Back in control : the episodic retrieval of executive control

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CHAPTER 6: SEQUENTIAL EFFECTS IN THE SIMON TASK REFLECT EPISODIC RETRIEVAL BUT NOT CONFLICT ADAPTATION: EVIDENCE FROM LRP AND N2.

Behavioral and psychophysiological studies on the Simon effect have demonstrated that stimuli automatically activate spatially corresponding responses, even if their location is irrelevant to the task. Interestingly, this Simon effect is attenuated after stimulus-response incompatible trials (Gratton effect), a pattern that has often been attributed to online conflict adaptation, even though an account in terms of episodic binding and retrieval is just as plausible. Here we show that the sequential pattern can be eliminated and partly reversed by rotating the boxes in which stimuli are presented in between two given trials, a manipulation that is likely to affect episodic representation but not online control. Sequential modulations of electrophysiological indicators of automatic response priming were also eliminated (N2) or even reversed in sign (LRP), suggesting that sequential effects are due to episodic retrieval of stimulus-response bindings but not, or to an only negligible degree, to online adaptation.

Chapter 6: Sequential effects in the Simon task reflect episodic retrieval but not conflict adaptation: Evidence from LRP and N2.

Psychologists and philosophers alike have long wondered how humans achieve their intended goals in the face of distractions and temptations. To study the conflict between will and distraction, numerous conflict-inducing tasks have been developed: Stroop (1935) found that it is difficult to ignore color words while naming incongruent colors; Simon and colleagues observed that it is difficult to ignore the location of stimuli when carrying out a spatially defined response (Simon & Rudell, 1967); and Eriksen discovered that irrelevant flankers are difficult to ignore when responding to a central stimulus (Eriksen & Eriksen, 1974). Such effects have often been taken to demonstrate an *automatic* impact of stimuli of action control: stimuli sometimes seem to be able to evoke unwanted and interfering action tendencies against an agent's will.

At the same time, however, in none of these or other experimental tasks participants are enslaved to what stimuli tell them: even though it may take them a few more milliseconds to respond in the face of incongruent or incompatible stimuli, they are commonly able to do so. This suggests that voluntary and involuntary action tendencies compete, which has prompted researchers to conceive of action-control models that comprise of at least two processing routes—an automatic route that translates stimuli into habitually acquired or otherwise associated response tendencies and a voluntary route that makes sure that the intended action comes out as planned eventually (for a review, see Hommel, 2000).

There is general agreement that automatic routes are not entirely independent of the current intention. Seeing a color word, processing a stimulus location, and confronting a flanker stimulus does not always evoke action tendencies in people but they do so because particular experimental tasks provide a context that promotes processing of color, location, and flanker information. So

in some sense, automaticity is enabled by intentions, thus creating what one may call a prepared reflex (Hommel, 2000; Woodworth, 1938).

However, recent research suggests that automaticity may be under much tighter voluntary control than suggested by this scenario. Gratton, Coles, and Donchin (1992) found that the effect of irrelevant flankers is mediated by the congruence of flankers and targets in the previous trial: the delay of responding with incongruent as compared to congruent flankers (i.e., the flanker effect) was significantly reduced after an incongruent as compared to a congruent trial. This reduction was visible in both behavioral and electrophysiological observations. It is well-known that response-incompatible flankers activate a lateralized readiness potential (LRP) reflecting the flanker-related response (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985). This suggests that flankers indeed prime the response they are associated with. Most interestingly, however, Gratton et al. observed that these incorrect LRPs are also reduced after an incongruent trial.

Conditions with response conflict usually also induce an increase in the N2 component of the event-related potential (ERP) relative to conditions without conflict. This peak has a fronto-central scalp distribution, presumably a source in the anterior cingulate cortex (ACC), and a peak latency around 300-400 ms (Nieuwenhuis, Yeung, van den Wildenberg, Ridderinkhof, 2003; Sasaki, Gemba, Nambu, & Matsuzaki, 1993; Watanabe et al., 2002). It has been claimed to reflect a general process of inhibiting erroneous responses (Kok, Ramautar, de Ruiter, Band, & Ridderinkhof, 2004) or exerting cognitive control (Folstein & Van Petten, 2008). Based on such observations, Botvinick, Nystrom, Fissel, Carter, and Cohen (1999) have suggested a model in which the ACC is held responsible for continuously monitoring for the occurrence of response conflict. As soon as conflict is detected, an adaptive mechanism fine-tunes control processes, thus reducing the risk of running into conflict in the future. Later modifications of this conflict-monitoring

model describe conflict as an aversive stimulus (Botvinick, 2007) that triggers the avoidance of decision-making strategies that are likely to lead to its re-occurrence.

Stürmer, Leuthold, Soetens, Schröter, and Sommer (2001) have suggested that the presence of such an error-detection/resolution mechanism may explain trial-to-trial adaptation effects as observed by Gratton et al. (1992) and others. In their own study, Stürmer et al. (2001) demonstrated that the Simon effect, characterized by delayed responding to stimuli that spatially correspond to an alternative action (Simon & Rudell, 1967), is affected by manipulations of the probability of stimulus-response compatibility and by the compatibility of the previous trial. Similar to the observation of Gratton et al., Stürmer and colleagues found that, after incompatible trials, the Simon effect is smaller, absent, and sometimes (if compatible trials are more frequent) even reversed. These manipulations caused response-incompatible stimuli to induce an LRP for the incorrect response, resulting in an initial 'dip' in the LRP before peaking in the direction of the final response. Similar to the Simon effect, the amplitude of this 'dip' was reduced after incompatible trials and in blocks with a high probability of incompatible responses. Stürmer et al. suggest that these observations reflect a mechanism of error detection/resolution along the lines of Botvinick et al. (1999). Experiencing response conflict leads people to suppress the automatic processing route, so that information processed by this route impacts response selection to a lesser degree or not at all. As a consequence, response selection is driven by the intentional route only and irrelevant information no longer impairs (or facilitates) performance.

It should be noted that the findings of Stürmer et al. provide a more process-pure indication of the possibility that response conflict is online-controlled by intentions than flanker experiments do. Flanker effects are likely to have multiple causes: in part they seem to result from direct interactions between target

and flanker representations (stimulus conflict) and in part from interactions between the responses that are mapped onto targets and flankers (response conflict; e.g., Fournier, Scheffers, Coles, Adamson, & Villa Abad, 1997; Hommel, 1997; Rösler & Finger, 1993). In contrast, stimulus conflict can be excluded in the case of the Simon task (where there is no contradiction between any stimulus location and the relevant non-spatial stimulus feature), which leaves response conflict as the most likely culprit.

Episodic retrieval

Recent behavioral results have shed doubt as to whether sequential conflict studies truly demonstrate a mechanism of conflict-adaptation, however. Mayr, Awh and Laurey (2003) showed that Gratton et al.'s (1992) findings can also be accounted for without referring to any higher-order mechanisms, such as conflict monitoring. Mayr et al. point to the fact that sorting trials into those following flanker-target congruence versus incongruence induces a confound with (stimulus- and/or response-) priming effects, and that excluding the conditions in which stimuli and responses are repeated eliminates the adaptation-like effect. Hommel, Proctor, and Vu (2004) have made a similar argument for the Simon effect. They point out that there is independent evidence suggesting that stimulus features and responses are spontaneously integrated and bound into episodic memory traces (Hommel, 1998, 2004). These bindings have been shown to impair performance in subsequent trials if some features and/or the response are repeated while others alternate (partial repetitions), suggesting that repeating components of a binding leads to the retrieval of the whole binding, thereby inducing code conflict if repetitions are only partial. Again, sorting trials into those following compatible versus incompatible trials leads to a confound with partial-

repetition costs[5], which may account for parts or all of what looks like adaptation effects (Hommel et al., 2004).

Two different strategies have been applied to disentangle whether sequential effects in conflict tasks reflect true adaptation through cognitive control, an effect of stimulus-response binding, or a mixture of the two. Most authors advocate the use of only those conditions that are unaffected by binding processes. For instance, Akçay & Hazeltine (2007) restricted their analyses of trial-to-trial effects in the Simon task to trial transitions where not a single stimulus or response feature is repeated, and argued that this would avoid any contribution from binding-related effects.

Unfortunately, there are reasons to assume that even non-repetitions may be affected by binding (Dutzi & Hommel, 2009). Assume, for instance, the combination of stimulus S_b and R_y is encountered right after having processed S_a and R_x, and assume that the representations of S_a and R_x were bound on this occasion. Discriminating between the two stimuli and the two possible responses requires the code of S_b to outcompete the code of S_a and the code of R_y to outcompete the code of R_x. This process can be assumed to benefit from the

[5] 1. To see that, consider RT_{cC}, RT_{cI}, RT_{iC}, and RT_{iI} the means of reaction times in compatible trials after compatible trials, incompatible trials after compatible trials, compatible trials after incompatible trials, and incompatible trials after incompatible trials, respectively. The standard pattern that is interpreted to reflect adaptation is that the Simon effect after compatible trials (RT_{cI}-RT_{cC}) is larger than the Simon effect after incompatible trials (RT_{iI}-RT_{iC}). Now consider that partial repetitions of stimulus-response combinations (which are known to delay responding for reasons unrelated to control: Hommel, 1998) only occur in conditions where the compatibility in the present trials differs from the one in the previous trial. This would selectively increase RT_{cI} and RT_{iC}, and may thus mimic adaptation effects even in the absence of any control-related effects.

previously created binding between S_a and R_x: losses of S_a in its struggle against S_b would also weaken R_x in its struggle against R_y, and vice versa—a mechanism that Duncan (1996) has called integrated competition. In other words, the previous binding of stimulus and response components helps rejecting them in alternation trials. This means that binding and episodic retrieval can affect performance even if not a single stimulus or response feature is repeated, suggesting that confounds between binding effects and possible adaptation effects are impossible to avoid in principle.

Therefore, Spapé and Hommel (in press) suggested a different research strategy. Rather than trying to isolate possible contributions from binding and control, they sought for manipulations that strongly impact, and even eliminate trial-to-trial effects while being unlikely to have any bearing on control. In fact, Spapé and Hommel (in press) demonstrated that a seemingly minor modification of the visual background in between two trials is sufficient to eliminate adaptation-like sequential effects.

In the present study, we aimed to extend this observation to LRPs, that produced outcomes that hitherto were taken as particularly convincing support of control accounts. In a nutshell, we compared performance in what one may consider a standard Simon task with performance in an only slightly modified version of this task where the left and right box in which the targets appeared rotated in the intertrial interval. In the standard condition, we expected to replicate the observations of Stürmer et al. (2001): the Simon effect should be reduced in size or even disappear after incompatible trials in both RTs and LRPs.

Given that our minor manipulation is unlikely to affect any control process but, as we will argue, can be expected to affect binding processes, a control account is unable to explain any impact of this manipulation on sequential effects. However, merely showing some effect of any binding-related manipulation is not particularly revealing. Control researchers increasingly admit that binding does play

some role in attenuating conflict (e.g., Verguts & Notebaert, 2008) so that modulations of sequential effects may easily be attributed to the "binding portion" of these effects without invalidating the assumption of further "control portions". What would be more informative is the demonstration that sequential effects can be eliminated altogether or even reversed by means of exclusively binding-related manipulations. And this is what we aimed to achieve in the present study.

Aim of Present Study

To test whether sequential effects in the Simon task can be eliminated or even reversed in both reaction times and LRPs we combined the design of Spapé and Hommel (in press), who demonstrated such an effect in reaction times, with EEG recordings along the lines of Stürmer et al. (2001). Sequential effects were assessed by presenting pairs of trials of a rather standard Simon task. Participants responded to the shape of the visual stimuli by pressing a left versus right key, and the stimuli were presented randomly in the left or right of two boxes on a screen. For the sake of clarity, we will call the first stimulus of each pair S1 and the second stimulus S2. Not only did we expect the standard Simon effect—better performance if the location of the stimulus corresponds to the location of the response (i.e., with stimulus-response compatibility) than if it does not—but a sequential effect as well: the Simon effect should be reduced, absent, or even reversed after incompatible as compared to compatible trials. In our terminology, the Simon effect for S2 should be less pronounced after an incompatible as compared to a compatible S1 trial, and this was expected for both reaction times and LRPs (Stürmer et al., 2001).

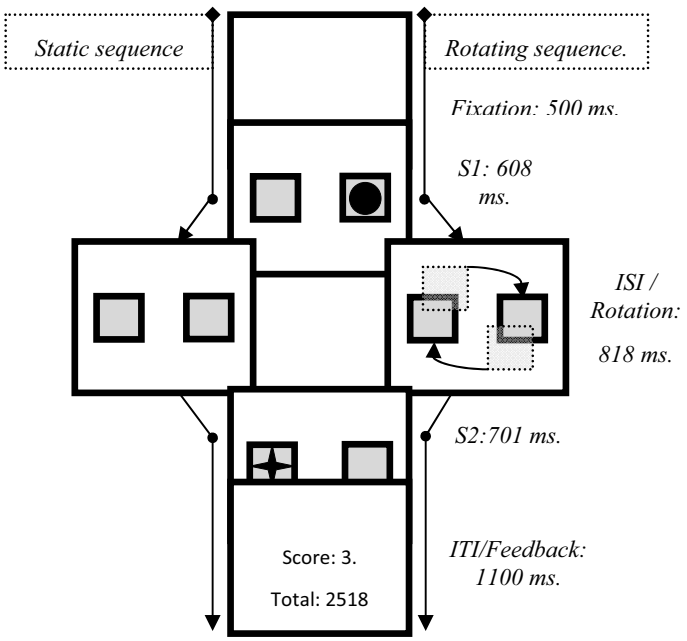

Figure 1: Schematic depiction of the trial-sequence of two example trials. After presenting a fixation crosshair, two boxes were presented for 500 ms in the left and right of the screen, one containing the shape (S1) to which participants were required to respond. In the "static" condition (left), an 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.

This replication was expected for what we will call the *static* condition, where the two boxes in which the stimuli appeared stayed on the screen in the same positions throughout the whole experiment. However, in another condition, the *rotation* condition, the boxes were gradually rotated 180^{o} around the screen center, as is schematically shown on the right branch of Figure 1, which led to the reversal of the two boxes. This rotation was taking place after the response to S1 was given and before S2 was presented, so that this manipulation should not have any effect on online conflict-monitoring in the sense of Botvinick et al. (1999) or

Stürmer et al. (2001). In contrast, a binding approach would lead one to expect an impact on sequential effects.

Let us consider, for example, that a participant responds to circles and stars by pressing a right and a left key, respectively. In the scenario shown in Figure 1, he or she might encounter a compatible S1 (location: right, response: right) followed by an incompatible S2 (location: right, response: left), which typically results in long reaction times and many errors on S2—according to control theories the result of a lack of suppression of the automatic route (e.g., Stürmer et al., 2001). However, according to binding-theories of attention (Treisman, 2000), the rotation would cause the binding representing the right circle to be updated, so that at the timepoint of S2 presentation it would refer to a left circle (Kahneman, Treisman & Gibbs, 1992). If sequential effects reflect the benefits and costs of the repetition and alternation of feature bindings (Hommel et al., 2004), this should produce one of two outcome patterns. On the one hand, it might be that S2 processing is affected by the updated binding only. In this case, one would expect a complete reversal of the pattern obtained in the static condition, as turning left into right, and vice versa, should render compatible transitions incompatible, and vice versa. On the other hand, it may also be that updating a binding does not overwrite the original binding altogether, so that S2 processing should reflect a mixture of compatible and incompatible transitions. As this mixture should be the same for all conditions, one would expect that sequential effects are eliminated in this condition. Indeed, this is the pattern that was observed by Spapé and Hommel (in press), who therefore preferred the mixture hypothesis. They were also able to demonstrate independent contributions from original and updated bindings with rotations of 90^{o}, which rules out the less theoretically interesting possibility that rotations simply erase existing bindings and/or the aftereffects of control processes.

Even though the elimination of sequential effects by means of control-unrelated manipulations provides a strong challenge of the control account of sequential effects, converging evidence seems necessary to provide positive support for the binding account. Given that the prediction of a behavioral null effect remains somewhat unsatisfactory in principle, we sought for more insights by using EEG recordings, especially with regard to the temporal dynamics of rotation-induced effects on response tendencies as measured by LRPs. We thus computed LRPs for all compatibility sequences as a function of rotation. In line with previous findings (for an overview, see Praamstra, 2007), we predicted activation of the incorrect response as a result of incompatibility. Following Stürmer et al. (2001), this "invalid" activation was expected to be reduced after incompatible trials in the static condition. Similarly, the N2 component was predicted to be greater for incompatible following compatible trials as compared to incompatible following incompatible trials. However, both effects were expected to be reduced or even reversed in sign in the rotation condition. In order to determine whether this could be due to proactive conflict-monitoring mechanisms (cf. Botvinick, 2007), we also analyzed the S1 stimulus-locked LRPs. If the conflict-monitoring mechanism would adapt during the rotation, this was predicted to reduce amplitudes of the LRPs collected during this time-frame. On the other hand, if the LRPs of rotating trials would not differ from those of static trials up until the S2 was presented, binding-retrieval mechanisms that were prompted by the onset of S2 could be considered as the responsible mechanism.

Method

Participants

Sixteen students from Leiden University voluntarily participated in this experiment for a small fee or course credits. During the analysis of the LRPs over all conditions, four participants showed no negative LRP during responses, implying

that their LRP was not diagnostic of motor priming, so they were left out from further analysis.

Apparatus and stimuli

Stimuli were presented on a flat-screen 17" CRT monitor in 800 x 600 pixel resolution and a refresh-rate of 120 Hz. A Pentium-IV 2.60 GHz PC running E-Prime 1.2 on Windows XP SP2 controlled stimulus-presentation and recorded reactions via serial response boxes mounted on the armrests, left and right of the participant. The visual boxes that contained the targets were gray (RGB value of 128, 128, 128), black-edged squares of 60 x 60 pixels or an approximate visual angle of 2.4° presented against a silver (RGB value of 191, 191, 191) background. The target also measured 60 x 60 pixels and was either a circle or a four-pointed star. Boxes were presented 180 pixels (approximately 7.3°) left and right from the center of the screen and kept at this distance during the gradual shifts in location.

EEG was recorded at 512 Hz from seven Ag/AgCl scalp electrodes, positioned on the Fz, FCz, Cz, CPz, Pz, C3 and C4 locations, mounted in an elastic cap, using the Biosemi Active Two recording system. Common Mode Sense and Driven Right Leg electrodes (see www.biosemi.com/faq/cms&drl.htm) were used for online grounding and as initial reference, but the signal was re-referenced to the average mastoid signal off-line. Bipolar recording from approximately 1 cm above and below the left eye, and 1 cm lateral of the outer canthi of the eyes provided vertical and horizontal electrooculograms (EOGs), respectively. EEG and EOG were passed through a low-cut filter of 0.10 Hz and corrected for eye-movements using the Gratton, Coles, & Donchin (1983) algorithm, after which they were passed through high-cut filters of 8 Hz (for LRPs) or 16 Hz (for N2). Trials with EEG or EOG artifacts were excluded from the calculation of average ERPs.

Procedure

As outlined in Figure 1, 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 approximately 606 ms, the targets disappeared. The empty boxes stayed on the screen for another 818 ms, either in the same position (the "static" condition) or being rotated around the screen center at a speed of approximately 4 degrees per 44 ms (the "rotated" condition). Then the second target (S2) was presented for 700 ms before a screen with feedback informed the participant about his or her performance. This last screen disappeared after 1100 ms and then the next trial started.

Participants were instructed to ignore the location of the stimuli but react to their shapes using their index fingers. Half of the participants were to press the left response key for stars and the right key for circles, whereas the other half received the opposite stimulus-response mapping. They were required to respond as quickly and accurately as possible and during the ITI they 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 trial-pairs) high score. Participants received a break after about every quarter of the trials. The experimented lasted about 100 minutes in total.

Design

Results were coded for S1 and S2 compatibility (vs. incompatibility) and rotation (static versus rotated). The design was fully balanced, with 18 blocks of 64

trials, which resulted from the orthogonal combination within blocks of the two S1 and S2 locations and shapes, and the two types and directions of rotation.

LRPs were calculated by averaging the differences between contralateral and ipsilateral ERP for left and right responses to S2. Magnitudes of *Gratton-dips* (after Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988) –thought to reflect the stimulus-induced activation of incorrect hand responses–were measured as the maximally positive local voltage between 100 and 200 ms. Effects of rotation on S1 response encoding were investigated by calculating LRPs for S1 and the average difference between static and rotating conditions in the time-window rotation was tested (i.e. between 604 and 1426 ms after S1 onset).

N2 amplitude was measured as the difference in Cz amplitude between S2 compatible and incompatible conditions, the onset and offset of which was measured as the negative area of the FCz, Cz and CPz electrodes between 232 and 356 ms. This window corresponded with the period of a significant (>4 SD of baseline activity) difference between the grand average ERPs of compatible and incompatible conditions.

Results

Responses with latencies below 50 ms and above 1000 ms were not considered, and all incorrect reactions to S1 or S2 were excluded from RT and ERP analyses. Few errors were made during S1 (M = 6.9%, SD = 2.3%) and S2 given correct response to S1 (M = 5.5%, SD = 2.7% of the remaining correct responses).

Behavioral Results

In repeated measures analyses of variance (ANOVAs) on the reaction times (RTs) and error percentages (error %) of S2, with rotation (vs static), S1 compatibility (vs incompatibility), and S2 compatibility (vs incompatibility), rotation did not significantly affect RTs, $p > .9$, or error %, $p > .08$. Neither did S1 compatibility reach significance for RTs, $p > .4$, or error %, $p > .09$. S2 compatible trials were significantly faster than S2 incompatible trials, $F(1, 11) = 54.22$, $p < .001$, but only marginally more accurate, $p = .05$. A significant S1 compatibility-by-S2 compatibility interaction for both RTs, $F(1, 11) = 80.83$, $p < 001$, and error %, $F(1, 11) = 23.03$, $p < .001$, revealed a substantial conflict-adaptation effect. After compatible trials, participants were 52 ms slower and 4% more often incorrect with incompatible S2s, but after incompatible trials, a compatibility effect of only 9 ms and 0% errors was found. This conflict adaptation pattern was significantly modulated by rotation for both RTs, $F(1, 11) = 79.89$, $p < .001$, and error %, $F(1, 11) = 47.42$, $p < .001$. The conflict-adaptation pattern of some 89 ms / 8.3 % that was found under static conditions (see Table 1 for calculus), broke down after rotation to values of -4 ms / -0.4%. Two ANOVAs testing the static and rotating conditions separately revealed that the S1-by-S2 compatibility interaction was only significant for RTs, $F (1, 11) = 111.43$, $p < .001$ and for error % $F(1, 11) = 37.51$, $p < .001$, of static conditions, but not for RTs, $p > .4$ or error %, $p > .7$, of rotating conditions.

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

Reaction Times (ms)

		S2 Compatible	*S2 Incompatible*	*Simon Effect*	*Conflict Adaptation*
Static	*S1 Compatible*	341 (9)	411 (11)	70	
	S1 Incompatible	381 (10)	362 (9)	-19	89
Rotating	*S1 Compatible*	356 (9)	390 (10)	34	
	S1 Incompatible	355 (9)	393 (10)	38	-4

Error rates (%)

		S2 Compatible	*S2 Incompatible*	*Simon Effect*	*Conflict Adaptation*
Static	*S1 Compatible*	9.3 (0.3)	12.3 (3.0)	4.0	
	S1 Incompatible	6.3 (0.9)	2.0 (1.0)	-4.3	8.3
Rotating	*S1 Compatible*	2.5 (0.5)	6.6 (1.7)	4.1	
	S1 Incompatible	2.0 (0.5)	5.7 (1.2)	3.7	-0.4

S2 EEG Results

In repeated measures ANOVAs on the LRP Gratton-dip magnitude with S1 compatibility, S2 compatibility and rotation as factors, neither rotation nor S1 compatibility produced a significant main effect, *p*s > .8. However, S2 compatibility strongly affected the Gratton-dip magnitude, $F(1, 11) = 39.78$, $p < .001$. Incompatible trials showed activations of the incorrect hand of ca. 1.4 µV compared to compatible trials. S1 compatibility did not interact significantly with S2 compatibility, $p > .9$. This appeared to be due to the interaction with the rotation factor, as evidenced by a significant three-way interaction with rotation, $F(1, 11) = 13.46$, $p < .004$. It indicated a change in sign for the static conflict adaptation (tested with a separate ANOVA as $F(1, 11) = 3.90$, $p = .08$) versus

rotating conflict adaptation (separate ANOVA F(1, 11) = 11.40, p < .01). That is, in the static condition, the Gratton-dips were reduced after incompatible trials by 0.8 µV (compare the two upper panels in Figure 2), whereas in the rotated condition, the dips *increased* by 0.8 µV (compare the two lower panels in 2).

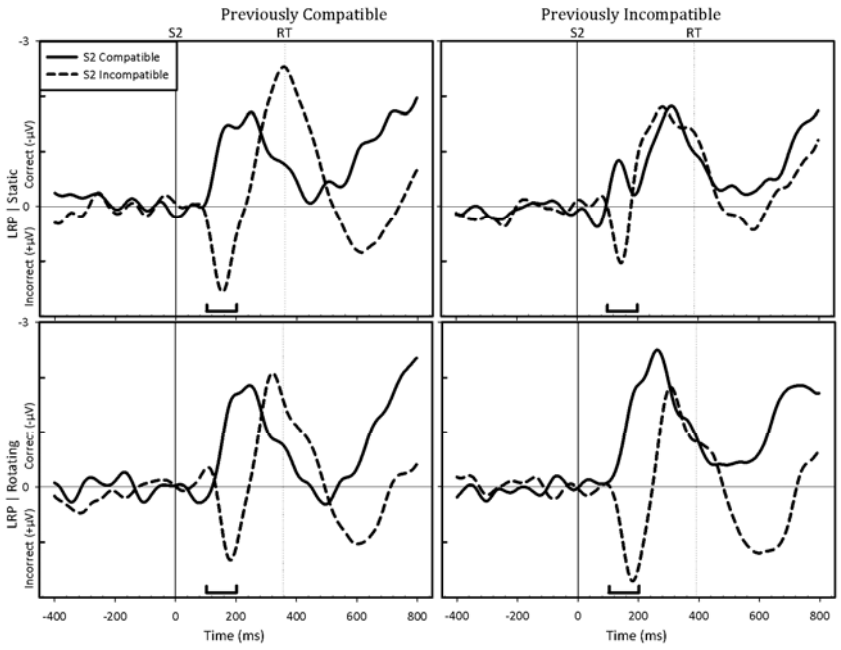

Fig. 2: Effect of current (S2) compatibility on the LRP as a function of preceding (S1) compatibility. Reaction times (RT) are averaged across the two conditions in each panel. Horizontal lines show latency where initial 'incorrect' activation – or, 'Gratton dip' – of the LRP was detected.

Further ANOVAs on the Cz mean amplitude of the N2 (computed as the difference between incompatible and compatible S2s) with S1 compatibility and rotation as factors showed that S1 compatibility decreased mean N2 activity, F(1, 11) = 34.48, p < .001. Rotation itself did not have a significant effect, p > .5, but did interact with S1 compatibility, F(1, 11) = 23.73, p < .001. We conducted two post-hoc tests to better understand this interaction. In post-hoc comparisons between

the S1 compatible and incompatible conditions, the difference was shown to be strongly present in static conditions, $t(11) = 5.61$, $p < .001$, but not significantly in rotating conditions, $t(11) = -1.10$, $p > .2$. That is, in static trials, following incompatible S1s, the N2 difference changed sign (compatible showed larger N2 amplitudes than incompatible trials), whilst in rotating trials, no such change was present. Another set of post-hoc comparisons, now between the static and rotation conditions, revealed that there was no significant difference between the S1 compatible conditions, $t(11) = -1.64$, $p > .1$, but only between the S1 incompatible conditions, $t(11) = 4.10$, $p < .005$. Thus, the difference between static and rotation in N2 magnitude was only found after incompatible conditions. Table 2 shows that these results in the N2 component based on the Cz measurements were generally similar in the other midline (FCz, CPz) electrodes.

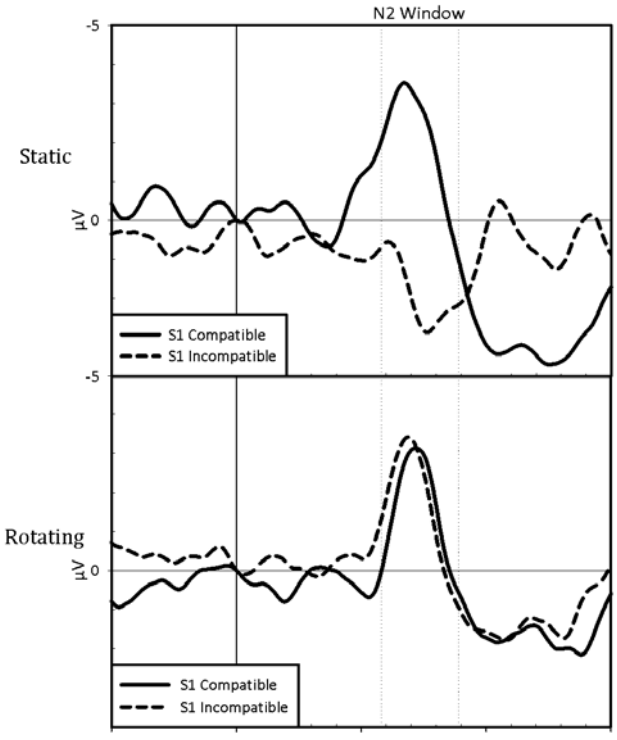

Fig. 3: Results experiment 1: N2 difference waves over Cz (subtraction of compatible from incompatible conditions) as a function of preceding compatibility and rotation.

Table 2: ERP results*. Average effect sizes for lateralized readiness potential (LRP) and the N2 effect for individual electrodes, stimulus-locked to the second stimulus (S2). Gratton Dip refers to the positive peak in the LRP at ca. 150 ms after stimulus, which is thought to be associated with the automatic (i.e. location-based) activation of the response. N2 voltages were calculated as the difference between compatible and incompatible conditions in mean amplitude of the FCz, Cz and CPz electrodes between 232 and 356 ms after S2 onset. Effect of conflict adaptation was measured as the difference in compatibility as a function of preceding compatibility for both rotating and static conditions. Difference shows the results of post-hoc comparisons between the static and rotation conditions, adjusted for the number of tests (Bonferroni), in terms of significance.*

		Simon Effect (I - C) after		*Conflict Adaptation*
LRP	*Rotation*	*Compatible*	*Incompatible*	*Conflict after C - I*
Gratton Dip Magnitude	*Static*	1.7	0.9	0.8
(μV)	*Rotating*	1.1	1.9	-0.8
	Difference	*ns*	*	**
		N2 (I - C) component after		
N2		*Compatible*	*Incompatible*	*N2 after C-I*
Mean Amplitude FCz (μV)	*Static*	-1.2	1.7	-2.9
	Rotating	-0.8	-0.7	-0.1
	Difference	*ns*	*	**
Mean Amplitude Cz (μV)	*Static*	-2.6	1.4	-4.0
	Rotating	-1.0	-0.8	-0.2
	Difference	*ns*	**	**
Mean Amplitude CPz (μV)	*Static*	-2.8	1.1	-3.9
	Rotating	-1.9	-1.5	-0.4
	Difference	*ns*	**	**

*ns: not significant, *: p < .05, **: p< .01*

S1 ERP Results

A repeated measures ANOVA on the averaged LRP waveform between 604 (rotation onset) and 1426 (rotation offset) with S1 compatibility and rotation as factors revealed that after incompatible S1s, the incorrect response became more activated, $F(1, 11) = 10.52$, $p < .01$, in a manner best described as an 'echo' of the Gratton-dip caused by S1. More importantly, rotation did not affect LRP, $p > .4$, nor did it interact with compatibility, $p > .4$.

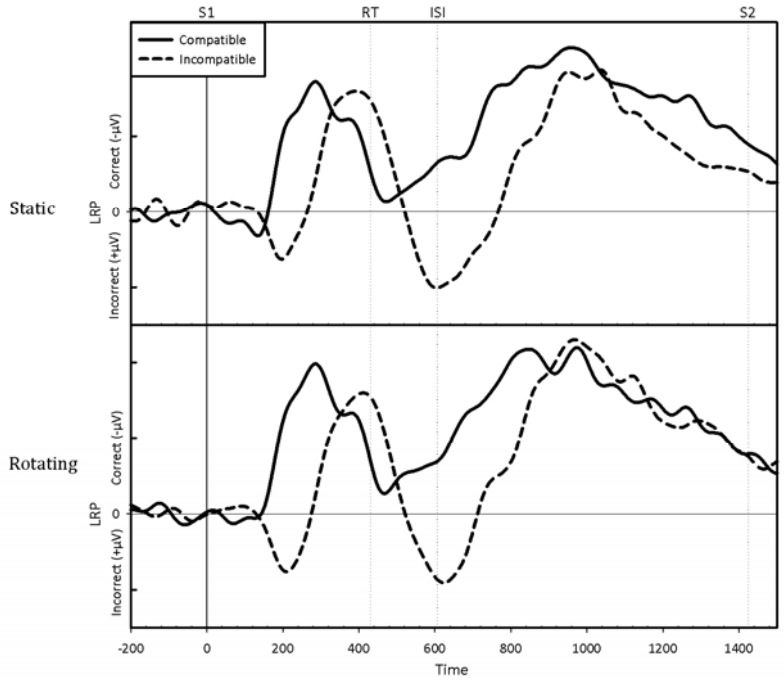

Fig. 4: Results experiment 2: Effects of rotation and compatibility on the LRP of the first stimulus (S1).

Discussion

The aim of this study was to test whether what looks like effects of control might be due to the impact of previously created stimulus-response bindings on present performance. We argued that if the sequential effects that are taken to diagnose the impact of control could be eliminated entirely, and perhaps even reversed in sign, by means of a manipulation that is arguably unrelated to any control process; this would provide strong evidence for a binding approach to sequential effects. We applied this logic to the Simon task that was previously demonstrated to produce particularly strong sequential effects in both reaction times and LRPs. We attempted to replicate these previous findings in our static condition and, indeed, the standard patterns were obtained: notably, the Simon effect was reduced after incompatible trials, as witnessed by reduced reaction time effects and less stimulus-induced activation of incorrect responses as indexed by LRPs (e.g., Stürmer et al., 2001).

Not so for rotating conditions however: Closely replicating the behavioral observations of Spapé and Hommel (in press), conflict-adaptation patterns disappeared in the rotation condition. As the electrophysiological findings demonstrate, this was not due to the overwriting of control effects or the flushing of control systems (Logan & Gordon, 2001). Rather than just disappearing in the rotation condition, the 'incorrect' parts of the LRP that are commonly taken to indicate the automatic, stimulus-induced activation of responses was strongly affected.

A control account would need to explain why a task-unrelated rotation would suddenly make nonconflicting stimuli to activate incorrect responses. As this seems rather difficult and counterintuitive, we suggest attributing the impact of trial transitions on LRPs to binding effects entirely. As pointed out by Hommel et al. (2004) and explained in footnote 1, what looks like adaptation effects may also

result from a confound with sequential effects and the repetition versus alternation of stimulus and response aspects. In particular, stimulus and response features may be bound upon S1 processing and the resulting bindings be automatically retrieved upon S2 processing (Hommel, 2004). If the combination of stimulus and response features is the same in both trials, or if no feature overlaps, performance is unimpaired or even facilitated, but with partial overlap, code conflict occurs and performance suffers (Hommel, 1998).

In the rotation condition, bindings are updated to reflect the spatial change (Kahneman et al., 1992; Zacks et al., 2007), so that "left" codes become "right" codes, and vice versa. This change can account for the reversals we have seen in the LRP data. However, the overall pattern including the behavioral data does not look like a complete reversal, confirming the claim of Spapé and Hommel (in press) that overt performance on S2 is affected by both the original (not-updated) binding and the updated binding, resulting in a mixture of effects ranging from elimination to reversal. Whether and how the two bindings interact, how strong their relative contribution to present performance is, and whether this relative strength depends on context and task requirements, remains to be determined. As long as this is so, it seems logically impossible to exclude contributions from control in principle. More detailed and more quantitative predictions from both binding and control approaches would be necessary to conclusively decide on this issue. We do emphasize, however, that none of our findings is predicted by a control approach and that our outcome does not leave much space, if any, for contributions from control processes to sequential effects.