effect on R2 in this condition as compared to the sequence C-I as shown in the second row.

From an episodic view, one of two alternative predictions can be derived. Following Kahneman et al. (1992), one may assume that rotating the boxes leads to an update of the object representation that codes S1 from {CIRCLE↔LEFT} to {CIRCLE↔RIGHT}—given that the box in which the circle appeared on S1 presentation is now moved to the right. If so, seeing the circle to fall into the left box on S2 presentation would amount to a partial feature mismatch: the shape repeats but the location alternates. This would turn the relative benefit obtained without rotating boxes (which produces a complete repetition) into a partial-overlap cost. In contrast, sequences that without the moving boxes would result in partial feature overlap, as the one depicted in the lowest row, would be turned into complete repetitions or “complete” alternations (e.g., if a left circle is followed by a left star, or vice versa). In a recent paper (Spapé & Hommel, in press), we showed that moving an object does not only move all of its features with it (in the sense that even currently invisible features are spatially updated) but also the actions linked to that object.

In other words, episodic traces of previous actions are apparently accessed via representations of the object they operated on, so that the action in a sense moves with the representation of the object. This would imply that all the effects observed under static conditions should reverse in sign. Note that this prediction presupposes that moving the boxes consistently induces a complete update of all aspects of object representations or event files, so that the content of the original file created upon R1 execution is entirely overwritten. However, recent observations suggest that this may not be what happens in tasks such as those investigated here. Rather, people seem to maintain the original file representing the stimulus-response relationship before the rotation and create a second, updated file after the rotation, so that the effects of reversals of features (such as if left is turned into right) tend to cancel each other out (Spapé & Hommel, in press). If so, one would expect rotations to eliminate sequential effects rather than to reverse their signs. In any case, however, the event file approach would predict a substantial effect of box rotation whereas the control approach would not.

To summarize, the rationale underlying this study was that bridging the gap between research on object tracking and on event coding would help to better understand the relationship and possible contingencies between conflict control and episodic retrieval. In the following, we will introduce and test the basic paradigm in Experiment 1 and show that conflict-adaptation patterns drastically change when a conflicting stimulus is “mentally” repositioned.

Experiment 1

In a Simon task, participants respond to a non-spatial stimulus feature by carrying out a left or right response, whilst ignoring the irrelevant location of the stimulus. In our version, participants responded to circles and stars by pressing a left or right key. The stimuli appeared in the left or right of two constantly visible boxes. Trials were presented in pairs, so that one circle or star was presented (S1) and responded to (R1) before a second circle or star (S2) appeared to signal a second response (R2). The boxes remained visible in between the two trials of a pair and they were rotated by 180° in 50% of the trials. Based on Kahneman et al. (1992), we assumed that the target stimuli would integrate with the box they appear in and thus be “mentally rotated” with it—turning left stimuli into right stimuli, and vice versa. We further assumed that actions would also be integrated with the boxes and the features having appeared therein (Spapé & Hommel, in press). Hence, carrying out a left-hand action to a left stimulus would create an event file linking a LEFT stimulus code (LEFT_s) to a LEFT response code (LEFT_r). If then rotating the boxes would turn the LEFT_s code into a RIGHT_s code, this would result in a representation that links a RIGHT stimulus code to a LEFT response code $\{\mathrm{RIGHT}_s \leftrightarrow \mathrm{LEFT}_r\}$. If so, responding with a left-hand response to a stimulus on the right would now imply a complete match, whereas repeating the physical stimulus and response locations would imply a partial mismatch.

Given the presence of two approaches that differ with respect to the factors they consider relevant, we analyzed our data in two ways. In the first analysis, which we in the following will call the Conflict-Control analysis, we analyzed the data in terms of the sequence of compatibility conditions, testing whether the effect of compatibility on S2-R2 would be modulated by the compatibility of S1 and R1. In view of the available evidence, we expected that such a modulations would exist, showing a reduced or even eliminated S2-R2 compatibility effect after incompatible S1-R1 trials. The main question here was whether rotation, a factor that should be meaningless from a conflict-control point of view, would affect the interaction between S2-R2 compatibility and S1-R1 compatibility.

The second analysis, which we will call the Event-File analysis, concerned the data from a feature integration point of view and tested whether the effects of response repetition (which was confounded with shape repetition) and stimulus-location repetition would interact. Here we expected the standard partial-repetition cost pattern: complete repetitions and alternations should produce better performance than repeating the response but not the stimulus location, or vice versa (Hommel et al., 2004). Of particular theoretical interest was whether rotation would tend to eliminate these effects (as the two-event-files account of Spapé and Hommel, in press, would suggest) or even reverse their sign (as a one-file extension of the approach of Kahneman et al., 1992, might imply).

Table 1*: Summary of predicted effects under the paradigms of conflict-adaptation and feature integration. Conflict-adaptation is based on the compatibility (C) or incompatibility (I) of the first stimulus (S1) and its pro-active effect on the second stimulus (S2). A compatible stimulus followed by an incompatible stimulus (i.e. C-I) is predicted to result in slow reaction times. Effects of feature integration are related to the repetition (R) or alternation (A) between the stimuli's location- and response characteristics. If the location alternates (L:A) between two stimuli whilst the response is repeated (R:R), reaction times are predicted to be slow – unless the stimulus-display rotates in between S1 and S2 (as with trial types 5–8)***.**

	S1		***ISI***	***S2***		***Effects***	
Type	*Location*	*Response*	*Rotation*	*Location*	*Response*	*Conflict-Adaptation*	*Feature integration*
1	*Left*	*Left*	*Static*	*Left*	*Left*	*C-C: fast*	*L:R-R:R: fast*
2	*Left*	*Right*	*Static*	*Right*	*Left*	*I-I: fast*	*L:A-R:A: fast*
3	*Left*	*Left*	*Static*	*Right*	*Left*	*C-I: slow*	*L:A-R:R: slow*
4	*Left*	*Right*	*Static*	*Left*	*Left*	*I-C: slow*	*L:R-R:A: slow*
5	*Left*	*Left*	*Rotating*	*Left*	*Left*	*C-C: fast*	*L:R-R:R: slow*
6	*Left*	*Right*	*Rotating*	*Right*	*Left*	*I-I: fast*	*L:A-R:A: slow*
7	*Left*	*Left*	*Rotating*	*Right*	*Left*	*C-I: slow*	*L:A-R:R: fast*
8	*Left*	*Right*	*Rotating*	*Left*	*Left*	*I-C: slow*	*L:R-R:A: fast*

Method

Participants

Eighteen students from Leiden University voluntarily participated in this experiment for a small fee or course credits.

Apparatus and stimuli

Stimuli were presented on a flat-screen 17" CRT monitor in 800 x 600 pixels resolution and a refresh-rate of 120 Hz. A Pentium-IV dual 1.67 GHz PC running E-Prime (1.1, SP3) on Windows XP SP2 controlled stimulus-presentation and recorded reactions via the USB connected keyboard. Target-containing boxes were gray (RGB value of 128, 128, 128), black-lined squares of 60 x 60 pixels or approximately 32 x

32 mm presented against a silver (RGB value of 191, 191, 191) background. The target itself was also 60 x 60 and was either a circle or a four-pointed star. Boxes were presented 180 pixels (approximately 96 mm) left and right from the centre of the screen and also kept at this distance during the gradual shifts in location.

Procedure

As outlined in Fig. 2, a fixation cross was presented for 500 ms, after which the two boxes were presented in the left and right of the screen, one of them containing the target shape (S1) to which participants were required to respond. After 500 ms, the targets were no longer shown on the screen. In the "static" condition, the boxes stood still, without targets, for 800 ms, whereas in the rotating condition, they rotated around their axis at a speed of approximately 4 degrees with each 44 ms. After the 800 ms, both in the static condition and the rotating condition, the boxes were presented for another 200 ms before the second target (S2) was presented. S2 was shown for 700 ms before a screen with feedback informed the participant of the performance. This last screen also comprised the inter-trial interval and was shown for 1100 ms.

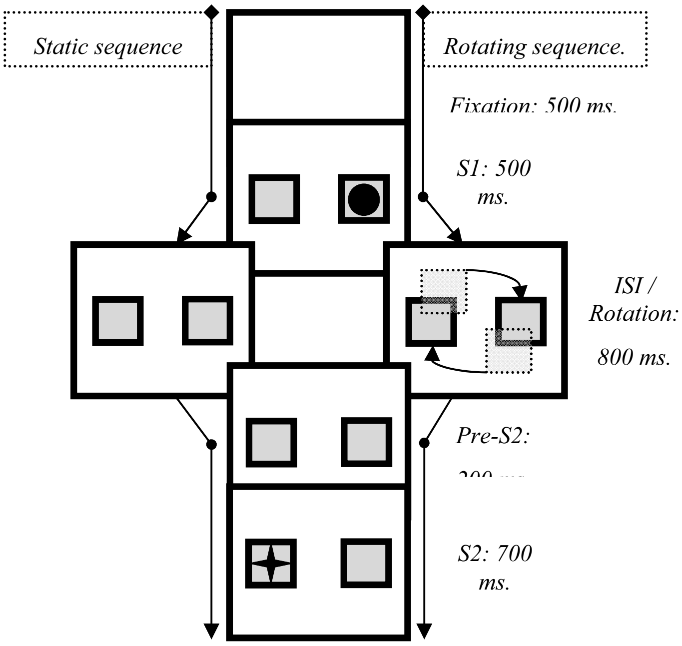

Figure 2: Schematic depiction of the trial-sequence of two example trials. After presenting a fixation crosshair, two boxes were presented for 500 ms in the left and right of the screen, one containing the shape (S1) to which participants were required to respond. In the "static" condition (left), an inter-stimulus interval (ISI) followed in which the boxes stood still for 800 ms, whereas in the rotating condition, they rotated around their axis during this ISI. In both conditions, the boxes were statically presented for another 200 ms before the second target (S2) was shown. S2 was shown for 700 ms before an inter-trial interval of 1100 ms ended the trial.

Following the instruction, the first 20 trials of the experiment were considered practice of acquiring the mapping between circles or stars with a <Q> or <P> keypress. Half of the participants were to press <Q> for stars and <P> for circles, the other half received the opposite stimulus-response mapping. They were required to respond as quickly and accurately as possible and were shown a personal score next to a high score which they were encouraged to break. Getting points could only be done by responding both fast (1 point for each reaction below 600 ms) and accurately (1 point for each accurate reaction) and although breaking the high score was not reinforced with any kind of monetary or other incentive; most participants did indicate being positively motivated to aim for a (fictional, computed as 3 × number of trials) high score. The experimented lasted about 30 minutes.

Design

Results were coded so as to analyze them with two different three-factor repeated measures designs. First, predictions from the conflict adaptation approach were tested by considering rotation (static versus rotating), compatibility of the first stimulus and response, and compatibility of the second stimulus and response. Second, predictions from the event coding approach were tested by considering rotation, shape/response repetition, and stimulus-location repetition. For both types of analyses, the eight design cells resulting from crossing these factors were replicated an even 32 times. The four blocks consisted of the 64 possible, randomly presented, combinations of rotation (versus non-rotation), direction of rotation (clockwise versus counter-clockwise), target shapes (in S1 and S2) and the location of the targets (in S1 and S2).

Results

Responses with latencies longer than 1000 ms were not considered, and all incorrect reactions to S1 or S2 were excluded from RT analyses. Few errors were made during S1 (M = 6.7%, SD = 5.7%) and S2|S1 (M = 4.3%, SD = 2.7% of the remaining correct responses).

Conflict-Control analysis

In a repeated measures analysis of variance on the RT to S2 with rotation, S1 compatibility and S2 compatibility as factors, reactions were some 30 ms faster after seeing the boxes rotate, F(1, 17) = 52.09, MSe = 31661.46, *p* < .001, while error rates were not affected, F(1, 17) = 2.03, MSe = .01, p > .1. Compatibility on S1 had no effect on RT, F(1, 17) = .08, MSe = 34.73, p > .7, but increased accuracy, F(1, 17) = 4.54, MSe = .01, p < .05. Participants were 30 ms slower if S2 and R2 were incompatible, F(1,17) = 73.05, MSe = 32753.76, *p* < .001, and made 4% more errors, F(1, 17) = 24.784, MSe = .06, p < .001. The conflict-adaptation-type effect was replicated, as evidenced by a significant interaction between S1 compatibility and S2 compatibility on RT, F(1,17) = 25.49, MSe = 16578.71, *p* < .001, and errors, F(1, 17) = 21.11, MSe = .02, p < .001: The compatibility effect was larger after compatible than incompatible trials. Indeed, on static trials, the Simon effect was significantly *inverted* after incompatible trials, t(17) = 2.27, p < .04, although not for errors, t(17) = .29, p > .7. However, this effect was modulated by rotation in both RTs, F(1,17) = 40.93, MSe = 14174.49, *p* < .001, and errors, F(1, 17) = 12.63, MSe = .02, p < .005. To test the effect of conflict-adaptation under static and rotating conditions, two t-tests of the interactions between S1 and S2 compatibility were computed. Whereas the interaction between S1 compatibility and S2 compatibility was very pronounced and reliable with static boxes, RTs: t(17) = 6.17, p < .001), errors: t(17) = 4.72, p < .001), it entirely disappeared with rotating boxes, RTs: t(17) = .50, p > .6, errors: t(17) = .59, p > .5, see Table 2a.

Table 2a. *Experiment 1, compatibility and conflict-adaptation results. Reaction times, error rates and standard errors (in parentheses) for S2 (the probe or "current trial") as a function of S1 compatibility, S2 compatibility, and rotation. Effect sizes to the right show the compatibility (Simon) effect and how it is affected by preceding (S1) compatibility. The conflict-adaptation effect is measured as the degree to which the compatibility-effect of S2 is attenuated after incompatible S1s.*

					Compatibility effect		*Conflict*
S1	*Compatible (C)*		*Incompatible (IC)*		*after C*	*after I*	*Adaptation*
S2	*C*	*I*	*C*	*I*	*CI - CC*	*II - IC*	*(CI - CC) - (II - IC)*
		Reaction times					
Static	448 (9)	515 (15)	489 (13)	473 (11)	66	-16	83
Rotating	432 (10)	469 (12)	436 (12)	470 (11)	37	34	3
		Error rates					
Static	2 (1)	11 (2)	4 (1)	3 (1)	9	0	10
Rotating	2 (1)	6 (1)	2 (1)	5 (1)	4	3	1

Event-File analysis

Rotation had a comparable effects here, both on RTs, F(1, 17) = 52.39, MSe = 32831.63, *p* < .001, and errors, F(1, 17) = 2.23, MSe = .01, p > .2. The only other main effect indicated that responses were faster if the shape/response was repeated, F(1, 17) = 18.77, MSe = 15887.34, p < .001. As expected (Hommel et al., 2004), stimulus-location repetition interacted significantly with shape/response repetition in RTs, F(1, 17) = 25.34, MSe = 17916.27, p < .001, and errors, F(1, 17) = 23.84, MSe = .03, p < .001. The standard cross-over interaction indicated that performance was better with complete repetitions and alternations than with partial-repetitions (see Table 2b). In other words, performance was good if stimulus shape, stimulus location, and the response was repeated or if all three features changed, but comparatively bad if shape and response were repeated while stimulus location alternated or if shape and response alternated while stimulus location repeated. This interaction was further modified by rotation in both RTs, F(1, 17) = 43.47, MSe = 14077.43, p < .001, and errors, F(1, 17) = 12.83, MSe = .02, p < .005. As shown in Table 2b, partial-repetition costs and, thus, the interaction of location and shape/response repetition) were restricted to static boxes and disappeared with rotating boxes. Interestingly, overlap costs were not negative in the rotation condition.

Table 2b. *Reaction times, error rates and standard errors (in parentheses) for responses to S2 (the probe or "current trial") as a function of rotation, S1-S2 location- and response-repetition. Effect sizes to the right show response-priming effects and how they are modulated by location-repetition. Partial Overlap-costs (the effect of repeating only the location or response between S1 and S2) were measured as the difference between response-priming effects of location-repetitions (Loc. R) and location-alternations (Loc. A).*

	Location				*Response Priming*		*Partial Overlap-costs*
	Repeated (R)		*Alternated (A)*		*Loc. R*	*Loc. A*	
Response	*R*	*A*	*R*	*A*	*RA - RR*	*AA - AR*	*(RA-RR) - (AA-AR)*
	Reaction times						
Static	451 (9)	519 (15)	487 (14)	470 (12)	68	-16	84
Rotating	441 (7)	460 (13)	446 (10)	459 (13)	18	13	5
	Error rates						
Static	2 (1)	8 (2)	7 (2)	3 (1)	5	-5	10
Rotating	3 (1)	4 (1)	4 (1)	4 (1)	1	0	0

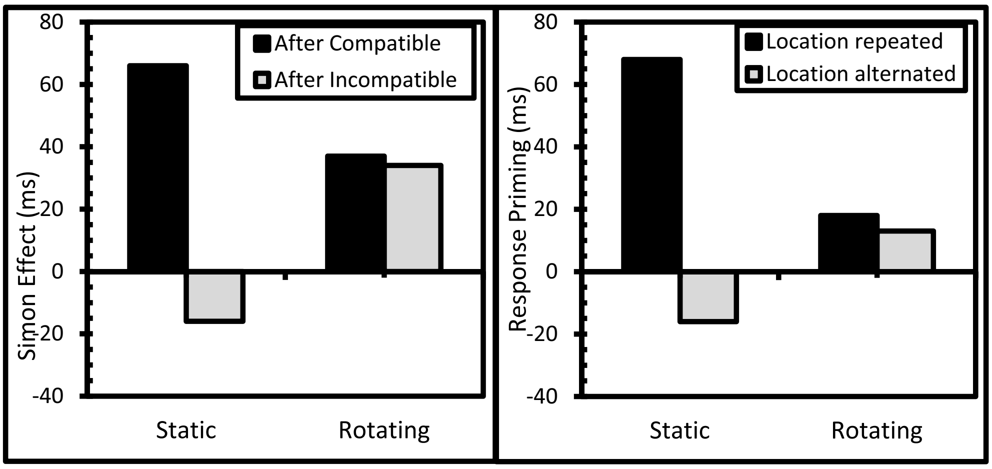

Fig. 3: Results experiment 1: Effects of rotation on sequential Simon effects (left) and event-coding (right). Conflict-adaptation was measured as the reduction in Simon effect after incompatibility. Event-coding effects were measured as the decrease in response-priming benefits if the location did not repeat along with the required response.

Discussion

The outcome of Experiment 1 is rather clear-cut. With static boxes, we replicated the earlier finding that the Simon effect is larger after compatible than incompatible trials (Stürmer, Leuthold, Soetens, Schröter & Sommer, 2002). From a conflict-monitoring perspective, it has often been suggested (cf. Stürmer et al., 2002) that Simon stimuli are processed via two pathways from perception to action: an automatic route, based on an automatic triggering of the response by the location of the stimulus (Simon, 1969) and a voluntary route, based on the task requirements (Kornblum, Hasbroucq & Osman, 1990). Detecting a conflict may trigger the gating or blocking of the automatic route (Botvinick et al., 1999), which would predict less or no Simon effect after incompatible trials. This account fails to account for the *reverse* Simon effect after incompatible trials that was encountered in the present and other previous studies. Alternatively, the automatic route may be actively suppressed, as suggested by Ridderinkhof (2002), which could account for reverse Simon effects after incompatible trials. In any case, our findings for static conditions are consistent with at least some versions of the conflict-control approach.

The rotation conditions, however, during which the sequential effects disappeared altogether, are harder to fit in such models. Since the boxes themselves are unlikely to cause any conflict, and as they do not even contain any targets while being rotated, there is no reason why moving the boxes should have any effect on conflict-adaptation. Accordingly, we see no way how conflict-monitoring theories can account for our observations. Would the sequential effects have been only smaller (but not absent) in the rotation condition, one could have argued that they consist of an adaptation component and an independently operating episodic component—with the latter being eliminated and the former being constant. Given the total elimination of the effect, however, this does not seem to be an option.

From an event-file perspective (Hommel, 2004; Hommel et al., 2001) the outcome pattern makes more sense. As predicted, rotating the boxes strongly affected the interactions between stimulus- and response-repetition effects. To the degree that these interactions reflect the creation and later retrieval of feature bindings, this suggests that rotation at least co-determined how the features were coded. In the introduction to Experiment 1, we considered two possible scenarios of how that might work. The first extended Kahneman et al.'s (1992) logic to event files that contain response information and holds that R2 performance is affected by the retrieval of one event file only. In particular, it assumes that rotating the boxes leads to an update of the event file that had just been formed to represent the S1-R1 episode: left stimulus codes are turned into right and right stimulus codes into left codes. If so, the event-file analysis should show positive partial-overlap costs under static conditions and negative costs under rotation conditions. This was clearly not the case, supporting the claim of Spapé and Hommel (in press) that updating is only part of the story.

The second scenario assumed that two events files are affecting R2 performance under rotation conditions: one that codes the original S1-R1 episode and another that represents the post-rotation state of affairs. Given that the spatial stimulus codes in these two files are always inconsistent their effects will tend to cancel each other out. If so, one would expect positive partial-overlap costs under static conditions costs around zero with rotation. This is exactly the pattern we have obtained, suggesting that the two-file account is more realistic.

To summarize, Experiment 1 provides evidence that, at least under the conditions tested here, sequential modulations of Simon effects are entirely due to episodic binding and retrieval. There is one fly in the ointment however: Although the null effect of event coding in the rotation condition may result from the counteracting effects from two event files, we have no direct evidence that it does. Rather than creating a second, updated file when the boxes move, the cognitive system may simply erase the previous (or any) file whenever a movement or any other dramatic change of the visual display is encountered (Zacks, Speer, Swallow, Braver & Reynolds, 2007). What is therefore needed is positive evidence that event files are actually updated and that the updated files actually affect performance—evidence that we attempted to provide in Experiment 2.

Experiment 2

In Experiment 2 we also rotated the boxes in which stimuli appeared in between S1 and S2 presentation. Two of the three rotation conditions conceptually replicated Experiment 1: A 0-degree rotation condition corresponded to the static condition of Experiment 1, in which the boxes were not moving, and a 180-degree rotation condition corresponded to the rotation condition of Experiment 1. The outcomes of these two conditions were expected to replicate the basic finding that conflict-adaptation-type effect should be restricted to the 0-degree condition and be eliminated in the 180-degree rotation condition. The more important manipulation, however, was the introduction of a third rotation condition. Here, the boxes were rotated only 90 degrees, so that boxes did not overlap between S1 and S2 displays. S2 could still appear either in the same box (e.g., in the location towards which the box where S1 appeared was rotated) or in the other box (i.e., in the location opposite to the box where S1 appeared was rotated). However, given that the 90-degree rotation always moved the boxes to locations that were not occupied by the boxes in the S1 display, old and new event files could no longer cancel each other out. Accordingly, their effects should be reliable and more pronounced than in the 180-degree condition.

Method

Twenty-two students from Leiden University between the age of 19 and 25 volunteered for a small fee or course credits. The procedure was the same as in Experiment 1, except that S1 and S2 could also appear above and below the screen center, that the boxes could be rotated by 0, 90, or 180 degrees, and that the rotation could take 800 or 1200 ms (a factor that was introduced for reasons unrelated to the present study and that therefore was not considered further in the analyses). The two boxes could thus be either horizontally or vertically oriented in both the S1 and S2 displays, which created four types of transition: horizontal-to-horizontal (H-H) and vertical-to-vertical (V-V), the two 180-degree conditions, and horizontal-to-vertical (H-V) and vertical-to-horizontal (V-H), the two 90-degree conditions. The experiment lasted about forty minutes.

Results

Trials with incorrect responses to S1 (11.6%) were excluded from the error analyses, and trials with incorrect responses to S1 or S2 (another 11.6%) were excluded from RT analyses.

Conflict-Control analysis

The factors were again rotation (rotated vs. static) and compatibility of S1 and S2 (compatible vs. neutral vs. incompatible), where the compatible and incompatible conditions were taken from the horizontal displays and the neutral conditions from the vertical displays. In repeated measures ANOVAs, S1 compatibility approached significance in RTs, F (2, 42) = 3.01, MSe = 575.99, p < .07, but not in error proportions, F(2, 42) = .79, MSe = .002, p > .7; while S2 compatibility had a significant effect on both RTs, F(2, 42) = 42.82, MSe = 20235.00, p < .001, and errors, F(2, 42) = 48.85, MSe = .21, p < .001. Participants were 15 ms faster with rotating trials, F(1, 21) = 26.19, MSe = 13974.68, p < .001, but not more often correct, F(1, 21) = 1.75, MSe = .01, p > .2. Rotation modulated the effect of S1 compatibility, F(2, 42) = 4.55, MSe = 626.31, p < .02, for RTs, but not errors, F(2, 42) = .46, MSe = .001, p > .6. The standard conflict-adaptation pattern was found for RTs, F(4, 84) = 10.54, MSe = 2521.80, p < .001, and errors, F(4, 84) = 8.60, MSe = .03, p < .001, with larger S2 compatibility effects after compatible than incompatible S1 (effect sizes: 39 ms and 13% as opposed to 12 ms and 2% respectively). Adaptation-type patterns after a neutral S1 were in between (24 ms, 7%). The three-way interaction was also significant in RTs, F(4, 72) = 14.65, MSe = 3527.93, p < .001, again showing that rotation eliminated all adaptation-type effects: strong conflict-adaptation was found under static conditions, RTs: t(21) =

5.57, p < .001, errors: t(21) = 4.59, p < .001, but insignificant under rotating conditions, RTs: t(21) = -1.10, p > .1, errors: t(21) = .15, p > .8.

Table 3a*: Experiment 2, compatibility and conflict-adaptation results. Reaction times, error rates and standard errors (in parentheses) for responses to S2 as a function of S2 compatibility, S1 compatibility, and rotation. Effect sizes to the right show how the compatibility effect is affected by preceding (S1) compatibility (see table 2a). Note that Neutral S1s indicate trials in which the stimuli were vertically aligned.*

					Conflict	Conflict Adaptation
			S2			*(CI-CC) –*
Rotation	*S1*	*Compatible*	*Incompatible*	*Neutral*	*C - I*	*(II-IC)*
			Reaction times			
Static	Compatible	378 (4)	428 (9)	410 (6)	51	61
	Incompatible	415 (9)	405 (7)	418 (8)	-10	
	Neutral	402 (6)	428 (7)	406 (6)	26	
Rotating	Compatible	386 (5)	413 (6)	396 (6)	27	-6
	Incompatible	379 (5)	412 (6)	398 (6)	33	
	Neutral	389 (5)	411 (6)	399 (6)	22	
			Error rates			
Static	Compatible	2 (1)	19 (3)	6 (2)	17	21
	Incompatible	10 (2)	6 (2)	5 (1)	-4	
	Neutral	3 (1)	11 (2)	8 (1)	7	
Rotating	Compatible	3 (1)	12 (2)	6 (1)	9	0
	Incompatible	4 (1)	12 (2)	5 (1)	8	
	Neutral	4 (1)	11 (1)	5 (1)	8	

Event-File analysis

To establish whether we were able to replicate our findings of experiment 1, we conducted repeated measures ANOVAs with rotation (rotated vs. static), location-repetition and response-repetition on the conditions where the displays were horizontally aligned and rotated either 180 degrees or not at all. Rotation had a significant effect on RTs, F(1, 21) = 19.65, MSe = 7459.94, p < .001, and a marginally significant effect on errors, F(1, 21) = 4.19, MSe = .03, p < .06, with rotated conditions being 13 ms faster and 2.7% more often correct. Location repetitions were slightly (7 ms) slower, F(1, 21) = 12.33, MSe = 2404.12, p < .005, but not less often accurate, p > .6, than location alternations, whereas response repetitions were significantly faster (10 ms), F(1, 21) = 5.81, MSe = 4536.24, p < .03, but not more often accurate, p > .2, than response alternations. In a similar fashion to experiment 1, response-repetition interacted significantly with location-repetition for both RTs, F(1, 21) = 42.02, MSe = 13192.65, p < .001, and errors, F(1, 21) = 24.17, MSe = .24, p < .001, the effect of which itself was modulated by rotation for RTs, F(1, 21) = 29.89, MSe = 13046.56, p < 001, and errors, F(1, 21) = 16.23, MSe = .16, p < .001. These findings replicate our observations in Experiment 1 and confirm that they represent a robust pattern.

The next analysis compared the two rotation conditions, which required us to recode the data. We compared trials where S1 location (i.e., the box that contained S1) was *rotated towards* the location of the upcoming S2 (e.g., if S1 appeared in the top box, this box was rotated to the right, and S2 appeared in the right box) with trials where the box holding S1 was *rotated away* from the location where S2 would appear (e.g., if S1 appeared in the top box, this box was rotated to the right, and S2 appeared in the left box). ANOVAs were run with the factors shape/response repetition (repetition vs. alternation), direction of rotation (towards vs. away the location of S2), and degree of rotation (0 degree vs. 90 degree—taken from V-H and H-V transitions –vs. 180 degree—taken from V-V and

H-H transitions). Repeated responses were faster, F(1, 21) = 7.28, MSe = 3347.00, p < .02, but not more accurate, F(1, 21) = .001, MSe = .00, p > .9. Direction of rotation had no effect on RT, F(1, 21) = .09, MSe = 9.83, p > .7 or errors, F(1, 21) = .01, MSe = .00, p > .9. Degrees of rotation had no effect on RT, F(1, 21) = .10, MSe = 9.09, p > .7, but had a small effect on errors, F(1, 21) = 6.32, MSe = .00, p < .03, with 90-degree rotations eliciting 1.0% more errors than rotations of 180 degrees. More importantly, shape/response repetition significantly interacted with direction of rotation in RTs, F(1, 21) = 6.76, MSe = 752.28, p < .02, and marginally in errors, F(1, 21) = 3.13, MSe = .00, p < .09. While rotations towards the target location generally resulted in (4 ms) faster, more (0.7%) accurate reactions than with rotations away with repeated shapes/responses, rotations away yielded (5 ms) faster, more (0.6%) accurate responses than rotations towards with alternated shapes/responses. This effect itself, however, was modulated by the degrees of rotation, for both RTs, F(1, 21) = 7.82, MSe = 436.06, p < .02, and errors, F(1, 21) = 8.57, MSe = .01, p < .01. Post-hoc tests comparing the partial-repetition costs (see table 3b for calculus) for the 90 and 180 degrees revealed that partial-repetition costs were larger for both RTs, t(21) = 2.80, p < .02, and errors, t(21) = 2.93, p < .01, with rotations of 90 degrees than with rotations of 180 degrees (see table 3b).

Table 3b. *Experiment 2, response-priming and Event-file results. Reaction times, error rates and standard errors (in parentheses) for S2 as a function of degrees of rotation (0^o degrees indicating static conditions), response-repetition and (rotated) location. Note that, different from table 2b, rotating is either "towards" – as with conditions where the box containing the stimulus in S1 gradually rotated towards the location in which S2 was presented – or "away" – under conditions in which the box containing S1 rotated away from the location in which S2 was presented. Thus, with rotations of 0^o, rotating towards and away are tantamount to location-repetitions and alternations respectively.*

	Location / Rotation				Response Priming		Partial Repetition Costs
	Towards (R)		Away (A)		Loc. R	Loc. A	
Response	R	A	R	A	RA - RR	AA – AR	(RA-RR) - (AA-AR)
Degrees		*Reaction times (ms)*					
0^o	385 (5)	427 (8)	403 (7)	389 (8)	42	-14	56
90^o	391 (5)	407 (7)	398 (6)	399 (6)	16	2	15
180^o	394 (5)	403 (6)	394 (5)	402 (7)	10	8	2
Degrees		*Error rates (%)*					
0^o	2 (1)	20 (3)	10 (2)	4 (1)	18	-6	24
90^o	5 (1)	8 (1)	7 (1)	6 (1)	3	-1	4
180^o	7 (1)	5 (1)	6 (1)	5 (1)	-2	0	-2

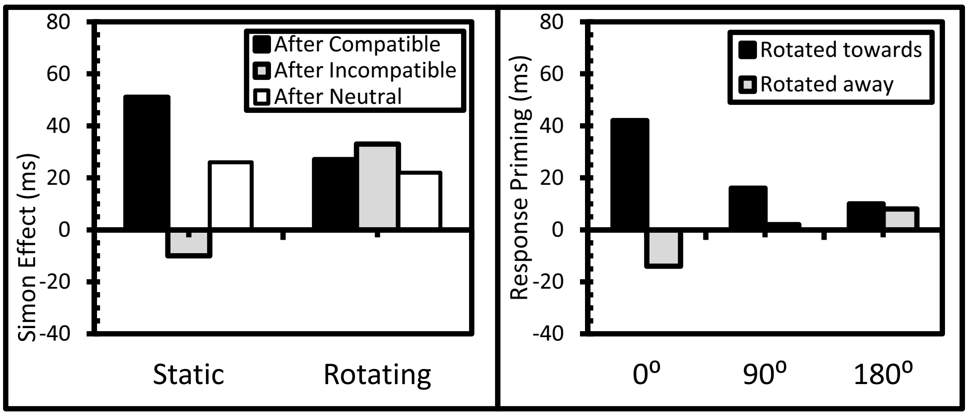

Figure 4: Results experiment 2: Effects of rotation on sequential Simon effects (left) and event-coding (right).

Discussion

The findings of Experiment 2 demonstrate that the degree of rotation matters and that, as expected, the 90-degree rotation condition produces stronger binding effects. The results of Experiment 1 showed that after rotating the stimulus display for 180 degrees, both conflict-adaptation and partial-repetition costs were reduced to numbers around zero. Following Spapé & Hommel (in press), we employed a design in Experiment 2 in which the boxes rotated for 90 degrees, yielding two conditions in which presentations either rotated from neutral *to* conflicting or vice versa. Although the conflict-control analysis essentially had no clear predictions for these conditions, we predicted partial-repetition costs due to the rotated position of the stimuli being not repeated in a lower-level manner.

One might argue, however, that the results of Experiment 2, merely show that rotation in and of itself reduces feature-integration, and/or conflict-adaptation. The results of experiments 1 and 2 suggested that this may be so, since partial-repetition costs were found to be smaller with each 'extra degree of rotation': from a sizable 80 ms in 0° (i.e. static) conditions, via a smaller but significant 15 ms in 90° conditions to insignificant near-zero in 180° conditions. Thus, one could argue that the more the boxes rotate, the lesser be the binding. Likewise, rotation itself could have disrupted conflict adaptation, as after rotating the boxes, no conflict-adaptation was found. If rotation in and of itself eliminates both conflict-adaptation and feature-integration, however, this would predict that partial-repetition costs, nor conflict-adaptation should occur after rotating the boxes 360°. In our third experiment, we sought to test this hypothesis.

Experiment 3

In Experiment 3, the boxes in which stimuli appeared were rotated in similar fashion to Experiment 1, thereby again conceptually replicating two of the three rotation conditions: in one third of the trials, the boxes did not move at all (the static condition of Experiment 1 or the 0-degree condition of Experiment 2) and in another third of the trials, they rotated 180-degrees. Crucially for this experiment, however, was the new 360-degrees condition in which the boxes rotated fully around their axis. Thus, if a conflict-inducing stimulus first appeared left, it would rotate to its original location. If rotating itself eliminates conflict-control, no conflict-adaptation was predicted after a 360-degrees rotation. However, if conflict-adaptation would depend on episodic retrieval, significant conflict-adaptation should still be present.

Method

Twenty students from Leiden University between the age of 18 and 27 volunteered in exchange for course credits or money. As in Experiment 1, S1 and S2 could only appear to the left and right of the screen. Also similar to Experiment 1, the boxes in which S1 initially appeared either kept their fixed positions or gradually rotated around their axis during the ISI. Unlike the previous experiments, however, the ISI was either 800 or 1600 ms to cancel out the confounding effect of rotation (in degrees) on rotation-speed (which should be important for tracking, cf. Pylyshyn & Storm, 1988). Two thirds of the trials replicated the static and rotating conditions of Experiment 1 – the boxes rotating 0 or 180 degrees – whereas in the other third, the boxes rotated 360 degrees. The experiment lasted for approximately 50 minutes.

Results and Discussion

Trials with incorrect responses to S1 (10.9%) were excluded from the error analyses, and trials with incorrect responses to S1 or S2 (another 9.6%) were excluded from RT analyses.

Conflict-Control analysis

In repeated measures ANOVAs with rotation (static vs. 180 degrees vs. 360 degrees), ISI (800 vs. 1600 ms) and compatibility of S1 and S2, S1 compatibility had a significant effect on error proportions, F (1, 19) = 4.50, MSe = .005, p < .05, but not on RTs, F(1, 19) = 1.42, MSe = 323.01, p > .2 whereas S2 compatibility affected both RTs, F(1, 19) = 165.86, MSe = 125054.10, p < .001, and errors, F(1, 19) = 35.42, MSe = .57, p < .001. Rotation had no significant effect on RTs, F(2, 38) = 1.91, MSe = 1578.36, p > .1 and only approached significance on errors, F(2, 38) = 2.65, MSe = .02, p < .09. ISI significantly affected RTs, F(1, 19) = 18.24, MSe = 10520.22, p < .001, and errors, F(1, 19) = 29.28, MSe = .09, p < .001, with longer ISIs being 9 ms faster, but 2.7% more often incorrect. Furthermore, ISI interacted with S2 compatibility on RTs, F(1, 19) = 6.48, MSe = 1719.27, p < .02, and errors, F(1, 19) = 5.26, MSe = .04, p < .04. The effect of S2 compatibility was greater after longer ISIs (36 ms, 8.8%) than after shorter ISIs (28 ms, 5.1%). Rotation interacted with ISI on RTs, F(2, 38) = 4.48, MSe = 1578.84, p < .02, but not on errors, F(2, 38) = .61, MSe = .004, p > .5. Also, rotation interacted with S1 compatibility on errors, F(2, 38) = 4.07, MSe = .01, p < .03, but not on RTs, F(2, 38) = .85, MSe = 92.33, p > .4, and with S2 on RTs, F(2, 38) = 12.60, MSe = 3525.34, p < .001, but not on errors, F(2, 38) = 2.65, MSe = .01, p > .08.

S1 and S2 compatibility significantly interacted on RTs, F(1, 19) = 147.53, MSe = 32287.75, p < .001 and errors, F(1, 19) = 91.36, MSe = .39, p < .001. Larger S2 compatibility effects were found after compatible than incompatible S1s (50 ms and 12.6% as opposed to 16 ms and 1.2% respectively). The three-way interaction between rotation, S1 compatibility and S2 compatibility was again significant on RTs, F(2, 38) = 69.07, MSe = 19484.08, p < .001 and errors, F(2, 38) = 35.69, MSe = .19, p < .001, showing rotating had a great effect on conflict-adaption.

To further analyze the effects of rotation on conflict-adaptation, separate ANOVAs testing the degree to which S1 and S2 compatibility significantly interacted were conducted for each type of rotation. This interaction proved significant for static trials on RTs, F(1, 19) = 188.91, MSe = 68587.80, p < .001, and errors, F(1, 19) = 81.08, MSe = .74, p < .001. Although the interaction was smaller, it was still significant for trials in which the boxes rotated 360 degrees for both RTs, F(1, 19) = 12.57, MSe = 2662.96, p < .003, and errors, F(1, 19) = 11.82, MSe = .03, p < .003. However, the conflict adaptation pattern was completely eliminated after rotating the boxes 180 degrees for RTs, F(1, 19) = .03, MSe = 5.14, p > .8, and errors, F(1, 19) = .43, MSe = .001, p > .5.

Table 4a: *Experiment 3, compatibility and conflict-adaptation results. Reaction times, error rates and standard errors (in parentheses) for responses to S2 as a function of S2 compatibility, S1 compatibility, and rotation. Effect sizes to the right show how the compatibility effect is affected by preceding (S1) compatibility (see table 2a).*

S1	Compatible (C)		Incompatible (IC)		Compatibility effect After C	After I	Conflict Adaptation
S2	C	I	C	I	CI - CC	II - IC	(CI - CC) - (II - IC)
			Reaction times				
Static	375 (7)	438 (7)	413 (8)	393 (6)	63	-20	83
180°	381 (9)	416 (7)	381 (9)	417 (8)	35	36	-1
360°	377 (9)	424 (8)	383 (8)	415 (9)	48	32	16
			Error rates				
Static	2 (1)	21 (2)	12 (2)	4 (1)	19	-8	27
180°	3 (1)	12 (2)	4 (1)	12 (2)	9	8	1
360°	3 (1)	13 (1)	5 (1)	9 (1)	10	4	6

Event-File analysis

In repeated measures ANOVAs with rotation (static vs. 180 degrees vs. 360 degrees), ISI (800 vs. 1600 ms), location-repetition and response-repetition, rotation had marginally significant effect on RTs, F(2, 38) = 2.62, MSe = 2226.78, p <

.09 and error proportions, F(2, 38) = 3.11, MSe = .02, p < .06. Longer ISIs were significantly faster, F(1, 19) = 22.53, MSe = 12788.14, p < .001, but also more often incorrect, F(1, 19) = 29.68, MSe = .09, p < .001. Location repetition was significant for RTs, F(1, 19) = 9.35, MSe = 1650.65, p < .01, but not for errors, F(1, 19) = 2.85, MSe = .01, p > .1. Response repetition was significant for RTs, F(1, 19) = 5.53, MSe = 9163.96, p < .03, but only marginally for errors, F(1, 19) = 4.10, MSe = .02, p < .06. Repeating the response significantly interacted with ISI on RTs, F(1, 19) = 12.89, MSe = 3474.06, p < .002, but not errors, F(1, 19) = .34, MSe = .0004, p > .5. ISI interacted significantly with rotation on RTs, F(1, 19) = 4.69, MSe = 1623.81, p < .02, but not on errors, F(1, 19) = .62, MSe = .004, p > .5.

More interestingly, we replicated the overall pattern Experiment 1 and 2: location-repetition significantly interacted with response-repetition for RTs, F(1, 19) = 178.94, MSe = 38853.61, p < .001 and errors, F(1, 19) = 80.07, MSe = .46, p < .001. This interaction was modulated significantly by rotation for RTs, F(1, 19) = 65.14, MSe = 18809.87, p < .001, and errors, F(1, 19) = 34.41, MSe = .20, p < .001.

To evaluate whether the cost of partially repeating location or response was dependant on rotation, separate ANOVAs were conducted for each type of rotation (or lack thereof). For static trials, the interaction between repeating location and response was significant for RTs, F(1, 19) = 191.64, MSe = 72363.01, p < .001 and errors, F(1, 19) = 75.10, MSe = .80, p < .001, with partial-repetition costs of approximately 85 ms or 28.3%. With rotations of 360 degrees, these costs were smaller (20 ms or 6.5%), but still significantly present for both RTs, F(1, 19) = 19.72, MSe = 4030.82, p < .001, and errors, F(1, 19) = 14.24, MSe = 04, p < .002. However, with rotations of 180 degrees, the costs were almost non-existent (2 ms or 2.3%) for RTs, F(1, 19) = .37, MSe = 79.52, p > .5, or errors, F(1, 19) = 1.55, MSe = .005, p > .2.

Table 4b: *Experiment 3, response-priming and Event-file results. Reaction times, error rates and standard errors (in parentheses) for responses to S2 as a function of rotation, S1-S2 location- and response-repetition. Effect sizes to the right show response-priming effects and partial-repetition costs.*

	Location				Response Priming		Partial Repetition costs
	Repeated (R)		Alternated (A)		Loc. R	Loc. A	
Response	R	A	R	A	RA - RR	AA - AR	(RA-RR) - (AA-AR)
	Reaction times						
Static	381 (8)	436 (7)	416 (8)	386 (7)	54	-31	85
180°	395 (8)	404 (9)	393 (8)	398 (9)	8	6	3
360°	390 (9)	407 (9)	400 (7)	398 (9)	17	-3	20
	Error rates						
Static	1 (1)	19 (2)	14 (1)	4 (1)	18	-10	28
180°	8 (1)	10 (1)	7 (1)	6 (1)	2	-1	3
360°	6 (1)	8 (1)	10 (1)	6 (1)	2	-4	7

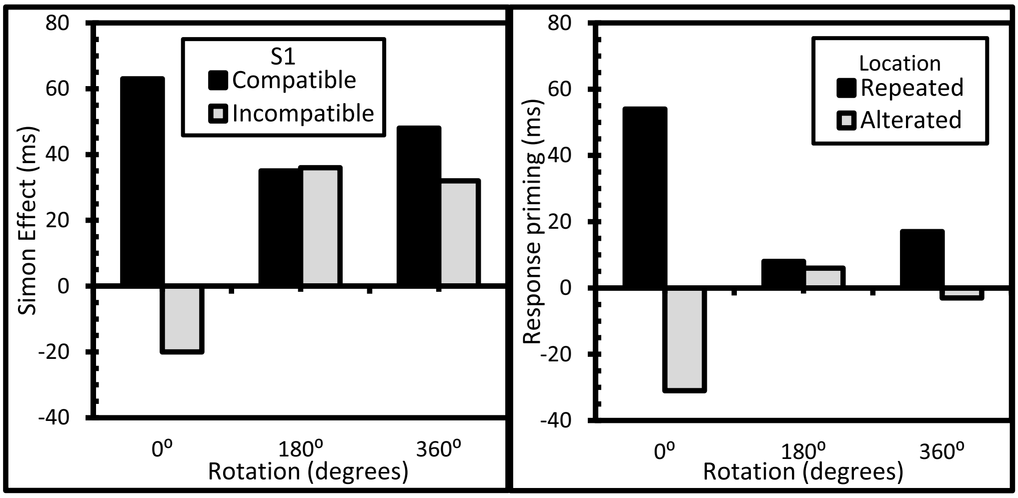

Figure 5: Results experiment 3: Effects of rotation on sequential Simon effects (left) and event-coding (right).

Discussion

The event-file analysis shows us that rotation in and of itself does not reduce binding cost. In Experiment 2, more degrees of rotation resulted in less partial-repetition costs, leading to the hypothesis that rotation itself might reduce binding. Experiment 3 falsified this hypothesis: only in the 180 degrees condition, the partial-repetition costs were completely eliminated, whereas in the 360 degrees, they were again present.

More importantly, the conflict-control analysis provides evidence that rotation itself does not eliminate conflict-control. If conflict-inducing stimuli rotated back to their original location, a normal – albeit smaller – conflict adaptation pattern emerged. The previous experiments show that there is ample reason for them to be smaller. For one, if the previous location of a stimulus leaves an episodic trace of both where the box *is* and where it *had been* (as suggested by Spapé & Hommel, in press), instances of the objects could have formed all around their axis. Since the object travelled via the opposite (180 degree) location to its former (360 or 0 degree) place, an instance of its 180 degree position may well have been created. Second, if a participant "lost track" halfway during the rotation – i.e. paying more attention to the fact that the boxes moved as such than where they actually landed – similar patterns as during the 180 degrees conditions would be found.

General discussion

Trial-to-trial modulations in response-conflict inducing tasks are commonly taken to reflect adaptive control processes. According to this idea, conflict is registered by conflict-monitoring control process, which then signal the enhancement of the amount of control exerted (Botvinick et al., 2001; Botvinick, 2007). If so, control processes would be more efficient in trials following conflict-inducing trials, a result pattern that has been reported for various sorts of conflict tasks. In keeping with these predictions and previous observations, we were able to replicate the finding that the Simon effect is strongly reduced after incompatible trials (cf. Stürmer et al., 2002; Wühr & Ansorge, 2005). However, this sequential modulation was eliminated altogether by rather simple manipulations of the visual display in between two stimulus presentations. From a control-theoretic view this is unexpected and difficult to explain without additional assumptions, whereas an episodic approach provides a straightforward interpretation of the obtained pattern.

We have suggested that carrying out a response to a stimulus leads to the integration of stimulus and response features (shape, stimulus location, and response location in our case) into an event file that is retrieved if at least one element of the file is repeated (Hommel, 1998, 2004). Following Kahneman et al. (1992) we have assumed that visual conditions that suggest that the object that contained a stimulus has moved to a different location induce the creation of a spatially updated file. The two present experiments provide evidence that this updated file also contains information about the response, so that the response in a sense travels with its object (Spapé & Hommel, in press). The experiments also provide evidence that the updated file does not flush or overwrite the previous file, and that both files can affect performance concurrently. In the 180-degree conditions of all three Experiments, the impact of the two files apparently canceled each other out but when assessed separately, as in the 90-degree condition of Experiment 2, both could be shown to have an effect.

What do our findings imply for the relationship between adaptive control mechanisms and episodic integration and retrieval effects? We think that two different answers to this question are possible and that it would be premature to decide between them at this point. The radical response would be to consider that all effects that have been assumed to reflect adaptive control mechanisms are artefacts of priming and integration processes. Indeed, there are more possible effects of that sort than proponents of control approaches have considered, ranging from simple repetition priming (Mayr et al., 2003) over feature integration and the partial-repetition costs they produce (Hommel et al., 2004) to effects of integrated competition (Duncan, 1996; Dutzi & Hommel, in press). Even though the basic characteristics of these types of processes are reasonably well understood, it is entirely unclear how they affect performance in the standard conflict tasks and the often rather complicated task versions that have been designed to minimize episodic effects. With respect to the present study, it is fair to say that our event-coding analyses are much easier and straightforward to interpret than the conflict-control analyses, and the latter are actually not needed to understand the data pattern we obtained. If so, it would be defendable to consider the reasoning underlying the conflict-control analyses as unnecessary theoretical overhead.

An alternative, less radical response could consider that adaptive control does take place and can indeed affect subsequent performance, but that the adaptations achieved by the respective control processes are entirely integrated into episodic event files. For instance, a given file may not only contain pointers to, or associations with codes of stimulus and response features but also information about association weights, that is, about how strongly each given stimulus feature is associated with, or predicts successful responses. There are several observations that are consistent with this scenario. For instance, event files are relatively liberal with regard to the precise timing relation between the stimuli and the responses they integrate, as long as the stimuli appear close to response execution (Hommel, 2005, 2007). This might suggest that the integration takes place vis-à-vis an evaluation of the response’s success and is informed by the outcome of this evaluation.

Consistent with that possibility is the observation that the partial-repetition costs that we attribute to event files are systematically affected by experimental manipulations impacting the current dopamine level: Partial-repetition costs are positively correlated with the spontaneous eye-blink rate, a marker of dopaminergic activity (Colzato, Van Wouwe & Hommel, 2007b); they increase if stimulus-response pairings are followed by task-irrelevant pictures with positive affective content (Colzato et al., 2007a), stimuli that are suspected to induce a phasic increase of the individual dopamine level (Ashby, Isen & Turken, 1999; Cohen, Braver & Brown, 2002); and they decrease in the case of stress, a condition that is known to induce an overproduction of dopamine (Colzato, Kool & Hommel, 2008). Given the evidence that phasic changes in the dopamine level are essential for success-controlled learning and stimulus-response integration (Schultz, 2002), these findings fit with the idea that the creation of event files is regulated by success. If we further assume that success triggers the integration of information about all processing aspects that were responsible for it and consider that the cognitive states underlying the efficient handling of response conflicts belong to those aspects, it makes sense to think that event files include control-relevant information. If so, some part of trial-to-trial modulations in conflict tasks may well reflect adaptive control processes and finding that these modulations are in a sense controlled by episodic retrieval does not necessarily imply a contradiction. This idea fits well with recent revisions of the conflict-monitoring hypothesis (Botvinick, 2007) that consider conflict as aversive stimuli that operate as teaching signals to avoid using the same selection of associated tasks and strategies. Indeed, if cognitive control operations would really be smart they should make sure that control-relevant information is stored in such a way that it will affect future performance in comparable situations only —that is, in situations that trigger the retrieval of episodic memories related to that situation.

Although this interpretation would be in line with the present results, current theorizing seems to restrict itself to the boundaries of either conflict-control or event-files whilst their possible interdependency is left to be accounted for. In contrast to Spapé & Hommel (2008) or Akçay & Hazeltine (2008), who found conflict-adaptation to be dependent on the context of the stimulus or the task, others (e.g. Notebaert & Soetens, 2003; Wendt, Kluwe & Peters, 2006) still found conflict-adaptation even when task-relevant features changed between trials, making the present state of affairs heterogeneous (or conflicting, if you will). Rather than arguing that the effects of sequential conflict effects are a by-product of stimulus/response-repetition or feature-integration as such, we feel that a framework that focuses on the interplay of control and episodic retrieval could provide the more adequate solution to this puzzle. One of the greater challenges, then, becomes to be able to predict which contextual discontinuities reduce episodic retrieval, thereby disrupting or preventing cognitive control and adaptation. By providing one example of this mechanism, future research must focus on re-integrating the fields of executive control with working memory.

To conclude, our findings suggest that sequential modulations of conflict effects, the bread-and-butter of adaptive-control approaches, are strongly dependent on episodic retrieval and disappear under conditions that make episodic retrieval unlikely. In any case, this suggests that sequential modulations cannot be taken to represent process-pure measures of adaptive control (cf., Hommel et al., 2004; Risko, Blais, Stolz & Besner, 2008). It is possible that they can be accounted for entirely in terms of proactive episodic effects but it may also be that control-relevant information is integrated into event files and retrieved only if the current situationis sufficiently similar to the situation in which the event file was originally created.