Psychological Research (2006) 70: 526–540
DOI 10.1007/s00426-005-0014-6

ORIGINAL ARTICLE

Stefanie Schuch · Iring Koch

Task switching and action sequencing

Received: 17 June 2004 / Accepted: 28 May 2005 / Published online: 19 November 2005

Abstract We investigated if task switching affects late response processes that occur after the selection of a response. Subjects performed a sequence of two responses. The first and second response were selected, and then executed in close succession. The interresponse interval (IRI) was taken as a measure of late response processes. The two responses could either belong to different tasks (task-switch condition), or to the same task that was performed twice (task-repetition condition). In all three experiments, the IRI was found to be longer in the task-switch condition than in the task-repetition condition, consistent with the idea that task switching affected late response processes. However, the effects of the manipulation of the stimulus-onset asynchrony revealed that the tendency to perform the two responses as a sequence was reduced in the task-switch condition relative to the task-repetition condition. Thus, the data do not provide unequivocal evidence for task switching affecting late response processes. The data show, however, that task switching affected action sequencing. Two actions that do not belong to the same task context are less likely to be performed as an action sequence. We suggest that task switching interacts with higher-order control processes that cannot be studied within the traditional task-switching paradigm.

Introduction

In order to understand the flexibility of the human goal-directed behavior, cognitive psychologists have developed the task-switching paradigm. Investigating subjects' performance of switching between different well-defined choice reaction-time tasks allows cognitive-switching processes to be explored in a closely controlled experimental paradigm. The basic idea of this paradigm is to analyze sequential task performance: performance in a certain task is slower when preceded by a different task than when preceded by the same task. This effect is called "switch costs." Originally, task switching had been thought to be a matter of task preparation, and therefore, to be occurring prior to task performance. However, evidence has accumulated that task switching also affects task performance per se. There is a growing amount of evidence that interference from the previous task slows down several processes of performance of the current task (see, e.g., Allport, Styles, & Hsieh, 1994; Mayr & Keele, 2000; Schuch & Koch, 2003). One such process affected by interference from the previous task is stimulus categorization (see, e.g., Meiran, 2000). For instance, if numbers have to be categorized as odd or even in the context of one task, but as smaller or larger than a certain number in the context of another task, number categorization is slowed down when the task has just changed. The reason is that there is interference of the different sets of categories (e.g., Logan & Schulkind, 2000; for a formal model of switching of stimulus category see Logan & Gordon, 2001). Another process affected by task switching is response selection. Several studies have shown that response selection is slower when the task has just switched, because of interference of the response rules of the different tasks (see Meiran, 2000; Schuch & Koch, 2003).

While these effects are well established, nobody has so far raised the question whether processes related to response execution might also be slowed on switch trials. This is probably due to the original idea of task switching still persisting in researchers' minds, namely that task switching is not a matter of task performance, but only of task preparation. However, given the evidence discussed above, it is quite possible that task switching affects many processes of task performance, be

S. Schuch (✉) · I. Koch
Department of Psychology, Max Planck Institute for Human Cognitive and Brain Sciences, Munich, Germany
E-mail: s.schuch@bangor.ac.uk

S. Schuch
Centre for Cognitive Neuroscience, School of Psychology, University of Wales, Bangor, LL57 2AS, UK

it stimulus categorization, response selection, or response execution. The idea of response execution processes being a locus of interference has been discussed for decades in the context of dual-task performance (for a review, see Pashler, 1994a). Several authors proposed that it is the interference between initiation of the first response and initiation of the second response that causes interference in dual tasks (e.g., De Jong, 1993; Keele, 1973; Logan & Burkell, 1986). Pashler (1994a) concluded that both response initiation and response selection might be slowed in dual-task situations.

Thus, while interference of late response processes has been an issue in the dual-task literature, it has not yet been considered in the task-switching literature. This is surprising given the similarity of dual-task and task-switching paradigms. Both paradigms typically involve two (or more) different tasks that must be performed at the same time, or in close temporal succession. The main difference is that in dual-task paradigms, the second task might start before the first task has finished, whereas in task-switching paradigms, the first task has usually been completed before the second task starts. Recently, several researchers have started to combine the two paradigms, and investigate task-switching processes in a dual-task setting (see, e.g., Lien, Schweickert, & Proctor, 2003; Logan & Schulkind, 2000; Luria & Meiran, 2003; Schuch & Koch, 2004). Given the similarities between the dual-task and the task-switching paradigms, it is likely that there are also similar processes underlying dual-task and task-switching performance. Therefore, the question arises whether interference of late response processes, such as response initiation, might play a role not only in dual-task performance, but also in the task-switching performance. The present study was designed to investigate whether task switching affects late response processes.

The present paradigm

To disentangle response execution from response selection, we developed a new variant of the task-switching paradigm. Subjects performed a response sequence consisting of two responses. They were first selecting both responses, and then executing them as a response sequence. We focused on the inter-response interval (IRI) of the response sequence. The idea was that the IRI reflected the time for the execution of the second response. The IRI did not include the selection of the second response, as this should have occurred before the sequence onset. We examined whether the two responses belonged to different tasks, or to the same task that was performed twice. If task switching affected processes of response execution, there should be task-switch costs in the IRI.

We also manipulated the stimulus-onset asynchrony (SOA), that is, the time between the onset of the first and the second stimulus. This was done to check whether the second response indeed was selected beforehand, and not during the IRI. The reasoning was the following: it is known from the dual-task literature that the second of two responses in dual tasks is massively delayed at short SOAs as compared to long SOAs, and this delay is usually attributed to the interference between selection of the first response and selection of the second response (see Pashler, 1994a, for review). With respect to the present paradigm, if response selection occurred during the IRI, this should be reflected by SOA effects in the IRI, with the IRI being substantially longer at short SOAs than at long SOAs. If, however, the IRI was not affected by SOA, this would indicate that there was no response selection occurring during the IRI.

Two different instructions were used to make subjects perform the two responses in a sequence (i.e., select both responses in advance and then perform the two responses in close succession). In Experiment 1, the participants were told to “wait for the second stimulus” before they started responding and in Experiment 2, the participants were told to “respond to the second stimulus first.” In Experiment 3, the “wait for the second stimulus” instruction was used again. The instructions to wait for the second stimulus, or to reverse response order, were sufficient to induce a grouping strategy. It is known from the dual-task literature that there is a tendency to perform the two required responses as a response sequence, which is sometimes referred to as “response grouping” (e.g., Borger, 1963; Pashler, 1994b; Ruthruff, Pashler, & Hazeltine, 2003; Ruthruff, Pashler, & Klaassen, 2001). There is evidence from both behavioral data (De Jong, 1993; Pashler & Johnston, 1989) and EEG data (Sommer, Leuthold, Abdel-Rahman, & Pfuetze, 1997) that participants applying a grouping strategy indeed select both responses in advance before executing either.

Two different tasks were used throughout all the experiments. In the magnitude task, participants had to decide whether a digit was smaller or larger than five. In the parity task, participants had to decide whether a digit was odd or even. In the task-repetition condition, the same task was repeated (i.e., the task-pairs were magnitude–magnitude or parity–parity). In the task-switch condition, the second task was different from the first (i.e., the task-pairs were magnitude–parity or parity–magnitude). In Experiments 1 and 2, the task-switch condition consisted of the magnitude–parity task-pair for half of the participants, and parity–magnitude task-pair for the other half of the participants. In the task-repetition condition, participants alternated between the magnitude-magnitude task-pair and the parity–parity task-pair. Thus, the total number of tasks was the same in the task-switch condition and the task-repetition condition (always two tasks involved). The total number of task-pairs, however, was different in the two conditions, with the task-switch condition involving one task-pair (either magnitude–parity, or parity–magnitude), but the task-repetition condition involving two task-pairs (i.e., magnitude-magnitude, and parity–parity). In Experiment 3, we controlled for the number of task-pairs. The task-switch condition involved either magnitude–parity, or parity–magnitude task pairs as before. The task-repetition condition, however, involved either in only the magnitude-magnitude task-pairs, or only parity–parity task-pairs. Thus, there was only one task-pair in both the task-switch and the task-repetition condition. This design, however, led to a different total number of tasks in the two conditions (with two tasks being involved in the task-switch condition, but only one task being involved in the task-repetition condition).

Another difference between Experiments 1, 2, and 3 was that task transition (i.e., task switch or task repetition) was manipulated between subjects in Experiments 1 and 2, but was manipulated within-subjects in Experiment 3.

The same two response keys (a left and a right key) were used for the two different tasks. This was done to achieve maximal interference of response-related processes (see Schuch & Koch, 2004). Interference is maximized because the response rules change during a task switch when the same response alternatives are being used for the different tasks. For example, the left response could mean "smaller" in the context of the magnitude task, and "odd" in the context of the parity task. The right response would mean "larger" and "even" in this example. Note that by using the same response alternatives for the first and second response of the response sequence, the response sequence could consist of repeating the same response. We checked whether the response repetition trials altered the results, by analyzing the response-repetition trials and the response-switch trials separately. To anticipate the results, we obtained the same data pattern for the response-repetition trials and the response-switch trials, indicating that the response repetitions did not constitute a special case.

Experiment 1

In a dual-task setting, subjects were instructed to wait for the second stimulus, and then to respond to both stimuli in the order of their appearance. The two stimuli were separated by different SOAs. Participants performed numerical judgment tasks, with digits occurring as stimuli. In the task-switch group, half of the participants judged the first digit as being odd or even, and the second digit as being smaller or larger than five. The order of tasks was reversed for the other half of the participants. In the task-repetition group, the first and second tasks were always the same. The participants performed the parity task twice in one trial, the magnitude task twice in the next trial, etc. We explored whether the IRI was larger in the task-switch group than in the task-repetition group. If we found such switch costs in the IRI, we would conclude that task switching affected the processes occurring during IRI. If, in addition, SOA did not have an effect on the IRI, we would conclude that there was no response selection occurring during the IRI. Thus, we would conclude that task switching affected late response processes.

Method

Participants

Twenty four participants (16 females and 8 males, mean age = 23.9 years) took part in the experiment and received 6 [euro]. Half of the participants were assigned to the task-switch group, the other half were assigned to the task-repetition group.

Apparatus, stimuli, and response requirements

Participants sat in front of a screen of an IBM compatible PC located in a booth. Viewing distance was 40 cm. Stimuli appeared at the screen center in white on black background. Two frames with 3.5 cm side length were used as fixation marks. They appeared one above the other and centered on the screen. The distance between the two midpoints of the frames was 5.5 cm. Each frame could either have the shape of a square or a diamond, indicating the parity task or the magnitude task, respectively. Stimuli consisted of the digits 1–9, excluding 5. The digits were 1 cm in height and approximately 0.5 cm in width, and appeared centrally in the frames. The first stimulus always appeared in the upper frame, the second stimulus after a certain SOA in the lower frame. After the second stimulus had appeared, participants responded with two key presses to the first and second stimulus, respectively. Each response was either a left or right key press. Participants responded with their index fingers.

Design

In a 2×5 mixed design, we manipulated task transition (task switch vs. task repetition from the first to the second response of each trial) as a between-subjects independent variable, and SOA (100, 500, 900, 1,300, and 1,700 ms) as a within-subjects independent variable. In every trial, there were two stimuli (S1 and S2), followed by two responses (R1 and R2). The main dependent variable was IRI, which was the time between R1 and R2. We also analyzed initiation time of the response sequence (INI), which was the time between S2 and R1 (see Fig. 1).

In addition to IRI and INI, we analyzed error rates. Participants could press the wrong response key at the first, the second, or both responses. We note, however, that pressing the wrong key in choice-RT tasks might result from different errors. It might reflect an error of stimulus categorization, an error at the time of response selection, or an error during late response processes (see Sanders, 1998, for an overview of models of judgment errors). In the present paradigm, it was not possible to

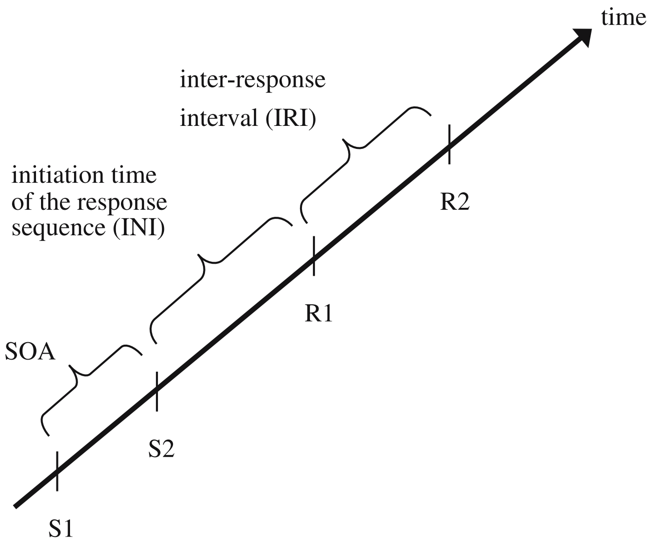


Fig. 1 Paradigm

distinguish errors during late response processing from errors during categorization or response selection. Therefore, we did not consider error data as informative concerning the question of which role late response processes play in task switching. We report error rates for the sake of completeness, but we do not focus on them in the interpretation of the data.

The independent variable task transition was manipulated between subjects. The task-switch group performed dual-task pairs containing a task switch. Half of the participants in this group performed the parity task as first task and the magnitude task as second task, the other half of participants performed the magnitude task as first task and the parity task as second task. The task-repetition group performed dual-task pairs containing a task repetition. This group performed the parity task as first and as second task in one trial, the magnitude task as first and as second task in the next trial, then the parity task in the next trial again, and so on.

SOA varied randomly from trial to trial. All SOAs occurred equally often within each block. Moreover, both kinds of response repetition (i.e., left–left and right–right) as well as both kinds of response shift (left–right and right–left) occurred equally often in each block and were combined with the five different SOAs equally often in each block. S-R mappings were counterbalanced across participants. Stimuli were selected randomly with the constraints that repetition of the immediately preceding stimulus was not possible, and repetition of the stimulus previously associated with the same task was not possible, either.

Procedure

Before the experiment started, the participants received verbal instructions concerning the tasks and procedure, and they could also read the instructions on screen. The experiment began with a short practice block consisting of 20 trials.

A trial started with two vertically arranged frames presented at screen center. In the task-switch group, two squares were presented on the screen in every trial. The S-R mappings for the first and second tasks, printed on a piece of paper, were attached to the bottom of the screen. In the task-repetition group, two kinds of frames were used. Squares were used to indicate the parity task, and diamonds were used to indicate the magnitude task. Thus, there were two squares occurring on one trial, two diamonds occurring on the next trial, etc. As in the task-switch condition, the S-R mappings were visible at the bottom of the screen.

The two frames stayed on the screen for 1,000 ms, then the first digit appeared in the center of the upper frame. After a variable SOA, the second digit appeared in the center of the lower frame. Both digits and frames remained visible until participants had given two responses. With the second response, the digits and frames disappeared. In case that one of the key presses (or both) were wrong, an error feedback appeared for 500 ms on the bottom of the screen (the German word “Fehler,” i.e., “error”). If the two responses had not occurred within 3,500 ms from the onset of the first stimulus, stimulus presentation would be aborted, and an error feedback occurred for 500 ms, saying “zu langsam” (i.e., “too slow”). In case participants responded before the second stimulus had occurred, an error message occurred (“auf die zweite Ziffer warten,” i.e., “wait for the second digit”). After either two correct responses or an error feedback message, a blank screen was presented for 500 ms, and then the next trial started with the presentation of two frames. Thus, the overall trial length was 5,000 ms (5,500 ms when an error feedback occurred). Participants performed 10 blocks of 40 trials each, resulting in 400 trials. Thus, there were 80 trials in each of the five SOA conditions in both the task-switch group and the task-repetition group.

Results

Data analysis

Significance was tested with an 2×5 analysis of variance (ANOVA) with task transition as a between-subject variable and SOA as a within-subject variable. The α-level was set to 0.05. We corrected for violations of the sphericity assumption using the Huynh-Feldt ε. We always reported the uncorrected degrees of freedom and uncorrected mean square errors (MSE), together with the ε value, and the P value according to the corrected degrees of freedom. As a dependent measure, we analyzed IRI and INI. The 2×5 ANOVA was conducted twice, first with the IRI as a dependent variable, second with INI as the dependent variable.

For the analysis of RT data, the first trial of each block was excluded. Also, all trials where one or both responses that were wrong, were excluded, affecting 8.1% of the trials. (Errors were analyzed separately; see below). Furthermore, only those trials that were included, where both responses were performed within the time window, provided for responding. The time window started at the onset of S2, and ended 3,500 ms after the onset of S1, at which time the trial was aborted. Trials in which the first response was given too early (i.e., before the onset of S2) were excluded from analysis (1.0% too-fast trials). Trials in which only one response, or no response at all, was given within the response window, were also excluded from analysis (1.8% too-slow trials). To ensure that only those trials that were included where participants had successfully grouped the responses together, an additional outlier criterion was set. Only trials with an IRI of less than 800 ms were included in the data analysis and this IRI criterion affected another 1.6% of otherwise valid trials. Overall, 86.1% of trials were included in RT analysis.

Overall data pattern

Fig. 2 shows INI and IRI for the five different SOAs, separately for the task-switch and the task-repetition condition. As can be seen, there was a large effect of SOA on INIs, but only a small effect of SOA on IRIs. This impression was confirmed by statistical analysis (see below). The data pattern is what one would have expected if participants selected both responses during the INI in majority of the trials, and only performed the two responses after having selected both of them.

Inter-response interval

A 2×5 ANOVA on IRI was conducted with the independent variables task transition (between subjects) and SOA (within subjects). The ANOVA yielded a main effect of task switch, $F(1,22) = 4.7$, MSE = 29,703, $P < 0.05$, with a larger IRI in the task-switch group (300 ms) than in the task-repetition group (232 ms). There was no main effect of SOA ($F < 1$). There was, however, an interaction of task transition and SOA ($F(4,88) = 4.2$, MSE = 214, $\varepsilon = 0.62$, $P < 0.02$), indicating that switch costs were larger for the shorter than for the longer SOAs (switch costs were 86, 75, 60, 58, and 61 ms for SOAs 100, 500, 900, 1,300, and 1,700 ms, respectively). When tested separately with one-tailed t tests ($\alpha = 0.05$), switch costs were significant in every SOA condition. When the effect of SOA was tested separately for the task-switch and task-repetition group, the effect of SOA was significant in the task-switch group ($F(4,44) = 3.7$, MSE = 222, $\varepsilon = 0.69$, $P < 0.03$), but not in the task-repetition group ($F(4,44) < 1.1$, $P > 0.30$).

INI

The same 2×5 ANOVA that was conducted on IRI was also conducted on INI. There was a large main effect of SOA ($F(4, 88) = 130$, MSE = 8,292, $\varepsilon = 0.41$, $P < 0.01$). There was no significant main effect of task transition ($F(1,22) = 1.1$, MSE = 181,291, $P > 0.30$). The interaction of task transition and SOA was not significant either ($F(4, 88) = 2.4$, MSE = 8292, $\varepsilon = .41$, $P < 0.13$). As Fig. 2 shows, there was a tendency of the INI being faster in the task- switch condition than in the task-repetition condition, and this difference tended to become smaller with longer SOAs.

Error data

As mentioned above, we did not consider error data as informative with respect to the present research question of whether task switching affected response execution processes in addition to response selection processes. It was not possible to distinguish response-selection errors from response-execution errors in the present paradigm.

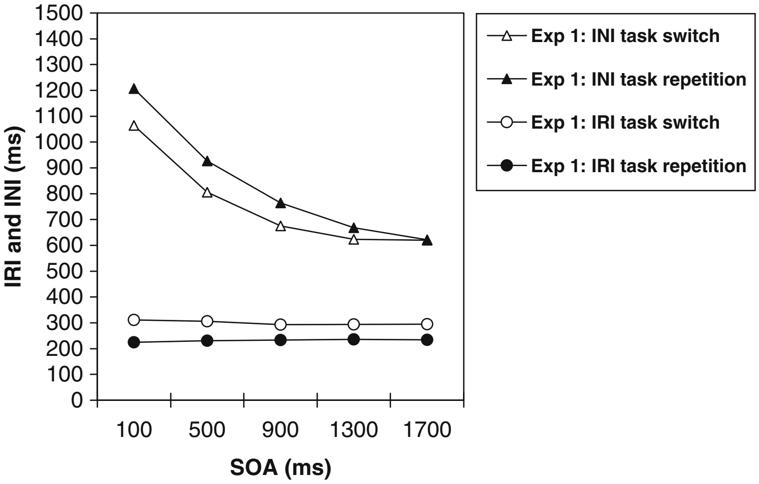


Fig. 2 Experiment 1 (*maintained response order*) INI and IRI as a function of task transition and SOA

For this reason, we did not conduct detailed statistical analyses on error data, but only an analysis on the overall error rates.

For the analysis of error data, the first trial of each block was excluded. Several kinds of errors were possible: Participants could either press a wrong key at the first response (2.0% of the trials), at the second response (4.3% of the trials), or at both responses (1.8% of the trials). We analyzed the overall error rate (the sum of first-response errors, second-response errors, and double errors) in a 2×5 ANOVA with the independent variables task transition and SOA (see Table 1). The ANOVA yielded only a main effect of SOA ($F(4, 88)=24.9$, $\mathrm{MSE}=0.00183$, $\varepsilon=0.45$, $P<0.01$), indicating higher error rates at short SOAs than at long SOAs. Error rates were 15.2%, 8.8%, 6.6%, 5.0%, and 4.5% at SOAs 100, 500, 900, 1,300, and 1,700 ms, respectively. There was no significant main effect of task transition ($F<1$), and no interaction ($F=1.0$). The magnitude of the overall error rate resembled what was found in the earlier dual-task studies using similar tasks (e.g., Schuch & Koch, 2004).

Discussion

In the present dual-task paradigm, participants were instructed to wait for the second stimulus before they started responding. This led them to group the responses, that is, to select both responses and then execute them as a response sequence. The data pattern is consistent with this notion: The IRI (which is the time between the two responses) was short relative to the INI (which was the time from the second stimulus on to initiate the response sequence). Moreover, the IRI did not differ across the different SOA conditions, whereas the INI massively increased with decreasing SOA. Such large SOA effects in the order of magnitude of several hundred milliseconds are usually interpreted as reflecting response selection of the second of two responses in (speeded) dual-task paradigms. Thus, the data pattern supports the assumption that the second response was selected prior to sequence onset, and that the IRI reflected only processes related to response execution, but not to response selection.

The important finding was that there were task-switch costs in the IRI. This finding is consistent with the idea that task switching affects late response processes. However, this conclusion is only preliminary. The reason is that the effect might be due to less efficient grouping in the task-switch condition relative to the task-repetition condition. The task-switch costs increased with decreasing SOA. Post hoc analyses revealed that in the task-repetition condition, the IRI did not depend on SOA. In the task-switch condition, however, the IRI became larger at shorter SOAs. These findings might indicate that participants did not group the responses in all the trials, and that grouping was less efficient in the task-switch condition relative to the task-repetition condition. Therefore, we conducted another experiment with a modified instruction to further enforce grouping of the responses.

Table 1 Experiment 1: Errors (in %) as a function of task transition and SOA

	SOA (in ms)				
	100	500	900	1,300	1,700
Task switch	17.9	9.5	7.8	5.6	5.2
Task repetition	12.5	8.0	5.5	4.4	3.8

Experiment 2

Experiment 2 aimed to replicate Experiment 1. A different instruction was used to further encourage grouping of the responses, that is, to select both responses and then perform them as a response sequence. Participants were instructed to respond to the second stimulus first.

Method

Participants

Twenty four new participants were tested. Their mean age was 22.8 years; 20 of them were females. They received 6 [euro].

Apparatus and Stimuli, Design and Procedure

Everything was identical to Experiment 1, except for the instruction. Participants were instructed to respond to the second stimulus first.

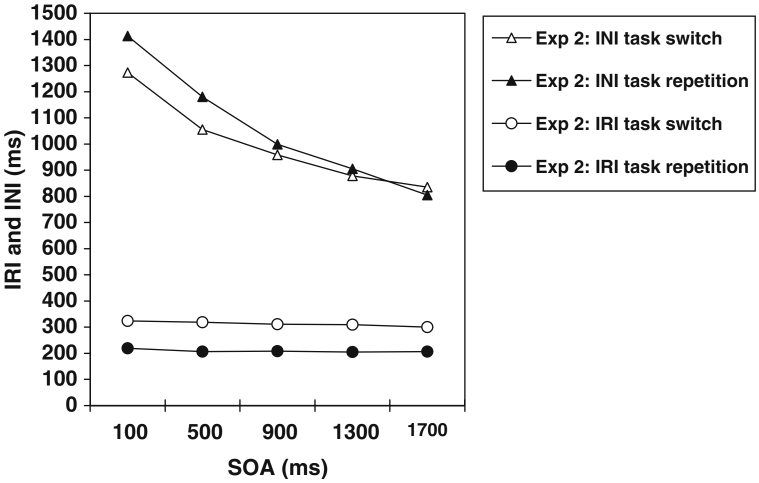
Results

Data analysis proceeded as before. The first trial of each block and all wrong-key error trials (9.5%) were excluded. Moreover, 2.1% of trials were excluded because responses were too early, and another 4.5% of trials were excluded because responses occurred too late. Of the remaining trials, another 2.7% of the trials were omitted because of an IRI larger than 800 ms. Overall, 81.6% of trials were included in the RT analysis.

Overall data pattern and comparison with Experiment 1

Fig. 3 shows INI and IRI as a function of task transition and SOA. As in Experiment 1, there was a large effect of SOA in INIs, and only a small effect of SOA in IRIs (for statistical analysis, see below).

Fig. 3 Experiment 2 (*reversed response order*). INI and IRI as a function of task transition and SOA



The instruction to reverse response order did not affect the IRI et al. The mean IRI, averaged across SOAs, was 266 ms in Experiment 1 and 261 ms in Experiment 2 ($t(46) < 1$). Thus, participants grouped responses in Experiment 2 in the same way as in Experiment 1. Interestingly, reversing the response order had a large effect on the INI. The mean INI, averaged across SOAs, was 798 ms in Experiment 1 (maintained response order), as opposed to 1,030 ms in Experiment 2 (reversed response order), $t(46) = 15.0$, $P < 0.01$, two-tailed.

Inter-response interval

The 2×5 ANOVA with the independent variables task transition (between subjects) and SOA (within subjects) again yielded a significant main effect of task transition ($F(1,22) = 6.3$, MSE = 51,067, $P < 0.03$). The IRI was larger in the task-switch group than in the task-repetition group (313 ms versus 209 ms). There was also a main effect of SOA ($F(4, 88) = 4.7$, MSE = 238, $\varepsilon = 0.73$, $P < 0.02$), indicating a numerically small (17 ms), but still significant, decrease of IRI from the shortest to the longest SOA (IRIs were 271, 263, 259, 257, and 254 ms at SOAs 100, 500, 900, 1,300, and 1,700, respectively). There was no significant interaction of task transition and SOA ($F(4, 88) < 1.5$, $P > 0.20$).

INI. As in Experiment 1, there was a large main effect of SOA ($F(4, 88) = 128.1$, MSE = 8,030, $\varepsilon = 0.47$, $P < 0.01$) in INIs, and no significant main effect of task transition ($F < 1$). The interaction of task transition and SOA was significant ($F(4, 88) = 3.8$, MSE = 8,030, $\varepsilon = 0.47$, $P < 0.04$). As in Experiment 1, the INI tended to be shorter in the task-switch group than in the task-repetition group, and this difference was most pronounced at short SOAs and became smaller at longer SOAs.

Errors

The wrong-key errors in Experiment 2 consisted of 3.9% R1 errors, 4.7% R2 errors, and 1.0% double errors. The 2×5 ANOVA on wrong-key errors yielded a significant main effect of SOA ($F(4, 88) = 16.1$, MSE = 0.0011, $\varepsilon = 0.74$, $P < 0.01$), indicating a decreasing error rate with increasing SOAs. The error rate was 11.4, 7.5, 6.0, 5.1, and 4.5% for the five different SOAs, respectively (see Table 2). There was also a marginally significant main effect of task transition ($F(1, 22) = 4.0$, MSE = 0.0157, $P < 0.07$), indicating a tendency for a higher error rate in the task-switch condition (9.2%) than in the task-repetition condition (4.7%). The interaction was not significant ($F < 1$). The pattern of error data of Experiment 2 resembled that of Experiment 1.

Discussion

In Experiment 2, by using the instruction to respond to the second stimulus first, the basic data pattern of Experiment 1 was replicated. That is, the IRI was short compared to the INI, and numerically similar across all SOA conditions. The INI, on the other hand, increased by several hundred milliseconds with decreasing SOA. As was outlined above, this data pattern suggests that the IRI reflects only response execution, but not response selection, in the majority of the trials. Moreover, the average size of the IRI was remarkably similar in the two experiments (266 ms in Experiment 1 and 261 ms in Experiment 2). We conclude that both the instructions to wait for the second stimulus (Experiment 1) and to respond to the second stimulus first (Experiment 2) led to the same strategy of grouping the responses, that is, selecting both the responses before executing either in the majority of the trials.

IRI data

The task-switching costs in the IRI that were found in Experiment 1 were replicated in Experiment 2 are consistent with the idea that task switching affected late response processes. However, this conclusion is only preliminary. The data revealed that task switching had another effect as well. Namely, the proportion of

Table 2 Experiment 2: Errors (in %) as a function of task transition and SOA

	SOA (in ms)				
	100	500	900	1,300	1,700
Task switch	14.0	9.7	8.2	7.3	7.0
Task repetition	8.8	5.3	3.9	3.0	2.2

grouped responses was reduced in the task-switch condition relative to the task-repetition condition. This differential grouping tendency presumably contributed to the task-switch costs in the IRI. The differential grouping tendency becomes apparent in the small but significant SOA effects in the IRI data that were found in both the experiments. In Experiment 1, the IRI was not affected by SOA in the task-repetition condition, but slightly increased at shorter SOAs in the task-switch condition. In Experiment 2, the IRI again slightly increased at shorter SOAs, as was indicated by a main effect of SOA. These SOA effects are probably due to the fact that response selection occurred during the IRI (i.e., the responses were not grouped) in a certain percentage of the trials. Note, however, that the SOA effects in the IRI were small relative to the size of the task-switching costs in the IRI. Thus, the differential grouping tendency can probably not account for the whole size of the task-switching costs in the IRI.

To summarize, participants were grouping the responses in most, but not in all of the trials. Thus, the task-switching costs in the IRI are at least partly due to the participants grouping less efficiently in the task-switch condition than in the task-repetition condition. Thus, the data do not provide unequivocal evidence for task switching affecting late response processes. The finding of task switching reducing the tendency to group responses is a novel finding, and will be further discussed in the General Discussion.

INI data

It was striking that the instruction to reverse response order did not affect the size of the IRI et al., but did considerably increase the INI. On average, the INI was 232 ms slower in Experiment 2 (respond to the second stimulus first) than in Experiment 1 (wait for the second stimulus). Possibly, this increase reflects the time needed to reverse the order of two selected responses. This effect is interesting, but was not the focus of the present study and therefore will not be further discussed.

Another effect observed in the INI data, however, needs further consideration. Although there were no significant effects of task switching in the INI, there was a tendency for the INI to be faster in the task-switch condition than in the task-repetition condition in both Experiments 1 and 2. Assuming that both responses were selected during the INI, one would have expected costs of switching tasks, rather than facilitation. It is known from the task-switching literature that task switching has large effects on response selection (see Allport & Wylie, 2000; Meiran, 2000; Schuch & Koch, 2003). Thus, if there was a task switch from the first to the second response, and if both responses were selected during the INI, this should have resulted in tasking-switch costs in the INI. The lack of task-switching costs in the INI was probably due to task-pair switching costs, which counteracted task-switching costs in the present paradigm. As was discussed earlier, two different kinds of task-pairs were used in the task-repetition condition (parity–parity in one trial, magnitude-magnitude in the next trial, etc.), but only one task- pair was used in the task-switch condition (either parity–magnitude only, or magnitude–parity only). It is known from the dual-task literature that task-pair switching produces costs (see De Jong, 1995; Lien & Ruthruff, 2004; Luria & Meiran, 2003). In the present paradigm, the task-pair switching costs might have counteracted the task-switching costs in the INI. Therefore, we conducted another experiment where we controlled task-pair switching costs.

Experiment 3

In Experiment 3, we aimed to replicate the task-switch costs in the IRI, and to obtain task-switch costs in the INI as well. To this end, we modified the design. Only one kind of task pair was used in each condition. In the task-repetition condition, only the parity–parity task pair or only magnitude-magnitude task pair was used (alternating between blocks). In the task-switching condition, only the parity–magnitude task pair or only magnitude–parity task pair was used (also alternating between blocks). As a further change of the paradigm, we manipulated task switch/task repetition as a within-subjects variable in Experiment 3, rather than between subjects as in Experiments 1 and 2. Moreover, we used only three SOAs (100, 900, 1,700) in Experiment 3 instead of five SOAs in Experiments 1 and 2. A response-grouping strategy was induced by instructing participants to wait for the second stimulus, just as in Experiment 1.

Method

Participants

Sixteen new participants (8 females, 8 males, mean age 24.6 years) were tested and received 12 [euro].

Tasks, stimuli, and responses

These were the same as before.

Design

Task transition (task switch/task repetition) and SOA (100, 900, 1700 ms) were both varied as within-subject variables. SOA varied randomly from trial to trial. Task switch and task repetition alternated blockwise. Every participant went through the two possible task-repetition blocks (magnitude-magnitude and parity–parity), and the two possible task-switch blocks (magnitude–parity and parity–magnitude).

The order of blocks was counterbalanced across participants. The first block could either be parity–parity, magnitude-magnitude, parity–magnitude, or magnitude–parity. The second block was a task-switch block if the first had been a task-repetition block, and a task-repetition block if the first had been a task-switch block. Moreover, the second task was constant across blocks 1 and 2. For instance, a participant starting with parity–parity in the first block would perform magnitude–parity in the second block. For that participant, block 3 would be magnitude-magnitude, and block 4 would be parity–magnitude. Blocks 5–8 repeated the order of task pairs applied in blocks 1–4. The S-R mappings were also counterbalanced across participants. There were four possible S-R mappings, resulting in 16 combinations of task-pair orders and S-R mappings.

Procedure

Participants received the same instructions as in Experiment 1, that is, they were told to wait for the second stimulus before they started responding. They went through four practice blocks of 36 trials each, with the task pairs parity–parity, magnitude-magnitude, parity–magnitude, and magnitude–parity, respectively. After the practice blocks, they performed 8 blocks of 84 trials each, resulting in 112 trials per condition.

Results

Data analysis proceeded as before. There were 5.1% wrong-key errors, 0.5% too-early errors, and 1.0% too-slow errors. Another 0.8% of the remaining trials were excluded due to an IRI of more than 800 ms. Overall, there were 91.9% of trials included in the RT analysis.

Overall data pattern

With respect to SOA effects, the overall data pattern resembled that of the previous experiments. There was a large SOA effect on INIs, but only a small SOA effect on IRIs (see Fig. 4). Again, IRIs were short (about 250 ms) at all SOAs, indicating grouping of responses. As in the previous experiments, there were switch costs in the IRI. However, in contrast to the previous experiments, there were also switch costs in the INI. (For statistical analysis of these effects, see below.)

Inter-response interval

The 2×3 ANOVA with the within-subjects variables task transition and SOA yielded a significant main effect of task transition ($F(1, 15) = 42.7$, $\mathrm{MSE} = 2558$, $P < 0.01$), indicating switch costs of 67 ms. There was also a main effect of SOA ($F(2, 15) = 21.2$, $\mathrm{MSE} = 364$, $\varepsilon = 0.65$, $P < 0.01$), indicating larger IRIs at short SOAs. (Mean IRIs were 266, 243, 236 ms at SOAs 100, 900, 1,700, respectively.) The interaction of task transition and SOA was also significant ($F(2, 15) = 22.1$, $\mathrm{MSE} = 395$, $\varepsilon = 0.66$, $P < 0.01$). Switch costs were 103, 61, and 38 ms at SOAs 100, 900, and 1700, respectively ($t(15) = 6.3$, $P < 0.01$; $t(15) = 6.2$, $P < 0.01$; $t(15) = 5.1$, $P < 0.01$; all t-tests two-tailed).

We suppose that the SOA effects in the IRI indicate a tendency of reduced grouping in the task-switch condition, as was discussed above. Possibly, participants did not always group responses in the task-switch condition, and this tendency might have contributed to the switch costs found in the IRI. Consistent with this assumption, the IRI increased with decreasing SOA in the task-switch condition ($F(2, 30) = 23.9$, $\mathrm{MSE} = 683$, $\varepsilon = 0.58$, $P < 0.01$), but the IRI did not differ across SOAs in the task-repetition condition ($F < 1.1$). Moreover, the IRI variances were larger in the task-switch condition (standard deviation: 76.8 ms) than in the task-repetition condition (standard deviation: 44.3 ms), all of which had also been observed in the previous experiments.

INI

INI. The ANOVA on INI times also yielded a main effect of task transition ($F(1, 15) = 110.0$, $\mathrm{MSE} = 6587$, $P < 0.01$), indicating switch costs (174 ms) in the INI. There was also a main effect of SOA ($F(2, 15) = 157.5$, $\mathrm{MSE} = 7{,}333$, $\varepsilon = 0.60$, $P < 0.01$), and an interaction of task transition and SOA ($F(2, 15) = 59.3$, $\mathrm{MSE} = 1{,}907$, $\varepsilon = 0.81$, $P < .01$). The interaction indicated that switch costs became smaller with increasing SOA (switch costs were 298, 162, and 61 ms, respectively).

Errors

The wrong-key errors consisted of 1.1% R1 errors, 3.2% R2 errors, and 0.8% double errors. The 2×5 ANOVA on wrong-key errors yielded a significant main effect of SOA ($F(4, 88) = 15.9$, $\mathrm{MSE} = 0.0012$, $\varepsilon = 0.66$, $P < 0.01$), with more errors at shorter SOAs, and a significant main effect of task transition ($F(1, 22) = 23.1$, $\mathrm{MSE} = 0.0024$, $P < 0.01$), with more errors in the task-switch condition than in the task-repetition condition. The interaction of SOA and task transition was also significant ($F(4, 88) = 10.8$, $\mathrm{MSE} = 0.0005$, $\varepsilon = 1.0$, $P < 0.01$), indicating larger switch costs at shorter SOAs than at longer SOAs (switch costs were 7.6, 4.2, 2.5% at SOAs 100, 900, and 1,700 ms, respectively; see Table 3). The data pattern of error rates resembled that of Experiments 1 and 2.

Task-switch costs in IRI quintiles

The SOA effects on IRI showed that participants might not have grouped the responses in all the trials.

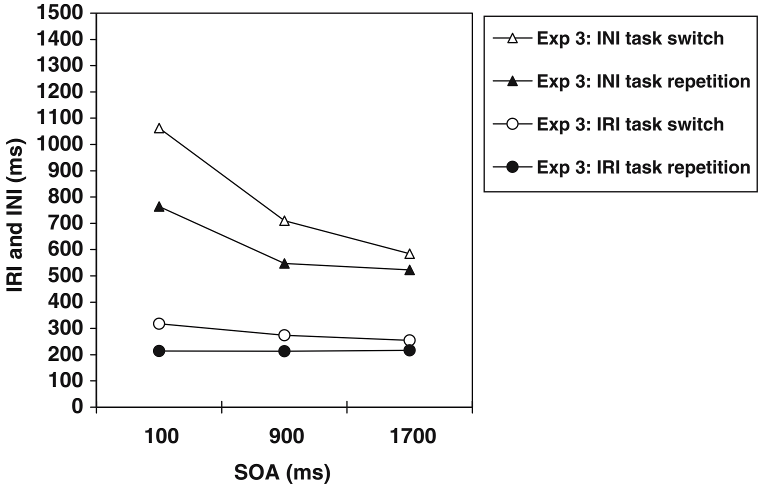


Fig. 4 Experiment 3 (*no task-pair switching*). INI and IRI as a function of task transition and SOA

Therefore, we conducted an additional analysis to explore whether the task-switch costs were confined to the non grouping trials. The non grouping trials are those with a long IRI, because in these trials, response selection occurred during the IRI. Thus, we analyzed whether the task-switch costs were confined to trials with long IRIs, or if they occurred even at short SOAs.

The IRIs were divided into quintiles, separately for the task-switch condition and the task-repetition condition. This was done separately for each participant, and then averaged across participants. Fig. 5 shows the mean IRIs in the different IRI quintiles, separately for the task-switch and the task-repetition condition. The ANOVA with the independent variables IRI quintile and task transition yielded a main effect of IRI quintile, $F(4,60) = 170.1$, MSE = 1,679, $\varepsilon = 0.29$, $P < 0.01$, a main effect of task transition, $F(1, 15) = 42.6$, MSE = 4175, $P < 0.01$, and an interaction, $F(4,60) = 41.1$, MSE = 532, $\varepsilon = 0.38$, $P < 0.01$, indicating larger switch costs at larger IRIs. From the smallest to the largest IRI quintile, the task-switch costs were 24, 33, 46, 77, and 153 ms. When tested separately for each IRI quintile, task-switch costs were significant in each IRI quintile ($t(15) = 3.6$, $P < 0.01$; $t(15) = 4.3$, $P < 0.01$; $t(15) = 4.5$, $P < 0.01$; $t(15) = 5.3$, $P < 0.01$; $t(15) = 8.0$, $P < 0.01$, respectively; all t-tests two-tailed). Thus, task-switch costs were larger at the larger IRIs, supporting the idea that there were more non-grouping trials in the task-switch condition than in the task-repetition condition. Importantly, however, task-switch costs were still present in the smallest IRI quintile. As the IRIs in the smallest quintile were in the order of 150 ms, it is likely that the majority of these trials were grouping trials.

To evaluate the relative proportion of grouping and non grouping trials, we plotted the IRI distributions for each IRI quintile, separately for the task-repetition and the task-switch condition. Fig. 6 shows the IRI distributions for the shortest IRI quintile, where the task-switching costs were the smallest. As can be seen, the IRI distribution in the task-switching condition was shallower and wider than in that in the task-repetition condition. This probably indicated a higher proportion of nongrouping trials in the task-switching condition than in the task-repetition condition. Thus, even in the shortest IRI quintile, where the smallest task-switching costs were observed, part of these task-switching costs seemed to be due to less grouping in the task-switching condition.

Response-repetition analysis

Half of the trials in the present paradigm in both the task-switch and the task-repetition condition required repeating the same response. There is evidence that task-switch costs are especially large in response-repetition trials (e.g., Schuch & Koch, 2004). To control whether the task-switch costs in the IRI were confined to these response-repetition trials, we analyzed the response-repetition data and the response-switch data separately. Fig. 7 shows that the response-repetition trials were slower overall, but with respect to task-switch costs, the same data pattern was obtained for the response-repetition trials and the response-switch trials. Statistical analyses confirmed that the task-switch costs in the IRI occurred in both response-repetition trials and in response-switch trials. The 2×3 ANOVA (with the independent variables task transition and SOA) on response-repetition trials revealed a main effect of task transition ($F(1, 15) = 38.1$, MSE = 2,531, $P < 0.01$), a main effect of SOA ($F(2, 15) = 28.8$, MSE = 370, $\varepsilon = 0.75$, $P < 0.01$), and an interaction of task transition and SOA ($F(2, 15) = 22.3$, MSE = 575, $\varepsilon = 0.70$, $P < 0.01$). Task-switch costs were 107, 54, and 29 ms for the SOAs of 100, 900, and 1700 ms, respectively ($t(15) = 5.9$, $P < 0.01$, $t(15) = 6.3$, $P < 0.01$, $t(15) = 4.1$, $P < 0.01$, respectively, all t-tests two-tailed). The same ANOVA on response switch trials revealed a main effect of task transition ($F(1, 15) = 41.0$, MSE = 3,051, $P < 0.01$), a main effect of SOA ($F(2, 15) = 9.9$, MSE = 548, $\varepsilon = .64$, $P < 0.01$), and

Table 3 Experiment 3: Errors (in %) as a function of task transition and SOA

	SOA (in ms)		
	100	900	1,700
Task switch	11.5	6.7	4.2
Task repetition	3.9	2.5	1.7

an interaction of task transition and SOA ($F(2, 15) = 16.0$, $MSE = 368$, $\varepsilon = 0.83$, $P < 0.01$). Task-switch costs were 101, 69, and 47 ms for the SOAs of 100, 900, and 1700 ms, respectively ($t(15) = 6.6$, $P < 0.01$, $t(15) = 5.6$, $P < 0.01$, $t(15) = 4.9$, $P < 0.01$, all t-tests two-tailed).

Discussion

IRI data

In Experiment 3, we replicated the basic finding of task-switch costs in the IRI of a response sequence. Again, this effect could either have been due to task switching rendering the grouping of responses less likely, or to task switching affecting late response processes. Further research is needed to determine the relative proportion of these two effects of task switching.

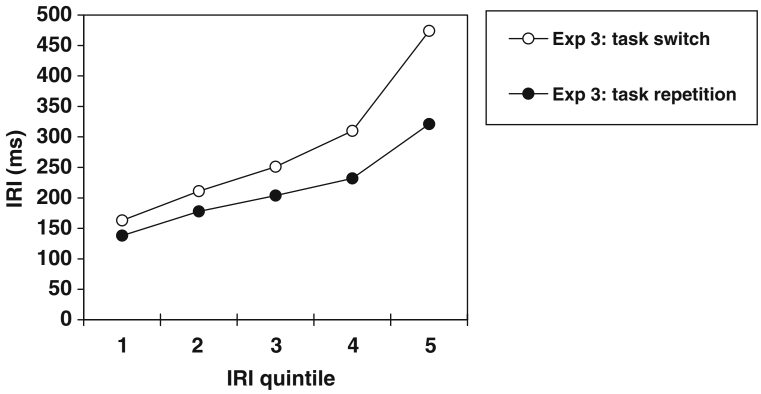
INI data

In contrast to the previous experiments, we found task-switching costs in the INI in Experiment 3. In the previous experiments, the task-switching costs had presumably been counteracted by task-pair switching costs. In Experiment 3, we controlled for task-pair switching costs by using only one task pair in both conditions, and obtained task-switch costs in the INI. The result of task-switch costs in the INI is in line with the assumption that both the first and the second responses were selected during the INI. It is known from the literature that response selection takes longer on task-switch trials than on task-repetition trials (e.g., Allport & Wylie, 2000; Meiran, 2000; Schuch & Koch, 2003). In the task-switch condition of Experiment 3, both the first and the second task constituted a task switch, whereas in the task-repetition condition, both tasks constituted a task repetition. Thus, the finding of task-switch costs in the INI is in line with the existing literature on response selection and task switching.

Note, however, that other processes might have contributed to the task-switching costs in the INI as well. In particular, mixing costs (e.g., Los, 1996; Meiran, 2000) probably played a role. Mixing costs are defined as the mean RT difference between blocks in which two tasks occur (as in the task-switch condition of Experiment 3), and blocks in which only one task will occur during the whole block (as is the case in the task-repetition condition of Experiment 3). Note that we had controlled mixing costs in Experiments 1 and 2, where two tasks had been occurring in both the task-switch condition and the task-repetition condition. Controlling for mixing costs led to the confound of task-pair switching costs, and vice versa. Thus, the effects in the INI in the present paradigm cannot be easily interpreted. The task-switching costs observed in the INI of Experiment 3 presumably consisted of at least two components: task-switching costs and mixing costs. The INI data in Experiments 1 and 2 presumably reflected two counteracting effects: task-switching costs and task-pair switching costs.

Another finding was that the task-switching costs became smaller at longer SOAs. This effect cannot be easily interpreted either, because it is not clear which of the processes occurring during the INI contributed to this effect. All we can say is that this effect is probably not related to task-pair switching. The reason is that a similar effect was observed in Experiments 1 and 2: The effect of task switching—which in Experiments 1 and 2 was a tendency for task-switch facilitation—tended to become smaller at longer SOAs. Other processes possibly responsible for the pattern of task-switch costs in the INI include categorization of the first stimulus, selection of the first response, categorization of the second stimulus, selection of the

Fig. 5 Experiment 3 (*no task-pair switching*). Mean IRI in task-switch trials and task-repetition trials, computed separately for the different IRI quintiles.



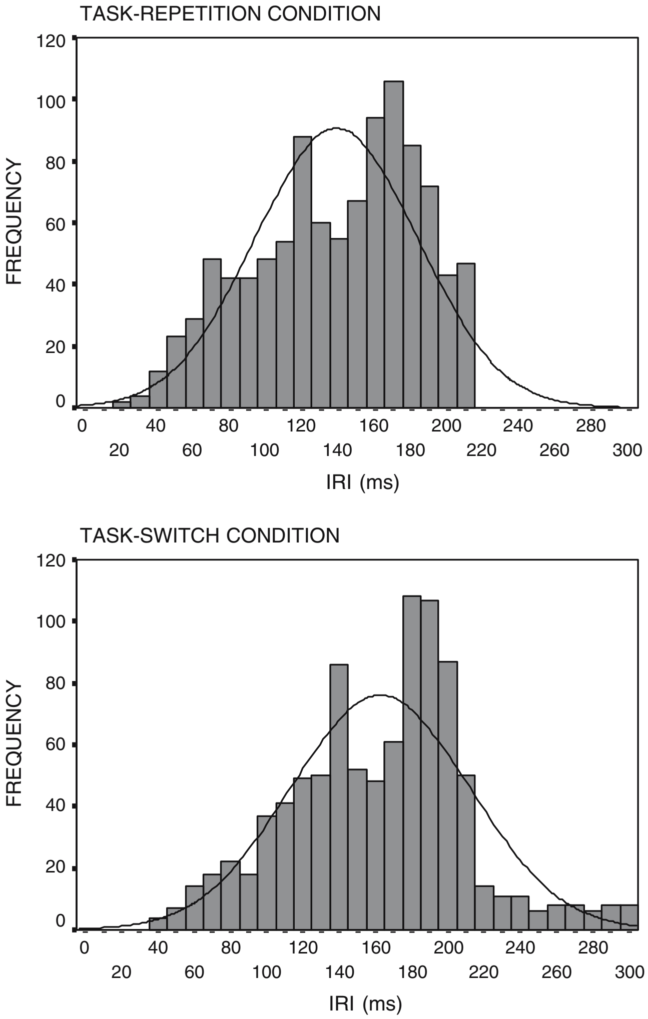


Fig. 6 Experiment 3. IRI distributions of the shortest IRI quintile for the task-switch condition and the task-repetition condition

second response, and possibly the construction of a response sequence. There is even evident that early perceptual processes may be slowed or postponed by task switching (Oriet & Jolicoeur, 2003). It remains to be determined which of these processes contributed to the task-switch costs becoming smaller at longer SOAs. The present paradigm is not well suited for exploring processes that occur during the INI, as it was specifically designed to investigate processes occurring during the IRI.

Response-repetition effects

In the present experiments, half of the trials consisted of performing the same response twice (i.e., left key – left key, or right key – right key). As it is known from the task-switching literature that task-switch costs are more pronounced in response-repetition trials than in response-switch trials (e.g., Rogers & Monsell, 1995; Schuch & Koch, 2004), we analyzed the response-repetition and response-switch trials separately. Importantly, the task-switch costs in the IRI were not confined to the response repetition trials, but also occurred in the response-switch trials. This was true for all three experiments. We reported the response-repetition analysis only for Experiment 3, where the task-switch costs were the smallest.

General discussion

Using a dual-task response grouping paradigm, we showed in three experiments that task-switch costs occurred in the interval between the first and the second responses. The IRI was always short relative to the latency of the first response, and was only marginally affected by the SOA manipulation relative to the SOA effects on the first response.

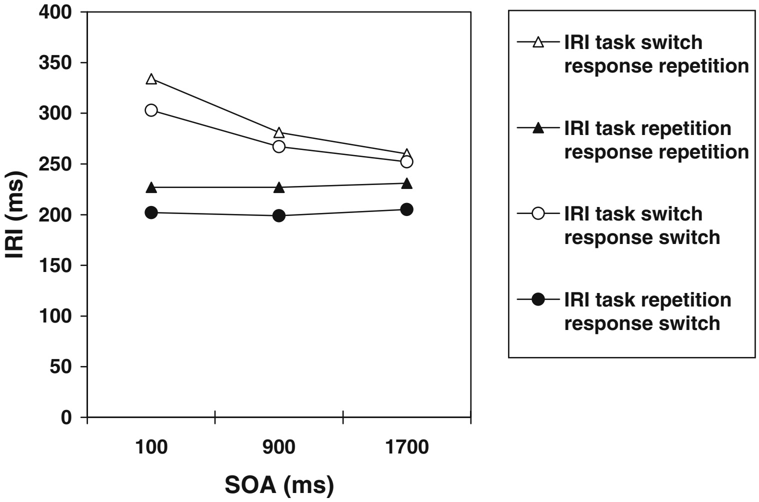
This data pattern implied that the two responses were performed as a response sequence. The IRI reflected the time needed for executing the second of the two responses. Selection of the second response had occurred prior to the IRI. Finding task-switching costs in the IRI is consistent with the idea that task switching affected late response processes. However, the data do not provide unequivocal evidence for this idea. The reason is that task switching had another effect on performance, namely, it reduced the probability of performing the two responses as a sequence. This second effect is suggested by the pattern of the numerically small SOA effects in the IRI data: In the task-switch condition, the IRI slightly increased of shorter SOAs. In the task-repetition condition, the IRI was constant across the different SOAs, as one would have expected when the responses were grouped in all SOA conditions. This data pattern suggests that in the task-switch condition, there was some percentage of nongrouping trials. In these trials, where the responses were not grouped, the second response was selected during the IRI, resulting in a longer IRI. Whether the tendency of reduced grouping in the task-switch condition can account for the whole size of the task-switching costs in the IRI remains to be determined.

On the basis of the present data, we conclude that task switching might have had two effects on task performance. First, it may have prolonged response execution and second, it reduced the tendency to perform the two responses as a response sequence. Both of these effects are novel findings, and need to be further investigated. In the following, we discuss the theoretical implications of these two possible effects of task switching.

Task switching and late response processes

The idea that task switching might affect late response processes is based on considerations in the dual-task

Fig. 7 Experiment 3. IRI as a function of task transition and response repetition



literature. It has been suggested that processes that occur when response selection has completed might be subject to interference in dual-tasks. In particular, several authors have argued that response initiation could be a locus of interference in dual task performance (De Jong, 1993; De Jong, Coles, Logan, & Gratton, 1990; Keele, 1973; Logan & Burkell, 1986; Pashler, 1994a).

Similar ideas can be found in the literature on motor control. For instance, Ilan and Miller (1999) suggested that the initiation of response preparation interferes with other cognitive processes. The initiation of response preparation is indicated by the onset of the lateralized readiness potential (LRP). They showed that the initiation of response preparation interferes with memory search, size discrimination, and categorization. In contrast, the continuation of response preparation, which is indicated by an increasing LRP after LRP onset, does not interfere with these other cognitive processes. In a similar vein, other researchers on motor control identified a central component of motor processes termed motor programming. During motor programming, movement parameters (such as movement amplitude, direction, etc.) are specified (e.g., Diedrichsen, Ivry, Hazeltine, Kennerly, & Cohen, 2003; Rosenbaum, 1980; Spijkers, Heuer, Steglich, & Kleinsorge, 2000). Importantly, motor programming is thought to result in a still central representation of the response that is not effector specific, that is, does not involve specific muscle groups. As opposed to the central processes of motor programming, the process of motor execution is thought to result in peripheral motor activity.

Given these ideas of early motor processes being central cognitive processes that interfere with other cognitive processes, we raised the question whether motor processes might also be affected by task-switch related interference. As has been outlined in the Introduction, task-switch related interference has been shown to affect several processes of task performance. For instance, task-switch interference involves stimulus categorization processes and response selection. The question addressed in the present study was whether task switching also affects late response processes. The answer to this question is still open. However, another interesting result emerged from the present study: Task switching affects response grouping, that is, the process of combining several responses into one response sequence.

Task switching and the tendency to group responses

In the motor-control literature, it has been suggested that performing a response sequence involves an extra process of sequence construction. Verwey (1994) suggested that sequence construction occurs after the selection of the respective responses, but before motor programming. The process of sequence construction is not well understood. Possibly, a higher-order response-sequence code is created that includes the identity of the responses as well as the order of the responses.

In the present paradigm, subjects presumably proceeded by selecting one response, remembering this selected response while selecting the second response, integrating the two response codes in one sequence code, and then executing the response sequence. We can only speculate how task switching affected the performance of the response sequence. One possibility is that the responses are less likely to be combined into a sequence when they do not belong to the same task context. Failing to establish a higher-order sequence code, subjects proceed by selecting and executing the first response, and then selecting and executing the second response. Another possibility is that there is interference between the response codes that belong to different task contexts. For instance, interference could occur when one response has to be selected while another, already selected, response has to be maintained in working memory. In a similar vein, interference could occur during the execution of one response, when another response code must be maintained in working memory for later execution of that action. This could have two consequences. First, the code for the second response could become impaired, so that the second response must be reselected. Second, the execution of the first response could be delayed. If this were true, then the effect of task switching slowing response execution, and the effect of task switching reducing the tendency to group the responses, would be two sides of the same coin.

The exact mechanisms of the interaction of task switching and action sequencing remain to be determined. On the basis of the present data, we conclude that performing two actions as an action sequence is less likely when the two actions belong to different tasks than when they belong to the same task context. Note that, in the present experiments grouping was not instructed explicitly. Rather, participants were instructed to wait for the second stimulus before they started responding, or to respond to the second stimulus first. Thus, we measured a "natural," or "automatic," tendency to perform the two responses as a response sequence. Possibly, an explicit instruction to group the responses would further increase the proportion of grouping.

In general, the finding of task switching affecting action sequencing might be only one of many ways that task switching is interacting with higher-order control processes. Such effects are difficult to investigate with the standard task-switching paradigm, with its narrow focus on single-task performance. To better understand the mechanisms of task switching, it might therefore be beneficial to move on to dual-task paradigms, or even multiple-task paradigms, where more control processes come into play.

Acknowledgements We thank Chris Oriet and Torsten Schubert for useful comments on an earlier version of this paper. We are also grateful to Werner Sommer for helpful discussions of this work.

References

Allport D.A., Wylie G. (2000) Task-switching, stimulus-response bindings and negative priming. In: Monsell S., Driver J.S. (eds) Attention and performance XVIII Control of cognitive processes. MIT Press, Cambridge MA, pp. 35–70

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

Borger R. (1963) The refractory period and serial choice-reactions. Quarterly Journal of Experimental Psychology 15:1–12

De Jong R. (1993) Multiple bottlenecks in overlapping task performance. Journal of Experimental Psychology: Human Perception & Performance, 19:965–980

De Jong R. (1995) The role of preparation in overlapping-task performance. Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology, 48A:2–25

De Jong R., Coles M.G., Logan G.D., GrattonG. (1990) In search of the point of no return: The control of response processes. Journal of Experimental Psychology: Human Perception & Performance, 16:164–182

Diedrichsen J., Ivry R. B., Hazeltine E., Kennerly S., Cohen A. (2003) Bimanual interference associated with the selection of target locations. Journal of Experimental Psychology: Human Perception & Performance, 29:64–77

Ilan A. B., Miller J. (1999) A distinction between the initiation and the continuation of response preparation. Psychophysiology 36:209–219

Keele S. (1973) Attention and human performance. Palisades CA, Goodyear

Lien M.-C., Ruthruff E. (2004) Task switching in a hierarchical task structure: Evidence for the fragility of the task repetition benefit. Journal of Experimental Psychology: Learning Memory and Cognition 30:697–713

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 & Performance 29:692–712

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

Logan G.D., Gordon R.D. (2001) Executive control of visual attention in dual-task situations. Psychological Review 108:393–434

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

Los S.A. (1996) On the origin of mixing costs: Exploring information processing in pure and mixed blocks of trials. Acta Psychologica 94(2):145–188

Luria R., Meiran N. (2003) Online order control in the PRP paradigm. Journal of Experimental Psychology: Human Perception & Performance 29:556–574

Mayr U., Keele S.W. (2000) Changing internal constraints on action: The role of backward inhibition. Journal of Experimental Psychology: General, 129:4–26

Meiran N. (2000) The reconfiguration of the stimulus task-set and the response task-set during task switching. In: Monsell S., Driver J. (eds) Attention and performance XVIII: Control of cognitive processes. MIT Press, Cambridge MA, pp. 377–400

Oriet C., Jolicoeur P. (2003) Absence of perceptual processing during reconfiguration of task set. Journal of Experimental Psychology: Human Perception & Performance 29:1036–1049

Pashler H. (1994a) Dual-task interference in simple tasks: Data and theory. Psychological Bulletin 116:220–244

Pashler H. (1994b) Graded capacity-sharing in dual-task interference? Journal of Experimental Psychology: Human Perception & Performance 20:330–342

Pashler H., Johnston J.C. (1989) Chronometric evidence for central postponement in temporally overlapping tasks. Quarterly Journal of Experimental Psychology 41(A):19–45

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

Rosenbaum D.A. (1980) Human movement initiation: Specification of arm, direction, and extent. Journal of Experimental Psychology: General 109:444–474

Ruthruff E., Pashler H., Klaassen A. (2001) Processing bottlenecks in dual-task performance: Structural limitation or strategic postponement? Psychonomic Bulletin & Review 8:73–80

Ruthruff E., Pashler H., Hazeltine E. (2003) Dual-task interference with equal task emphasis: Graded capacity-sharing or central postponement? Perception and Psychophysics 65:801–816

Sanders A.F. (1998) Elements of human performance: Reaction processes and attention in human skill. Erlbaum, Mahwah, NJ

Schuch S., Koch I. (2003) The role of response selection for inhibition of task sets in task shifting. Journal of Experimental Psychology: Human Perception & 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 & Performance 30:566–582

Sommer W., Leuthold H., Abdel-Rahman R., Pfuetze E.-M. (1997) Die Lokalisierung des Gruppierungseffektes bei überlappenden Aufgaben [Localization of the grouping effect in overlapping tasks]. Zeitschrift für Experimentelle Psychologie 154:103–117

Spijkers W., Heuer H., Steglich C., Kleinsorge T. (2000) Specification of movement amplitudes for the left and right hands: Evidence for transient parametric coupling from overlapping-task performance. Journal of Experimental Psychology: Human Perception & Performance 26:1091–1105

Verwey W.B. (1994) Mechanisms of skill in sequential motor behavior. Doctoral dissertation, Free University, Amsterdam