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Response execution, selection, or activation: What is sufficient for response-related repetition effects under task shifting?

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Abstract Repetition effects are often helpful in revealing information about mental structures and processes. Usually, positive effects have been observed when the stimuli or responses are repeated. However, in task shift studies it has also been found that response repetitions can produce negative effects if the task shifts. Although several mechanisms have been proposed to account for this interaction between task shifting and response repetition, many details remain open. Therefore, a series of four experiments was conducted to answer two questions. First, are motor responses necessary to produce response-related repetition effects, or is response activation sufficient? Second, does the risk of an accidental re-execution of the last response affect the repetition costs? The results show that response activation alone can produce repetition effects. Furthermore, the risk of accidental response re-execution largely modulates these effects.

Introduction

Much research in cognitive psychology is concerned with mental structures and processes involved in the performance of simple reactive tasks. Usually, these tasks consist of the selection of a response for a given stimulus according to a pre-specified stimulus–response mapping. That is, the participants have to learn the stimulus–response mapping by instruction. From this perspective, a crucial question is which mental representations and processes are involved in the response selection process. Since these components cannot be observed directly, they have to be inferred from observable effects. Among the effects that seem to be helpful in this respect are so-called *repetition effects*, which were investigated systematically for the first time by Bertelson (1963). He and others (e.g., Bertelson, 1965; Campbell & Proctor, 1993; Pashler & Baylis, 1991; Rabbitt, 1968; Smith, 1968) found that response times are faster in stimulus repetition trials than in stimulus shift trials. However, when a stimulus repeats, the response usually repeats too. Therefore, an important further question concerns the effect of response repetitions. Unfortunately, early attempts to separate the effects of stimulus and response repetitions led to inconclusive results (e.g., Bertelson, 1965; Peeke & Stone, 1972; Rabbitt, 1968; Smith, 1968).

Recently, the investigation of repetition effects has gained further interest in the area of task shift studies, where participants had to shift between different tasks across trials. For instance, numerals were used as stimuli for which parity and magnitude judgments were required as tasks (e.g., Hübner, Futterer, & Steinhauser, 2001; Rogers & Monsell, 1995). Although the main purpose of such studies was to examine task repetition effects, response repetitions have also been considered. Especially interesting in this respect is the interaction between task repetition and response repetition, which was first observed by Rogers and Monsell. Whereas response repetitions produced an advantage in task repetition trials, they had negative effects in task shift trials. Meanwhile, this interaction has been replicated several times (e.g., Kleinsorge, 1999; Meiran, 2000a, 2005; Schuch & Koch, 2004), and also holds true for the auditory modality (Quinlan, 1999). The origin of this interaction, though, is still unclear. Therefore, the aim of the present paper is to determine some of the relevant conditions for this interaction to occur.

In their seminal paper Rogers and Monsell (1995) considered several mechanisms that might account for the interaction between response repetition and task shifting. One account is based on a learning mechanism and has been further elaborated by Meiran (2000a, 2000b). If we again consider magnitude and parity

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judgments as tasks and assume that ''even'' and ''less than five'' are mapped onto one response, whereas ''odd'' and ''greater than five'' are assigned to another response, then, according to this account, the association between the response and the task-relevant stimulus category (e.g., ''even'') is strengthened, while at the same time the association of the response with the task-irrelevant stimulus category (e.g., ''less than five'') is weakened. In the next trial, the strengthening of such category response associations speeds up responding when the same stimulus category is used again to select the response. In case of a task shift, however, a response repetition implies that the same response has to be selected via a different stimulus category, whose association with the required response had been weakened in the previous trial, which explains the costs. Obviously, this strengthening mechanism is not shift-specific, that is, learning takes place in task repetition as well as in task shift trials.

A rather similar idea has been proposed by Hommel (1998b). He supposed that, after responding, stimulus and response features are bound together (see also Hommel, Müsseler, Aschersleben, & Prinz, 2001). Thus, if the same response is required again in a task shift trial, this binding has to be overcome, which results in costs. Similarly, Schuch and Koch (2004) assume that the meaning of the response changes with the task. For instance, a response might mean ''odd'' for the parity task, but ''greater than five'' for the magnitude task. There are costs if a response was selected within one task context and then has to be reselected under a different task context as its meaning has to be changed. Since all of these ideas are rather similar, we will consider all of them as *strengthening* accounts.

If we assume such a strengthening of the associations between stimulus categories and responses, then this might increase the risk of an accidental re-execution of the last response. Therefore, a mechanism would be required in order to prevent such false responses. Rogers and Monsell (1995), for instance, discuss a monitoring mechanism that checks whether the planned response is the same as the previous one and, if so, initiates a more thorough stimulus analysis to increase the reliability of the response selection process. A simpler mechanism, resulting in a similar effect, would be to generally suppress responses after their execution (Smith, 1968). We will refer to these theoretical positions as *response suppression* accounts. It predicts costs for response repetitions in all situations. These costs, however, can be outweighed by benefits resulting from stimulus category repetitions in task repetition trials.

The mechanisms considered so far are not task shift specific. That is, they are presumably in operation irrespective of the actual task conditions. It is also conceivable, however, that response repetition costs are due to mechanisms that are active only in task shift trials. For instance, in order to accomplish a task shift, it might be necessary to suppress all activations related to the old task, including the last response (Rogers & Monsell, 1995). Kleinsorge (1999) and Kleinsorge and Heuer (1999) proposed such a mechanism. They assumed that task shifting leads to a reconfiguration of the mental system according to the new task. Since this reconfiguration runs from the top-level task representation to the lower order task dimensions, including the response, it also results in a shifted response configuration in which the opposite response relative to the last one is in a prepared state. Consequently, if the same response is required again with a new task, re-reconfiguration of the response is necessary, which produces response repetition costs.

Obviously, although these accounts differ in some respect, they can all explain the interaction between task shifting and response repetition (Rogers & Monsell, 1995). At the same time, however, it is difficult to differentiate between them empirically. One reason is that the exact conditions producing or modulating the fresponse repetition effects are still largely unknown. One important question, for instance, is whether response execution is actually necessary or whether response *activation* is sufficient in order to produce response repetition effects. Some of the strengthening accounts explicitly assume that a response or at least response selection is needed (e.g., Meiran, 2000a, 2000b; Schuch & Koch, 2004). The same presumably also holds true for the reconfiguration model (Kleinsorge, 1999; Kleinsorge & Heuer, 1999), or the monitoring account (Rogers & Monsell, 1995), as it would be plausible to assume that at least response selection is needed in trial *n–1* in order to shift the response in trial *n*.

A further relevant aspect regarding the present study concerns the risk of accidentally re-executing the last response. Both the strengthening as well as the reconfiguration accounts do not consider this aspect. According to these views the repetition effects are either due to learning or to a specific reconfiguration mechanism and do not depend on any current risk. However, it is reasonable to assume that the risk of erroneous response repetitions strongly affects the repetition effects. If this should indeed be the case, then it might shed some light on the relevant processes involved in producing these effects.

In the present paper we will report a series of four experiments in which these questions were investigated. As methods we applied the PRP (Psychological Refractory Period) paradigm (Pashler, 1984; Welford, 1952), and the change paradigm (Logan, 1985; Logan & Burkell, 1986). In the PRP paradigm, two temporally overlapping tasks, T_1 and T_2, have to be performed in short succession for the consecutive stimuli, S_1 and S_2, respectively. This paradigm has already been used for the investigation of response repetition effects under task repetition and task shift conditions (e.g., Lien, Schweickert, & Proctor, 2003; Schuch & Koch, 2004). At first sight, this may seem surprising because different effectors (e.g., left and right hand) are usually used for responding to the individual tasks. Consequently, literal response repetitions are not possible. However, as has already been shown (e.g., Schuch & Koch, 2004), analogous repetition effects occur even when subsequent motor responses are different, but associated with the same response *category*. This suggests that response categories such as "left" and "right" are represented mentally and that response repetition effects also arise at this level (Campbell & Proctor, 1993). In other words, whether the same effector or different effectors associated with the same response category are used for responding seems to have only minor consequences with regard to the repetition effects. Thus, for convenience, we will continue to use the expression "response repetition," even when it actually means the subsequent execution of different responses associated with the same response category.

Due to the variable stimulus onset asynchrony (SOA) between S_1 and S_2, repetition effects can be observed depending on the degree of the temporal overlap between tasks. This is especially interesting with regard to the change paradigm (Logan, 1994; Logan & Burkell, 1986), which is similar to the PRP paradigm, except that S_2 does not appear in all trials. In those trials in which S_2 does show up, however, participants have to stop the processing of S_1 and to start immediately with the processing of S_2. It is supposed that, until S_2 appears, S_1 is processed as in a comparable PRP situation. By applying this method, it can be investigated whether a response or response selection is necessary for repetition effects to emerge. If this is not the case, then the repetition effects can be examined depending on the SOA, i.e., on the already accumulated degree of response activation. The change paradigm was applied in Experiments 2 and 4.

In our first experiment we used the PRP paradigm. One goal of this experiment was to replicate the interaction between task shifting and response repetition. At the same time it was planned as a control experiment for Experiment 2, in which the change task was applied under otherwise identical conditions.

The risk of accidentally re-executing the last response was varied across experiments. This objective was achieved by employing stimuli of different valence. The reasoning was as follows: In cases of *bivalent* stimuli, i.e., stimuli that can be evaluated according to both tasks, the risk of accidentally re-executing the same response as before is increased due to the fact that the respective stimulus category of the actually irrelevant task may also activate this response again. That is, there can be *two* sources of erroneous response activation in this case: First, activation left over from the previous task and second, activation due to the respective stimulus category of the actually irrelevant task. Consequently, bivalent stimuli also increase the risk of reselecting the old response. The situation is different, however, with *univalent* stimuli. In this case there is only the residual activation of the response categories from the previous task that affects the response in the current trial.

Thus, summarizing, two questions will be the main focus of this study: First, is it necessary for a response for a given task to be selected and executed in order to produce subsequent response repetition effects, or is response activation sufficient? This question should be answered by applying the change paradigm (Experiments 2 and 4) and by comparing the results with those from the PRP paradigm (Experiments 1 and 3). Second, does the risk of accidental response re-executions affect the response repetition effects? This question was investigated by applying stimuli of different valence (bivalent stimuli in Experiments 1 and 2; univalent stimuli in Experiments 3 and 4) and by comparing the results of the respective PRP experiments and change experiments.

Experiment 1

In this experiment the PRP procedure was applied. Although it has already been shown that response repetition also interacts with task shifting in this paradigm (e.g., Schuch & Koch, 2004), the result should be replicated under the specific conditions realized here. For Experiment 2, in which the change paradigm was applied, it was necessary to include trials in which no S_2 appeared. Therefore, we used a similar procedure in the present experiment in order to obtain comparable conditions, i.e., 50% of the trials were single task trials in which only S_1 appeared.

An important factor for the objective of the present study was whether the response repeated or shifted. This factor corresponds to the congruency relation between S_1 and S_2. If both stimuli were congruent, i.e., required the same response, there was a response repetition. Because S_2 appeared in dual task trials while response selection for R_1 was still in progress, this congruency relation might also affect R_1. Therefore, we will also consider the congruency of S_2 as a factor for R_1. S_2 was congruent if it activated the same response category for T_2 as S_1 for T_1.

Since parity and magnitude judgments were used as tasks, the numerals that served as stimuli for both judgment types were bivalent. Consequently, each stimulus could also be congruent or incongruent within itself, i.e., activate the same or different response categories with regard to the two judgment types. This within-stimulus congruency offered the possibility of testing whether the potential response suppression account is adaptive.

Assume that a response is generally suppressed after its execution. The question is then whether the degree of suppression also depends on the amount of previous activation. If this is the case, then the suppression should be stronger after a response to a congruent stimulus than after a response to an incongruent one, because the congruent stimulus leads to a larger activation of the response. Thus, under task shifting, we would expect larger response repetition costs in trials with a congruent S_1 than in those with an incongruent S_1. Likewise, under task repetition, the response repetition benefit should be smaller in trials with a congruent S_1 than in those with an incongruent S_1. Regarding the other accounts, it is not quite clear which effects of the within-stimulus congruency of S_1 on the response repetition effects they would predict. This certainly depends on several additional assumptions about the details.

Finally, in addition to these factors, the effects of task shifting and SOA were considered. For the latter factors we expect the usual results, that is, task shift costs and a PRP effect for R_2.

Method

Participants

Ten students (all women) from the Universität Konstanz participated in this experiment either for partial fulfillment of course requirements or for payment of 5 Euros an hour. The ages of the participants ranged from 19 to 26 years (mean = 21.7 years). All reported normal or corrected-to-normal vision and were reported being right-handed. Furthermore, the participants had not taken part in any similar experiments before.

Apparatus and stimuli

Stimulus presentation and response recording were controlled by an IBM-compatible PC. The stimuli were presented on a 21-inch color monitor (Sony 500 PS) with a resolution of 1,280 × 768 pixels and a refresh rate of 85 Hz. The digits 1–4 and 6–9 served as stimuli. They were presented in white on a black background and subtended a visual angle of 2° in height and approximately 1.36° in width (depending on the individual stimuli) at a viewing distance of 110 cm. S_1 was always presented in the center of the screen and S_2 appeared as flankers to the left and right of S_1 at an eccentricity of approximately 1.18° visual angle.

Procedure

Depending on the actual condition, participants had to judge either parity (odd/even) or magnitude (less/greater than five) of the stimuli presented. Responses to S_1 and S_2 had to be given with the left and right hand respectively. The buttons of two serial PC mice served as response keys, whereby the relative mapping for each judgment was the same for both hands: "Even" and "less than five" were mapped to the left buttons, whereas "odd" and "greater than five" required pressing the right buttons.

A trial started with the presentation of a cue for 400 ms at the center of the screen. This cue indicated which judgment type was relevant for S_1. The cues could have one of two forms: "g/u" (abbreviations of the German words "gerade/ungerade"), indicating the parity judgment, and "k/g" (abbreviations of the German words "kleiner/grösser"), indicating the magnitude judgment. After cue presentation a blank screen appeared for 600 ms, followed by S_1. A second stimulus (S_2) occurred in 50% of the trials and was presented at a variable SOA of 50, 150, 250, or 350 ms. S_1 and, if presented, S_2 remained on the screen until participants responded. Immediately after the last response the stimuli disappeared and were followed by a blank screen for 1,000 ms until the presentation of the next cue. Stimulus repetitions for T_1 and T_2 were not allowed.

There were four different task sequence conditions within a trial, realized in two different types of experimental blocks. Half of the blocks were *task repetition* blocks, i.e., the judgment type was the same for T_1 and T_2. In the other half of the blocks S_1 had to be evaluated according to the cued judgment and S_2 according to the other judgment (*task shift* blocks). The two types of blocks alternated, half of the participants starting with a task repetition block and the other half starting with a task shift block. All participants ran through 16 experimental blocks comprising 112 trials each. At a first session three practice blocks were followed by six experimental blocks. The remaining 10 experimental blocks were administered in a second session.

Results

Separate analyses of variance (ANOVAs) were computed for single task and dual task trials. Within the dual task condition, RT_1 and RT_2 were examined individually.

Single task trials

The latencies of correct responses and the error rates were subjected to one-way ANOVAs with the repeated measure factor *block type* (task repetition, task shift). The analysis of the response times revealed a significant effect for block type, $F(1,9) = 7.19$, $p < .05$. Responses in task repetition blocks were faster than those in task shift blocks (535 vs. 558 ms respectively).

The same analysis for the error rates revealed no significant effect.

Dual task trials

The data for R_1 in dual task trials were analyzed by three-way ANOVAs for repeated measures with the factors *block type* (task repetition, task shift), *response congruency* (congruent, incongruent), and *SOA* (50, 150, 250, and 350 ms). For the analysis of the R_2 data the factor *response type* (response repetition, response shift) was used instead of response congruency.

RT_1 The analysis revealed a significant main effect of block type, $F(1,9) = 26.06$, $p < .001$. Responses in task repetition blocks were 69 ms faster than in task shift

blocks. Furthermore, SOA had a significant effect, $F(3,27) = 30.48$, $p < .001$. However, the main effect of SOA was qualified by a two-way interaction of SOA and congruency, $F(3,27) = 9.16$, $p < .001$. This interaction is due to the fact that at the SOAs of 50, 150 and 250 ms, congruent S_2 led to faster responses than incongruent ones (34, 33, and 22 ms at the individual SOAs respectively). At the SOA of 350 ms, however, the effect was reversed by 25 ms.

Error rates The analysis of the error rates for R_1 revealed no significant effects.

RT_2 The main analysis of the response times revealed a significant main effect of block type, $F(1,9) = 46.04$, $p < .001$. RT_2 was slower in task shift blocks than in task repetition blocks (1,094 vs. 800 ms). Furthermore, the main effect of SOA was reliable, $F(3, 27) = 92.91$, $p < .001$. As can be seen in Fig. 1, this reflects a PRP effect, i.e., the latencies decreased with increasing SOA.

The main effect of response type was also reliable, $F(1,9) = 6.64$, $p < .05$. However, there was a significant interaction between response type and block type, $F(1,9) = 14.79$, $p < .01$. This effect is due to the fact that in task repetition blocks, response repetitions led to a benefit relative to response shifts (779 vs. 820 ms), whereas the opposite held true in task shift blocks (1,138 vs. 1,049 ms). This result is also shown in Fig. 1. Furthermore, there was a significant two-way interaction between SOA and response type, $F(3,27) = 9.18$, $p < .001$. It indicates that there was an overall response repetition benefit at the two shorter SOAs, but a disadvantage at the longer SOAs.

Given these interactions, separate comparisons for each block type were calculated. For the task repetition blocks they revealed a significant interaction between response type, and SOA, $F(3, 27) = 7.26$, $p < .01$. As can be seen in Fig. 1, the repetition effect was absent for the two longest SOAs. The analogous interaction for the task shift data was also significant, $F(3, 27) = 5.60$, $p < .01$. Here, however, it indicates that the repetition costs were larger for the two longest SOAs.

Error rates The error rates for R_2 show similar patterns to the response times. There was a main effect of block type, $F(1,9) = 17.12$, $p < .01$, indicating a higher error rate in task shift blocks compared with task repetition blocks (10.75 vs. 5.84%). The factor response type was also significant, $F(1,9) = 49.77$, $p < .001$. This indicates that participants made more errors when they should have repeated the response than when they should have shifted it (12.24 vs. 4.35%). Finally, the effect of SOA was reliable, $F(3,27) = 7.57$, $p < .01$, indicating a slight overall increase in error rate with increasing SOA (6.66, 7.37, 8.66, and 10.48%, at the individual SOAs from 50 to 350 ms respectively).

Furthermore, both interactions involving response type were reliable: First, the interaction of block type and response type was significant, $F(1,9) = 33.17$, $p < .001$. This interaction was due to an increased error rate under task shifting when the response should have been repeated relative to when it should have been shifted (17.90 vs. 3.59%). The corresponding error rates in task repetition blocks were 6.57 and 5.11%. Second, the interaction between SOA and response type was also significant, $F(3,27) = 4.24$, $p < .05$.

Separate analyses for the individual block types revealed a significant interaction between response repetition and SOA for the task repetition condition, $F(3,27) = 3.40$, $p < .05$. Whereas there were small benefits of response repetition at the two shortest SOAs, there were costs at the longest SOAs (see Fig. 1). For task

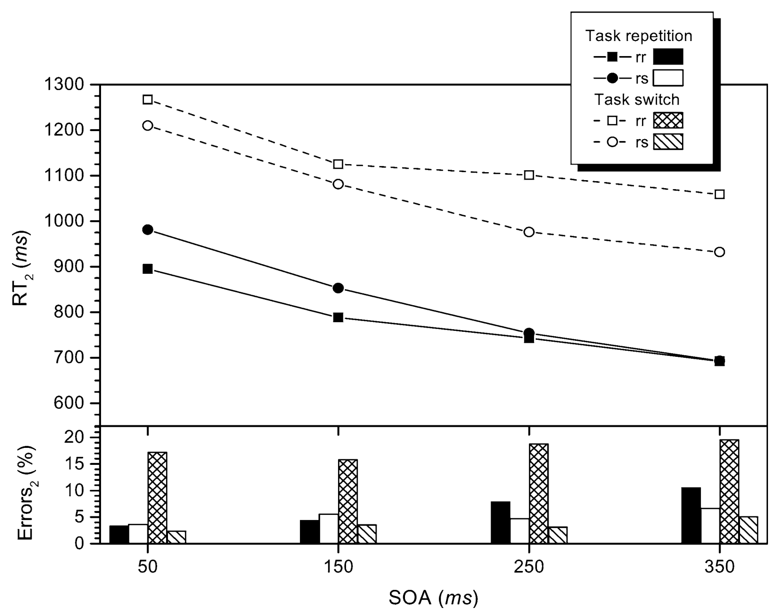

Fig. 1 Results for R_2 in Experiment 1. *rr* response repetition, *rs* response shift

shift blocks the respective interaction was not significant, $F(3,27) = .779$, $p = .52$. As can be seen in Fig. 1, there were costs of a similar size for all SOAs.

Repetition effects and S_1 congruency

We also examined the RT_2 data in order to see whether the repetition effects depended on the within-stimulus congruency of S_1. Therefore, the respective repetition effects were computed for each person and each condition. These data were then subjected to a two-way repeated measures ANOVA with the factors *block type* (task shift, task repetition) and *S_1 congruency* (congruent, incongruent). The analysis revealed a significant main effect of block type, $F(1,9) = 14.79$, $p < .01$. As can be seen in Fig. 2, this reflects the fact that there were response repetition benefits under task repetition, but costs under task shifting. Also, the main effect of S_1 congruency was reliable, $F(1,9) = 20.21$, $p < .01$. As Fig. 2 shows, congruent S_1 produced smaller response repetition benefits in task repetition trials and greater costs in task shift trials than incongruent ones. As is also obvious in Fig. 2, there was no interaction between the two factors ($p > .86$).

Discussion

In this experiment the PRP paradigm was applied in order to investigate response repetition effects and their relation to task shifting. Because this first experiment should also serve as a control experiment for the next one, half of the trials were single task trials. Nevertheless, the results revealed the usual effects that have already been observed before. First of all, there was a marked PRP effect. That is, the response times for S_2 increased with decreasing SOA. Furthermore, there were also task shift costs. Performance was considerably impaired under task shifting, relative to task repetition. Moreover, this even holds true for the single task trials. Both of these results demonstrate that mixing dual task trials with single task trials did not alter the main effects. As expected, response repetitions produced faster responses in task repetition trials, but slower ones in task shift trials. Since there were no literal response repetitions, but merely a consecutive execution of responses associated with the same response category, this interaction confirms our assumption that repeating the same motor response is not necessary for obtaining these repetition effects. It is sufficient that the same response category is repeated.

A further result is that the size of the repetition effects varied with SOA. Response time benefits were present only for the two shortest SOAs, whereas costs occurred mainly at longer SOAs. With regard to the error rates, however, there were response repetition costs for all SOAs under task shifting. Finally, there were even error costs under task repetition at the longest SOAs.

In order to see whether the potential response suppression mechanism is adaptive, we analyzed the effects of the within-stimulus congruency of S_1 on the response repetition effects. The results show that a congruent S_1 produced larger response repetition costs under task shifting and smaller response repetition benefits under task repetition. This indicates that the degree of response suppression depends on the response activation accumulated during T_1. If we consider Fig. 2, the data pattern provides a clear picture. Under task shifting, response suppression leads to repetition costs, whose amount depends on the degree of response category activation during the previous task. The same is valid for task repetition trials, except that in this case the benefit from the repetition of the stimulus category adds to the suppression effects, thereby shifting the combined effects into the positive region. Thus, these data seem to support the hypothesis of a general adaptive response suppression mechanism.

Concerning the first response, the results show that the earlier S_2 was presented, the more it affected the selection of R_1 (see also Hommel, 1998a). That is, if S_2 activated the same response as that required for S_1,

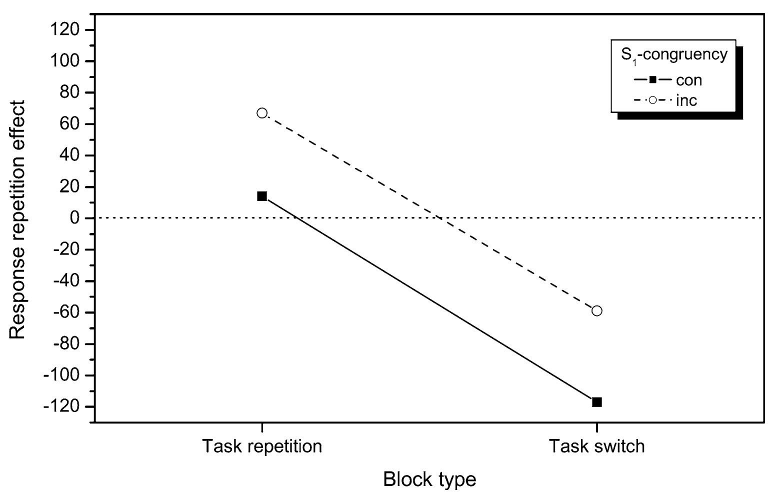

Fig. 2 Response repetition effects in Experiment 1 for task repetition and task shift conditions depending on the within-stimulus congruency of S_1. *con* congruent, *inc* incongruent

performance was improved. The fact that this effect did not depend on task shifting shows that the processes that were responsible for the selection of R_1 are different from those responsible for the selection of R_2.

Taken together, the results show that the specific PRP paradigm applied in this experiment is nevertheless suited for investigating interactions between task shifting and response repetition. Moreover, it allows us to examine the time course of the processes involved in more detail. The last property holds even more true for the modified version of the PRP paradigm, the change paradigm, which will be applied in the next experiment.

Experiment 2

Although the paradigm applied in this experiment was similar to that in Experiment 1, a crucial difference was that the processing of T_1 should immediately be abandoned when an S_2 appeared. This so-called change paradigm (Logan, 1985, 1994; Logan & Burkell, 1986) was applied in order to answer the question of whether response repetition effects show up even if no motor response was executed for T_1, and, if so, whether the effect depends on the SOA, i.e., on the progress of response activation before it was abandoned. Since in the change paradigm a response to S_1 is required if S_2 does not appear, we can be rather sure that S_1 is processed until the presentation of S_2. Previous change task studies revealed that, if participants did not respond to S_1, there was no PRP effect for RT_2, which indicates that participants did indeed abandon the processing of T_1 (Logan, 1985; Logan & Burkell, 1986). Moreover, if we assume that the PRP effect reflects a response selection bottleneck (Pashler, 1984), then this result can be taken as evidence that no response selection took place for T_1. If we accept this conclusion, it is even possible with the change paradigm to test whether response selection is necessary to produce response repetition effects or whether response activation is sufficient.

Since only one response had to occur in each trial, we will denote the different trial types as "single stimulus trials" and "dual stimulus trials," respectively. The proportion of single stimulus trials was set to 50% in order to encourage participants to respond as fast as possible to S_1 and not to wait for an S_2 that eventually appears.[1]

Since the same bivalent stimuli were used as in the previous experiment, the effect of the within-stimulus congruency of S_1 on the repetition effects should be analyzed again.

[1]Our proportion of single stimulus trials (50%) is rather small compared with other change task studies, where they were usually within a range of 75 to 90% (Logan, 1994). Nevertheless, we used this smaller proportion in order to keep the experiment within reasonable temporal limits.

Method

Participants

Ten students (3 men, 7 women with a mean age of 24.7 years) from the Universität Konstanz participated in this experiment.

Procedure

The apparatus and the stimuli were the same as in the previous experiment. The procedure was also similar, except that the participants were told not to respond to S_1 if an S_2 appeared, but to respond as fast and as accurately as possible to S_2 instead. Therefore, only one response had to occur in each trial (either to S_1 or to S_2). To discourage participants from a waiting strategy, they also had to respond to S_2 if they accidentally responded to S_1 and no error feedback was provided when they did so.

Results

Single stimulus trials

The data for the single stimulus condition were subjected to repeated measures one-way ANOVAs with *block type* (task repetition, task switch) as a factor. The analysis of the latencies revealed a significant effect, $F(1,9) = 9.62$, $p < .05$. Response times were faster in task repetition blocks than in task switch blocks (644 vs. 685 ms).

The analysis of the error rates revealed no significant effects.

Dual stimulus trials

Percentage of accidental responses to S_1 The analysis of the rates of accidental responses to S_1 in dual stimulus trials revealed a significant effect of SOA, $F(3,27) = 34.59$, $p < .001$. The rate of erroneous responses to S_1 increased with increasing SOA (.17, .22, .39, and .53).

Successful change trials The data of successful change trials[2] were analyzed by three-way ANOVAs with repeated measures on the factors *block type* (task shift, task repetition), *response type* (response repetition, response shift), and *SOA* (50, 150, 250, and 350 ms).

[2]Compared with the previous change task studies, we used a somewhat different terminology here. Instead of "signal inhibit trials", we denote the trials in which participants did not respond to S_1 but only responded to S_2 "successful change trials." Furthermore, instead of "signal respond trials" for trials in which participants erroneously responded to S_1 and S_2, we used "accidental dual task trials" here. The reasons for this adaptation are that (a) the latter terms are only descriptive and do not already imply theoretical connotations that may interfere with the concepts relevant to the purposes of this study, and (b) are more explicit regarding the cases they designate.

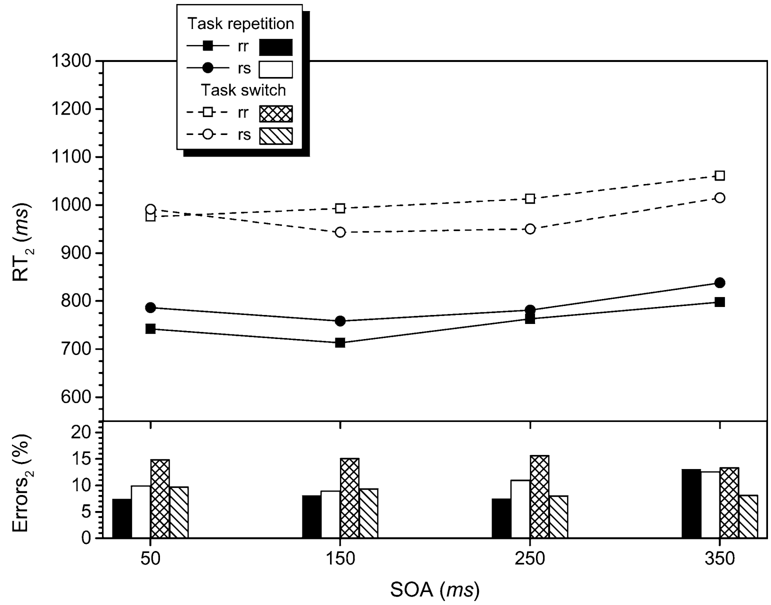

Fig. 3 Results for R_2 in the successful change trials of Experiment 2

With regard to *response times*, the analysis of the latencies[3] revealed a significant main effect of SOA, $F(3,27) = 7.17$, $p < .01$. As can be seen in Fig. 3, this effect is due to a nonlinear variation of response times with SOA (876, 854, 879, and 928 ms). There was also a significant main effect of block type, $F(1,9) = 52.41$, $p < .001$. Mean response time was faster in task repetition blocks than in task switch blocks (773 vs. 995 ms). However, the main effect of block type was qualified by a reliable two-way interaction between block type and response type, $F(1,9) = 6.86$, $p < .05$. Response repetition was beneficial by 38 ms in task repetition blocks, whereas it produced costs of 38 ms when the task shifted. As can be seen from Fig. 3, however, the response repetition disadvantage was not present at all SOAs. Thus, although the three-way interaction between block type, response type, and SOA failed to reach significance, $F(3,27) = 1.58$, $p = .218$, separate analyses were computed for both block types. For task shift blocks, there was a significant interaction between response type and SOA, $F(3,27) = 3.87$, $p < .05$. A further analysis revealed significant response repetition costs for the three longest SOAs, $F(1,9) = 5.33$, $p < .05$. On the other hand, for task repetition blocks there was a main effect of response type, $F(1,9) = 11.84$, $p < .01$, but no interaction with SOA, $F(3,27) = .43$, $p = .737$.

For the *error rates* there was a significant interaction of block type and response type, $F(1,9) = 36.60$, $p < .001$. Response repetition had a negative effect in task shift blocks (15.23 vs. 8.43%), but was beneficial in task repetition blocks (8.55 vs. 10.89%). Separate analyses for the individual block types revealed a significant negative effect of response repetition in task shift conditions, $F(1,9) = 14.49$, $p < .01$, whereas response repetition produced a positive, but nonsignificant effect in task repetition conditions, $F(1,9) = 1.67$, $p = .228$. There were no interactions with SOA.

Accidental dual task trials Because for some participants there were missing data in single cells, the R_2 data[4] of accidental dual task trials[5] were analyzed by two separate ANOVAs: A two-way analysis including the factors *block type* (task shift, task repetition) and *response type* (response repetition, response shift), and a one-way analysis with the factor *SOA* (50, 150, 250, and 350 ms).

With regard to the *response times*, in the first analysis there was a significant main effect of block type, $F(1,9) = 6.34$, $p < .05$. Again, participants responded faster in task repetition blocks than in task shift blocks (868 vs. 1,067 ms). Furthermore, the interaction between block type and response type was also significant, $F(1,9) = 5.57$, $p < .05$. There were response repetition benefits of 51 ms when the task

[3]Notice that the number of observations per condition were unequal due to the fact that the participants responded on average only to about 17% of the S_1 at the SOA of 50 ms, but to about 53% at the SOA of 350 ms. Consequently, the mean RTs for each participant and condition are based on unequal numbers of trials. However, since all conditions comprised at least eight valid trials, which were considered sufficient to estimate the respective mean response times, we did not apply special statistical procedures.

[4]We did not analyze the R_1 data in accidental dual task trials, because they are considered as erroneous responses here.

[5]Compared with the previous change task studies, we used somewhat different terminology here. Instead of "signal inhibit trials," we denote the trials in which participants did not respond to S_1 but only responded to S_2 "successful change trials." Furthermore, instead of "signal respond trials" for trials in which participants erroneously responded to S_1 and S_2, we used "accidental dual task trials" here. The reasons for this adaptation are that (a) the latter terms are only descriptive and do not already imply theoretical connotations that may interfere with the concepts relevant to the purposes of this study, and (b) are more explicit regarding the cases they designate.

repeated and response repetition costs of 36 ms when the task switched.

Regarding the second analysis there was a significant main effect of SOA, $F(3,27) = 3.78$, $p < .05$, indicating the usually observed PRP effect in dual task conditions. The response times at the individual SOAs from 50 to 350 ms were 1,048, 921, 868, and 840 ms respectively.

Regarding the first analysis, the *error data* almost perfectly mirrored the response time data. There was a reliable main effect of block type, $F(1,9) = 8.20$, $p < .05$, indicating that participants made fewer errors in task repetition blocks (11.10%) than in task shift blocks (16.70%). The interaction between block type and response type was also significant, $F(1,9) = 10.51$, $p < .05$. Repeating the same response produced a benefit of 5.52% when there was a task repetition and costs of 9% when the task shifted.

Regarding the second analysis, there was no significant effect of SOA ($p > .10$).

Repetition effects and S_1 congruency

As in Experiment 1 the RT_2 data were analyzed with regard to whether the observed repetition effects depended on S_1 congruency. In this analysis, all trials (successful change trials and accidental dual task trials) were included.

The analysis revealed significant main effects of block type, $F(1,9) = 10.06$, $p < .05$, and of S_1 congruency, $F(1,9) = 17.88$, $p < .01$. As can be seen in Fig. 4, the pattern of results is similar to that in Experiment 1. Again, there was no reliable interaction between the two factors ($p > .33$).

Discussion

The main goal of this experiment was to investigate whether response execution is necessary for response repetition effects to occur. This was obtained by applying the change paradigm, in which the participants had to stop the processing of T_1 when an S_2 appeared and to respond only to the second stimulus. First of all, an analysis of the trials in which the participants accidentally also responded to S_1 revealed similar results to those in Experiment 1. There was a PRP effect and an interaction between task shifting and response repetition.

Most importantly, however, the results of the successful change trials show that response execution is not necessary for the response repetition effects. Thus, even when no response was executed for T_1, a similar effect occurred as with an actually executed motoric response. As in Experiment 1 and for the accidental dual task trials, there were response repetition costs in task shift trials. Although there were no latency costs at the shortest SOAs under task shifting, reliable error costs were already present. Moreover, in task repetition conditions there were reliable response repetition benefits already at the shortest SOAs, supporting the hypothesis that they result from stimulus category repetition.

These results clearly demonstrate that a motoric response is not necessary for response repetition effects to occur. If we additionally assume that the response selection stage represents a bottleneck producing the PRP effect (Pashler, 1984), we can even go one step further. In this case, the absent PRP effect in the successful change trials and the fact that, at least at the short SOAs, RT_2 was substantially slower in accidental dual task trials than in successful change trials, implies that no response selection took place in the latter. Therefore, since we observed reliable repetition effects already for these short SOAs, it can be concluded that not even response selection is necessary for response repetition effects to show up. Rather, response activation alone is sufficient.

The fact that response repetition effects already occurred for the shortest SOAs suggests that response activation continued even after the presentation of S_2

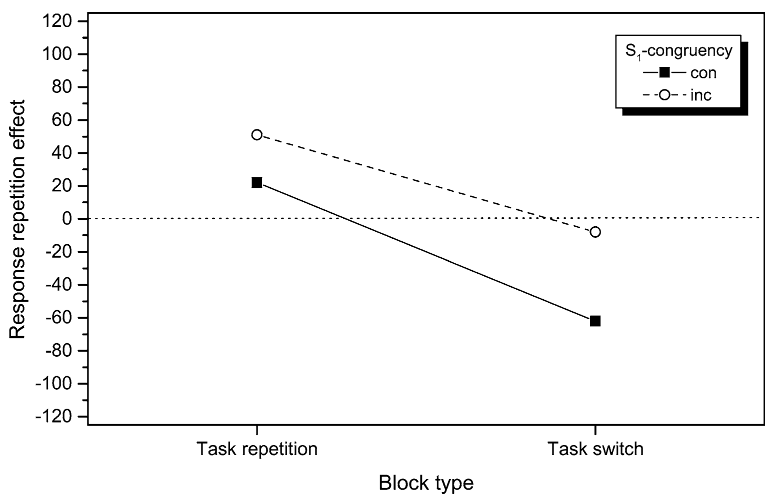

Fig. 4 Response repetition effects in Experiment 2 for task repetition and task shift conditions depending on the congruency of S_1

(Logan, 1985). If response activation had also been abandoned, then the presumably small amount of activation accumulated during the SOA intervals, which were all relatively short compared with those in other studies (e.g., Schuch & Koch, 2004), could hardly have caused repetition effects as large as those observed in the present experiment.

Regarding the effects of the within-stimulus congruency of S_1 on the response repetition effects, we obtained the same results as in Experiment 1. As can be seen in Fig. 4, congruent S_1 increased the repetition costs under task shifting and decreased the repetition benefits under task repetition. This further supports the view that an increased amount of response activation during T_1 increases the degree of response suppression.

Altogether, the experiments presented so far revealed reliable response repetition benefits or costs, depending on whether the task was repeated or shifted respectively. Moreover, these effects were largely independent of whether the response was actually performed or only activated. Finally, the absent PRP effect in RT_2 even indicates that, at least at the short SOAs, no response selection took place for T_1 in change trials. Therefore, response selection does also not seem to be necessary for response repetition effects. With regard to the strengthening accounts, this implies that they would have to assume that learning already takes place if response categories are activated to some extent. An overt response and supposedly also response selection is not necessary. Analogously, the reconfiguration accounts would have to assume that a small response activation is already sufficient for determining whether a re-reconfiguration of the response is necessary in the case of a task shift.

Experiment 3

In this experiment a further aspect of repetition effects was investigated. As already mentioned, pure strengthening accounts suppose that the association between the response and the stimulus category (e.g., ‘‘odd’’) that led to the response in one task is strengthened, while the associations between the response and the stimulus category related to the other task (e.g., ‘‘greater than five’’) is weakened. Consequently, if the same response is required again under task shifting, performance is impaired because the weakened association is now relevant for selecting the response. Similarly, the response meaning account (Schuch & Koch, 2004) assumes that response selection is more difficult under these conditions because the meaning of the response changes in the case of a task shift.

If we assume that some strengthening of the associations recently involved does indeed take place, or that the categories involved remain activated, then this should also affect the risk of an accidental response repetition. It should be especially harmful for bivalent stimuli, i.e., if the stimulus for T_2 also activates stimulus categories belonging to T_1. However, most of the accounts are indifferent with regard to the risk of an accidental response repetition. They would expect the same results for conditions with a reduced risk, e.g., for univalent stimuli. On the other hand, any strategy account for preventing accidental response re-executions predicts an adaptation to the reduced risk. That is, a possible strategy should be modified in the sense that response suppression is reduced according to the reduced risk.

This issue was tested in the present experiment, in which the PRP paradigm was applied again. The risk of accidental response re-executions was reduced relative to that in the previous experiments by using univalent stimuli (numerals and letters), i.e., stimuli whose features were related to only one of the tasks. According to the strengthening accounts (e.g., Meiran, 2000a; Schuch & Koch, 2004), this should have no effect on the learning processes with regard to the associations between the responses and the stimulus categories. On the other hand, if there is indeed a mechanism of strategic response suppression, then this would predict less suppression and, consequently, smaller repetition costs in task shift conditions and eventually larger repetition benefits in task repetition conditions in the present than in the previous experiments.

Method

Participants

Eight students (5 men, 3 women with a mean age of 22 years) from the Universität Konstanz participated in this experiment.

Stimuli and procedure

The tasks were parity judgment as in the previous experiments and consonant/vowel judgments with the letters A, E, I, U, G, K, M, and R. Presentation of letters and digits was also the same as in the experiments carried out before.

The response set and the stimulus-to-hand mapping were analogous to those in Experiment 1. Within the letter task, a ‘‘left’’ response was required for ‘‘consonant’’ judgments and a ‘‘right’’ response was required for ‘‘vowel’’ judgments. The cue indicating the letter task was ‘‘k/v’’ (abbreviations of the German words ‘‘Konsonant/Vokal’’). The timing of presentations, the SOAs and the block types were the same as in Experiment 1, with the two block types alternating and the starting condition being counterbalanced across participants. For comparison with the previous experiments, 50% of the trials were single task trials.

Altogether, there were eight practice blocks and 32 experimental blocks of 64 trials. The blocks were distributed across three 1-h sessions.

Results

Single task trials

One-way ANOVAs for repeated measures were computed for RTs and error rates with the factor *block type* (task repetition, task shift). The analyses did not reveal any reliable effect for the RT data or for the error rates (ps > .39).

Dual task trials

The R_1 data in dual task trials were analyzed by a three-way repeated measures ANOVAs. The factors considered were *block type*, *congruency*, and *SOA* as in Experiment 1. For the R_2 data, the factor *congruency* was replaced by *response type*.

R_1 The analysis of the *latencies* revealed a significant main effect of SOA, $F(3,21) = 24.66$, $p < .05$, indicating a PRP-like effect (769, 738, 709, and 628 ms at the individual SOAs from 50 to 350 ms respectively). Furthermore, the main effect of congruency reached significance, $F(1,7) = 12.01$, $p < .05$. Participants responded faster when S_2 was congruent (683 ms) than when it was incongruent (738 ms). However, there was also a reliable interaction between the two factors, $F(3,21) = 15.94$, $p < .001$, indicating a decreasing congruency effect with increasing SOA. No other effect was reliable ($p > .23$).

The analysis of the *error rates* revealed similar results. Again, the main effects of SOA, $F(3,21) = 4.45$, $p < .05$, and congruency, $F(1,7) = 6.03$, $p < .05$, were significant. The error rates decreased with increasing SOA (5.03, 3.73, 2.40, and 3.51%), and the participants made fewer errors with a congruent S_R than with an incongruent S_2 (3.23 vs. 4.11%). Also, the interaction between both factors was reliable, $F(3,21) = 4.19$, $p < .05$, which indicates a decreasing congruency effect with increasing SOA (3.76, .26, .05, and −.55% at the SOAs from 50 to 350 ms).

R_2 The analysis of RT_2 revealed a significant main effect of SOA, $F(3,21) = 60.07$, $p < .001$, indicating a PRP effect. Furthermore, the factor response type was reliable, $F(1,7) = 16.20$, $p < .01$. As can be seen in Fig. 5, this effect is due to an overall response repetition benefit. However, there was also a reliable interaction between SOA and response type, $F(3,21) = 14.64$, $p < .001$. This interaction reflects a decreasing response repetition benefit with increasing SOA (see Fig. 5). The main effect of block type was only marginally significant, $F(1,7) = 4.15$, $p = .081$. The task shift costs were rather small here (42 ms). Also, the interaction of block type and response type was marginally significant, $F(1,7) = 3.68$, $p = .098$. As can be seen in Fig. 5, there were overall response repetition benefits in task repetition and task shift conditions (104 and 48 ms respectively).

The analysis of *error rates* revealed only a significant main effect of SOA, $F(3,21) = 3.89$, $p < .05$, which was due to a nonlinear variation of error rates with SOA (see Fig. 5).

Comparison with Experiment 1

Because we hypothesized that stimulus valence should influence the costs of response repetition in task shift conditions, we compared the results of Experiment 1 (bivalent stimuli) with those of the present experiment (univalent stimuli). Separate two-way ANOVAs were computed for the R_2 data for each block type with the within-participants factor *response type* (response

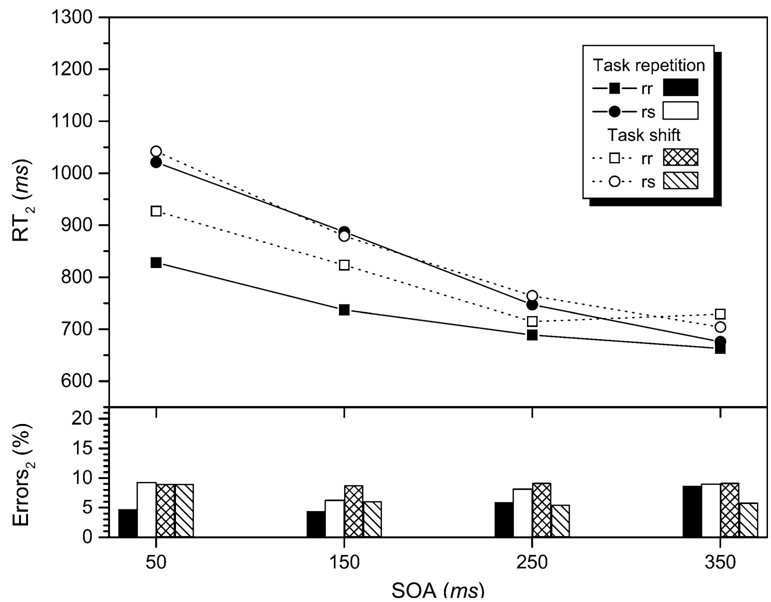

Fig. 5 Results for R_2 in Experiment 3

repetition, response shift) and the between-participants factor *stimulus valence* (bivalent, univalent).

Response times For the task repetition blocks the analysis revealed a significant main effect of response type, $F(1,16) = 51.99$, $p < .001$. However, this effect was qualified by a reliable interaction with stimulus valence, $F(1,16) = 10.78$, $p < .01$, indicating that response repetition benefits were larger with univalent stimuli (104 ms) than with bivalent (41 ms) ones.

For the task shift blocks the analysis revealed a significant main effect of stimulus valence, $F(1,16) = 11.17$, $p < .01$, showing that participants responded faster to univalent stimuli (823 ms) than to bivalent ones (1,094 ms). However, the interaction between response type and stimulus valence was also significant, $F(1,16) = 12.95$, $p < .01$. There were overall response repetition costs of 89 ms with bivalent stimuli, but response repetition benefits of 48 ms with univalent stimuli.

Error rates For the task repetition blocks the analysis of error rates revealed only a significant interaction between response type and stimulus valence, $F(1,16) = 5.43$, $p < .05$. This interaction was due to the fact that there were small overall error costs (1.46%) for response repetitions with bivalent stimuli, but benefits (2.23%) with univalent stimuli.

An analysis of task shift blocks revealed a significant main effect of response type, $F(1,16) = 38.04$, $p < .001$. However, this factor interacted significantly with stimulus valence, $F(1,16) = 16.21$, $p < .001$. Error costs were much larger with bivalent stimuli than with univalent ones (14.31 vs. 2.45%).

Discussion

The results of this experiment demonstrate that the negative effects of response repetition under task shifting largely depend on the risk of accidentally re-executing the last response. Relative to the previous experiments, the risk was reduced by presenting univalent stimuli instead of bivalent ones. If we consider the response times in the present experiment, there were also response repetition benefits under task shifting. This shows that repetition costs do not generally occur in task shift trials, but depend on the risk of accidental response re-executions. The variation of this effect supports the hypothesis that the participants applied an adaptive response suppression strategy.

Concerning the response repetition benefit under task repetition, they were larger in the present experiment than in Experiment 1. This indicates that response suppression also took place in task repetition trials. Since the benefits are presumably due to stimulus category repetitions, they should indeed be larger when response category inhibition is weaker.

Finally, the univalent stimuli had the additional effect that the task shift costs were considerably smaller than those in the previous experiments, an effect that has also been reported before (e.g., Meiran, 2000b; Rogers & Monsell, 1995).

Experiment 4

In this last experiment the change paradigm was applied again, but this time with univalent stimuli. The main objective was to replicate the main results of Experiments 2 and 3 within a single experiment. That is, we expected response repetition effects even though no response execution was required. On the other hand, due to the univalent stimuli we expected no response repetition costs under task shifting, whereas response repetition benefits should occur under task repetition.

Method

Participants

Sixteen students (7 men, 9 women with a mean age of 22.3 years) from the Universität Konstanz participated in this experiment.

Stimuli and procedure

The stimuli and tasks applied in this experiment were the same as in the previous experiment. Also, the response set and the stimulus-to-hand mapping were identical. Finally, as in Experiment 2, the participants were asked to stop processing S_1 when S_2 appeared, that is, they were again instructed according to the change procedure.

Results

Single stimulus trials

The data were subjected to repeated-measures one-way ANOVAs with factor *block type* (task repetition, task shift). There were no significant effects for either response times or error rates.

Dual stimulus trials

Percentage of accidental responses to S_1 The relative frequencies of accidental responses to S_1, even though S_2 appeared, increased with increasing SOA, $F(3,45) = 48.90$, $p < .001$. The individual values were .29, .44, .61, and .74.

Successful change trials The data from successful change trials were subjected to three-way ANOVAs with repeated measures on all factors *block type* (task repetition, task shift), *response type* (response repetition, response shift), and *SOA* (50, 150, 250, and 350 ms).

With regard to *response times*, the analysis of the latencies revealed a significant main effect of block type, $F(1,15) = 6.55$, $p < .05$. Responses were faster in task repetition blocks (915 ms) than in task shift blocks (964 ms). There was, furthermore, a reliable SOA effect, $F(3,45) = 5.18$, $p < .01$. As can be seen in Fig. 6, the response times varied in a nonlinear way with SOA. The RTs at the individual SOAs from 50 to 350 ms were 933, 894, 943, and 987 ms respectively. Finally, the main effect of response type was also significant, $F(1,15) = 5.63$, $p < .05$. There was, however, only a marginally significant interaction between block type and response type, $F(1,15) = 4.45$, $p = .052$. Separate analyses revealed a significant response repetition benefit under task repetition conditions, $F(1,15) = 6.40$, $p < .05$, whereas there was no reliable effect under task shift conditions ($p > .63$).

There were no significant effects for the *error rates* (see Fig. 6 for the data).

Accidental dual task trials With regard to the accidental dual task trials we computed the same analyses as with the successful change trials. However, one participant had to be excluded due to missing data under more than one condition.

With regard to the *response times*, the analysis of RT_2 revealed significant main effects of block type, $F(1,14) = 10.66$, $p < .01$, response type, $F(1,14) = 8.14$, $p < .05$, and SOA, $F(3,42) = 60.11$, $p < .001$. Participants responded faster in task repetition blocks than in task shift blocks (970 vs. 1,081 ms), and they responded faster when the response repeated (986 ms) than when it shifted (1,065 ms). Furthermore, there was a strong PRP effect. The RTs for the individual SOAs from 50 to 350 ms were 1,256, 1,029, 921, and 896 ms respectively. The interaction between block type and response type was also significant, $F(1,14) = 5.07$, $p < .05$. There was a large response repetition benefit under task repetition (138 ms) and a small one when the task shifted (20 ms). Finally, there was a marginally significant interaction between response type and SOA, $F(3,42) = 2.57$, $p = .067$, indicating slightly decreasing repetition effects with increasing SOA.

The analysis of the *error rates* revealed only significant interactions between block type and response type, $F(1,14) = 28.26$, $p < .001$, and between response type and SOA, $F(3,42) = 3.99$, $p < .05$. The first interaction was due to the fact that there were response repetition benefits under task repetition (1.61%), whereas there were costs when the task shifted (5.08%). The latter interaction reflects that the overall error rate benefits for response repetitions at the SOAs of 50 ms (1.89%) turn into increasingly larger costs with increasing SOA (.28, 3.01, and 5.55% at the SOAs from 150 to 350 ms respectively).

Comparison with Experiment 2

As for Experiments 1 and 3, we compared Experiments 2 and 4 with regard to the relevance of stimulus valence in the observed repetition effects. Therefore, separate two-way ANOVAs for the response times and the error rates of successful change trials were computed here, again for each block type.

Response times Regarding the response times there was only a reliable main effect of response type for task

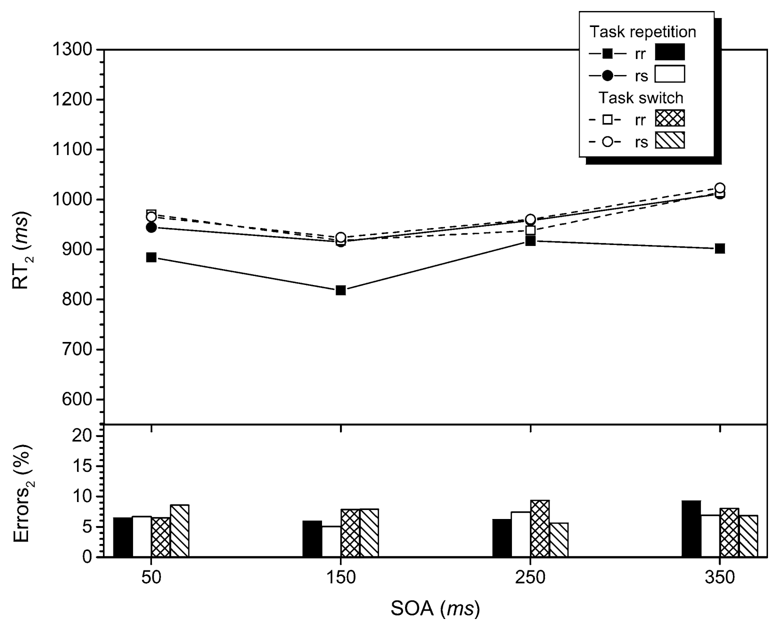

Fig. 6 Results for R_2 in Experiment 3

repetition blocks, $F(1,24) = 10.23$, $p < .01$, which was due to a general response repetition benefit.

Error rates Regarding the task repetition blocks there was a main effect of stimulus valence, $F(1,24) = 5.56$, $p < .05$. The participants made fewer errors with univalent stimuli than with bivalent ones (6.78 vs. 9.80%).

For the task shift blocks, the analysis revealed a significant main effect of stimulus valence, $F(1,24) = 4.56$, $p < .05$. Again, participants made fewer errors with univalent than with bivalent stimuli (7.66 vs. 11.84%). Also the response type effect was significant, $F(1,24) = 6.12$, $p < .05$. There were more errors when the response had to be repeated than when it had to be shifted (10.62 vs. 7.92%). Furthermore, the interaction between the two factors was reliable, $F(1,24) = 5.42$, $p < .05$. This interaction is due to the fact that there were large response repetition costs for bivalent stimuli (see Fig. 3), but only small costs for univalent stimuli (see Fig. 6).

Discussion

The results of this experiment show again that the negative effects of response repetition under task shifting largely depend on the risk of accidentally re-executing the last response. Relative to Experiments 1 and 2, the risk was reduced by presenting univalent stimuli instead of bivalent ones. As a result, there were no response repetition costs under task shifting for the successful change trials in the present experiment (benefits of 8 ms compared with costs of 38 ms in Experiment 2). On the other hand, the response time benefit under task repetition was about 50 ms, which is slightly (but not significantly) greater than the corresponding 38 ms benefit in Experiment 2. Notice, however, that this result is quite similar to the result we observed when comparing Experiments 3 and 1. This time, however, the respective interactions between stimulus valence and response repetition were not significant (*p*s > .18) for the RT data. For the task shift blocks, however, they were reliable with regard to the error rates.

The fact that there were response repetition effects again replicates the result that these effects do not depend on response execution.

General discussion

The aim of the present study was to examine response repetition effects. Of particular interest was the interaction between response repetition and task shifting, i.e., the often observed result that response repetitions produce benefits in task repetition conditions, but costs if the task shifts. Several mechanisms have been proposed to account for this interaction (Rogers & Monsell, 1995). First, there are strengthening accounts based on a learning mechanism that assume that the association between a response and the stimulus category that led to its selection is strengthened, while the associations with other stimulus categories are weakened (Hommel, 1998b; Meiran, 2000a; Meiran & Gotler, 2001; Schuch & Koch, 2004). Thus, in the case of a task shift, which also entails a change of the relevant stimulus category, the response has to be selected by means of one of the weakened associations. This could explain the response repetition costs under task shifting.

Another idea is to assume that task shifting leads to a reconfiguration of the mental system according to the new task and that this includes the generation of a generalizing switch signal propagating downstream to all subordinate task dimensions including the response. That is, it leads to the configuration of a different response relative to the last one (Kleinsorge, 1999; Kleinsorge & Heuer, 1999). Clearly, such a response reconfiguration is maladaptive if the response repeats, because the required re-reconfiguration of the response produces costs.

A third reasonable hypothesis for explaining the interaction between response repetition and task shifting is that a response is generally suppressed in order to prevent its accidental re-execution (Rogers & Monsell, 1995; Smith, 1968). In the case of task repetition, however, the resulting costs cannot be observed, because they are outweighed by the benefits of the simultaneously repeating stimulus category (Pashler & Baylis, 1991). It seems furthermore reasonable to assume that the degree of response suppression depends on the risk of accidental response re-executions. That is, the higher the risk, the stronger the suppression should be.

All of these different mechanisms can account for the interaction between response repetition and task shifting in a more or less rudimentary way. Thus, in order to differentiate between these approaches it is necessary to know more details regarding the conditions under which the interaction occurs and which factors modulate the corresponding effects. To provide such information, a series of four experiments was conducted. One of the questions to be investigated was whether response selection or response execution for the previous task is necessary for response repetition effects to occur. Some accounts are rather unspecific with regard to whether response selection or execution is necessary or not, whereas others assume that at least response selection has to be completed (e.g., Meiran, 2000a; Meiran & Gotler, 2001).

To test whether response execution is necessary for producing response repetition effects, the change paradigm (Logan, 1985; Logan & Burkell, 1986) was applied. This experimental paradigm is similar to the PRP paradigm, except that participants have to respond to S_1 only if no S_2 is presented. If an S_2 appears, which happens only in a certain fraction of trials, the processing of S_1 has to be abandoned and that of S_2 has to be started immediately. The fact that S_2 does not appear in all trials guarantees that S_1 is processed, at least to some extent, and cannot be ignored. Moreover, as in the PRP paradigm, S_2 is presented at a variable SOA. This offered the possibility not only to examine whether repetition effects depend on response execution, but also to explore their variation depending on the progress of response activation.

Before we applied the change paradigm, however, a PRP experiment was conducted (Experiment 1), which served two purposes. First, since our participants responded with different hands to S_1 and S_2, there were no literal response repetitions. Therefore, we had to show that the usual interaction between task shifting and response repetition also occurs when, instead of the repetition of a motor response, two different motor responses are executed in succession, which are associated with the same response category. In our case, the response categories were ''left'' and ''right.'' This is due to the fact that the stimulus categories (e.g., ''odd'' or ''even'') were either mapped to a *left* or a *right* response button, irrespective of the responding hand. Based on other results (e.g., Campbell & Proctor, 1993; Schuch & Koch, 2004), we assumed that this mapping leads to corresponding mental representations.[6] The results of Experiment 1 confirmed our assumptions. As expected, a response category repetition produced benefits for task repetitions, whereas costs appeared in task shift trials. This demonstrates that it is sufficient for observing the usual response repetition effects that the response categories repeat. A repetition of the motoric response is not necessary. For simplicity, we continued to use the term ''response repetition'' even though only the response category repeated.

The second purpose of Experiment 1 was to provide control conditions for our corresponding change experiment. Therefore, we had to realize conditions in the PRP experiment that were similar to those required for the change paradigm. Most importantly, S_2 appeared in only 50% of the trials. However, despite this unusual condition, the usual PRP effect and the interaction between response repetition and task shifting still occurred.

In Experiment 2 and in Experiment 4 the change paradigm was applied. If response execution were necessary for response repetition effects, then no effects should appear in successful change trials, i.e., in trials in which the processing of T_1 was abandoned successfully. As the results of Experiment 2 clearly show, this was not the case. There was a similar interaction between response repetition and task shifting as with the PRP paradigm in Experiment 1. Moreover, there were already costs at the shortest SOA of 50 ms, at least with regard to the error rates. Appreciable latency costs mainly appeared at the longer SOAs. In any case, the data definitively show that responding is not necessary for response repetition effects. Thus, whereas Experiment 1 demonstrates that even the execution of different responses is sufficient for producing repetition effects, as long as the responses are associated with the same response category, Experiment 2 shows that repetition effects also occur without a motoric response to S_1.

Although it could not be observed directly whether a response was selected under these conditions or not, the fact that there was a PRP effect for the accidental dual task trials in Experiments 2 and 4, but not for the successful change trials, strongly suggests that response selection did not take place for the abandoned tasks (Pashler, 1984). This indicates that S_1 merely activated the response category according to T_1, at least at the shortest SOAs. Thus, it seems to be sufficient for obtaining repetition effects that the response category is repeated and that this category is activated during the processing of T_1. The fact that the repetition effects were also present for short SOAs implies that the activation continued to build up even if the processing of T_1 was abandoned (see also Logan, 1985).

Given these conclusions, the strengthening accounts would have to assume that learning already takes place when response categories are merely activated to some extent. Neither response execution nor response selection is necessary. Likewise, the reconfiguration accounts would have to suppose that response category activation is sufficient for response reconfiguration and, consequently response re-reconfiguration as well (Kleinsorge & Heuer, 1999).

A further main question of the present study was whether the repetition effects depend on the risk of accidental response repetitions. If this is the case, then it would support the idea that response suppression contributes to the repetition effects. The higher the risk of an accidental response repetition the stronger the suppression should be. Consequently, the repetition costs should increase with an increasing risk. To test this prediction, the risk was varied across experiments by using bivalent and univalent stimuli. Clearly, bivalent and univalent stimuli also differ with regard to other effects such as task set cuing, etc. (Rogers & Monsell, 1995; Waszak, Hommel, & Allport, 2003). However, we had no reason to assume that these effects systematically change the effects we were interested in.

In the first two experiments, bivalent numerals served as stimuli. Consequently, the stimulus for one task also activated a stimulus category belonging to the other task. In the last two experiments, univalent stimuli were used. In this case, each stimulus could activate only one stimulus category. However, as with bivalent stimuli, each response was still associated with two stimulus categories. Therefore, in its present form, at least the strengthening account would predict the same repetition effects for both stimulus valence conditions. Contrary to this prediction, our results clearly show that the effects for the two stimulus types were rather different. Bivalent stimuli produced the usual response repetition benefits and costs under task repetition and shifting respectively.

[6]We could speculate that index/middle finger or inner/outer keys could also have served as response categories (Logan Schulkind, 2000). However, with these categories the mappings between stimulus categories and response categories are not spatially consistent across hands. Since spatial consistency between mappings plays an important role (Duncan, 1979), we assumed that the participants would choose spatial response categories. This assumption was confirmed by our data.

For univalent stimuli, however, there were almost no response repetition costs under task shifting. Under task repetition, there were response repetition benefits, which were even larger than those for bivalent stimuli.

These results show that the risk of accidental response re-execution largely determines the size of the repetition effects. This suggests that an adaptive response suppression mechanism strongly contributes to these effects. This adaptive mechanism follows the principle that the higher the risk of an accidental response re-execution, the stronger the suppression. Whereas this relation seems to reflect an overall strategy, the results from the first two experiments show that the degree of suppression also varies on a trial-by-trial basis, depending on the accumulated response activation during T_1. Due to the bivalent stimuli, the response activation during T_1 varied with the congruency of S_1. Since both features (i.e., parity and magnitude) of a within-stimulus congruent S_1 activated the same response, the activation was higher than with an incongruent S_1.

As can be seen in Figs. 2 and 4, the congruency of S_1 did indeed affect the response repetition effects. Congruent stimuli increased the response repetition costs under task shifting and decreased the benefits under task repetition. The data can be interpreted in the sense that response suppression generally leads to response repetition costs and that the degree of suppression depends on the previous response activation. In the case of task repetition, however, the negative response suppression effects are outweighed by the positive effects of stimulus category repetition. This reasoning explains perfectly the additive effects of task shifting and S_1 congruency as shown in Experiments 1 and 2.

Our data also provide interesting results with regard to task shifting. First of all, the univalent stimuli in Experiments 3 and 4 had the effect that the task shift costs were considerably reduced compared with those in the first two experiments. This is in accordance with previous studies (e.g., Meiran, 2000b; Rogers & Monsell, 1995). Furthermore, Schuch and Koch (2003) recently proposed that task shift costs depend largely on response selection. They conducted a series of experiments in which the task shift paradigm was combined with a go/no-go procedure. As expected, no shift costs appeared when the previous trial was a no-go trial. Since Schuch and Koch (2003) assumed that no response was selected in no-go trials, they concluded that response selection is necessary for task shift costs to occur. The present results, however, provide evidence that this conclusion may not hold true. It rather seems that their participants were even able to prevent response activation in no-go trials. This, however, is not surprising in our view as the no-go signal appeared simultaneously with stimulus onset, signaling that stimulus processing is not necessary at all (see also Kleinsorge & Gajewski, 2004). From this perspective, the change paradigm seems to be better suited for investigating such questions, because it affects response-related processes more specifically than the go/no-go procedure.

Another interesting result is that we observed task shift costs even for single task trials. These costs can be interpreted as general effects due to sustained control or mixing costs (Braver, Reynolds, & Donaldson, 2003; Hübner et al., 2001). Since we blocked task shift and task repetition conditions, the participants might have permanently implemented additional shift operations in task shift blocks, which generally impaired performance.

Taken together, the results of the present study suggest that in conditions with repeating tasks there is some risk of accidental response re-executions. This risk is especially high with bivalent stimuli. Therefore, in order to prevent a high rate of accidental response re-executions, the response that was activated during the preceding task is suppressed. This suppression eventually produces costs in task shift conditions, when the same response has to be executed again. Furthermore, this suppression mechanism also seems to be active in task repetition conditions. Its effect, however, is outweighed by the positive effects of the stimulus category repetition. Finally, the facts that the risk of accidental response re-executions and the within-stimulus congruency of S_1 affected the response repetition effects show that response suppression is adaptive and does not proceed in an all-or-none manner.

Thus, the data and our interpretation provide a sound picture. What remains puzzling, however, is that the suppression seems to be stronger than necessary for bivalent stimuli. The suppression mechanism successfully prevents accidental response re-executions, which could be due to pre-activations and conflicting stimuli. However, if the mechanism is as adaptive as our data suggest, then we can ask why the suppression is so strong that, if a re-execution is required in a task shift trial, many accidental response shifts occur. What is this overcompensation good for? This seemingly curious aspect, however, is similarly present for the reconfiguration account (Kleinsorge, 1999; Kleinsorge & Heuer, 1999), as we could ask why it should make sense to reconfigure all subordinate task dimensions in the case of a task shift, even though they might have been configured correctly before. Thus, despite the puzzling overcompensation, we think that general response suppression is the most parsimonious mechanism for explaining our data.

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References

Bertelson, P. (1963). S-R relationships and RT to new vs. repeated signals in a send task. *Journal of Experimental Psychology*, *65*, 478–484.

Bertelson, P. (1965). Serial choice reaction-time as a function of response versus signal-and-response repetition. *Nature*, *206*, 217–218.

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron*, *39*, 713–726.

Campbell, K. C., & Proctor, R. W. (1993). Repetition effects with categorizable stimulus and response sets. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 1345–1362.

Duncan, J. (1979). Divided attention: The whole is more than the sum of its parts. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 216–228.

Hommel, B. (1998a). Automatic stimulus-response translation in dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1368–1384.

Hommel, B. (1998b). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, *5*, 183–216.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, *24*, 849–878.

Hübner, R., Futterer, T., & Steinhauser, M. (2001). On attentional control as source of residual shift costs: Evidence from two-component task shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 640–653.

Kleinsorge, T. (1999). Response repetition benefits and costs. *Acta Psychologica*, *103*, 295–310.

Kleinsorge, T., & Gajewski, P. D. (2004). Preparation for a forthcoming task is sufficient to produce subsequent shift costs. *Psychonomic Bulletin & Review*, *11*, 302–306.

Kleinsorge, T., & Heuer, H. (1999). Hierarchical switching in a multi-dimensional task space. *Psychological Research*, *62*, 300–312.

Lien, M. C., Schweickert, R., & Proctor, R. W. (2003). Task switching and response correspondence in the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 692–712.

Logan, G. D. (1985). On the ability to inhibit simple thoughts and actions. II. Stop-signal studies of repetition priming. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *11*, 675–691.

Logan, G. D. (1994). On the ability to inhibit thought and action. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 188–239). San Diego: Academic Press.

Logan, G. D., & Burkell, J. (1986). Dependence and independence in responding to double stimulation: A comparison of stop, change, and dual-task paradigms. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 549–563.

Logan, G. D., & Schulkind, M. D. (2000). Parallel memory retrieval in dual-task situations. I. Semantic memory. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1072–1090.

Meiran, N. (2000a). Modeling cognitive control in task-switching. *Psychological Research*, *63*, 234–249.

Meiran, N. (2000b). Reconfiguration of stimulus task sets and response task sets during task switching. In S. Monsell, & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 377–399). Cambridge, MA: MIT Press.

Meiran, N. (2005). Task rule congruency and Simon-like effects in switching between spatial tasks. *Quarterly Journal of Experimental Psychology*, *58A*, 1023–1041.

Meiran, N., & Gotler, A. (2001). Modelling cognitive control in task switching and ageing. *European Journal of Cognitive Psychology*, *13*, 165–186.

Pashler, H. (1984). Processing stages in overlapping tasks: Evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 358–377.

Pashler, H., & Baylis, G. (1991). Procedural learning. II. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 33–48.

Peeke, S. C., & Stone, G. C. (1972). Sequential effects in two- and four-choice tasks. *Journal of Experimental Psychology*, *92*, 111–116.

Quinlan, P. T. (1999). Sequential effects in auditory choice reaction time tasks. *Psychonomic Bulletin & Review*, *6*, 297–303.

Rabbitt, P. M. A. (1968). Repetition effects and signal classification strategies in serial choice-response tasks. *Quarterly Journal of Experimental Psychology*, *20A*, 232–240.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207–231.

Schuch, S., & Koch, I. (2003). The role of response selection for inhibition of task sets in task shifting. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 92–105.

Schuch, S., & Koch, I. (2004). The costs of changing the representation of action: Response repetition and response-response compatibility in dual tasks. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 566–582.

Smith, M. C. (1968). Repetition effect and short-term memory. *Journal of Experimental Psychology*, *77*, 435–439.

Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: Role of episodic S-R bindings in task-shift costs. *Cognitive Psychology*, *46*, 361–413.

Welford, A. T. (1952). The 'psychological refractory period' and the timing of high-speed performance—a review and a theory. *British Journal of Psychology*, *43*, 2–19.