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Introspection Is Not Always Blind to the Costs of Multitasking: The Case of Task Switching

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Previous studies have provided evidence that introspection about dual-task performance in the psychological refractory period (PRP) paradigm is severely limited. The present study investigated introspection at the other pole of the multitasking continuum, namely task switching. In 2 experiments, participants provided estimates of their response times (i.e., introspective RTs) after each trial in modified versions of the alternating-runs and the task-cuing paradigm, which included only 2 tasks in a trial. In contrast to the previously observed unawareness of dual-task costs in the PRP paradigm, participants reported their switch costs in introspective RTs. Thus, introspection about multitasking performance appears to not always be as limited as in the PRP paradigm. Nevertheless, introspection is not without limits also in task switching. Participants only partly reported the beneficial impact of longer preparation time on their performance. The present results suggest that introspective RTs depend on multiple cues, of which some are valid and some are invalid.

Keywords: task switching, PRP, introspection, awareness, preparation

After more than a century of laboratory research on multitasking, we know that people have great difficulties in attending to more than one task at the same time and that concurrent task performance is often associated with dual-task costs (e.g., Jastrow, 1891; Pashler, 1994). The same holds true for the other pole of the multitasking continuum (see Salvucci, Taatgen, & Borst, 2009), namely task switching. Even when people perform multiple tasks sequentially without any temporal overlap, switching between the tasks usually leads to worse performance than when the tasks are to be repeated (e.g., Jersild, 1927; for a concise review, see Monsell, 2003). These costs of multitasking can be exacerbated by sleep loss, nonoptimal time of day, or both (Bratzke, Rolke, Steinborn, & Ulrich, 2009; Bratzke, Rolke, Ulrich, & Peters, 2007), and acute stress (Plessow, Kiesel, & Kirschbaum, 2012; Plessow, Schade, Kirschbaum, & Fischer, 2012). Nevertheless, there is no doubt that people often engage in multitasking even when they are free to choose. Why do they take the risk? A simple and obvious explanation would be that they lack awareness of the costs that arise in multitasking.

Indeed, a few applied studies using continuous dual-task paradigms (e.g., cell phone use during driving) have suggested that

people are often not aware of the costs associated with multitasking (e.g., Horrey, Lesch, & Garabet, 2009; Lesch & Hancock, 2004), even though they may actually anticipate costs before they engage in multitasking (Finley, Benjamin, & McCarley, 2014). Recent laboratory research using a discrete dual task confirmed that people cannot accurately introspect about their dual-task costs (Bratzke & Bryce, 2016; Bratzke, Bryce, & Seifried-Dübon, 2014; Bryce & Bratzke, 2014, 2015, 2017; Corallo, Sackur, Dehaene, & Sigman, 2008; Marti, Sackur, Sigman, & Dehaene, 2010). All these studies used the classical psychological refractory period (PRP) paradigm in which participants perform two tasks with varying temporal overlap (i.e., stimulus onset asynchrony, SOA). What is usually observed in this paradigm is an increase of the response time for the second task (RT2) with increasing temporal overlap (i.e., decreasing SOA), the so-called PRP effect (Pashler, 1994; Welford, 1952). Intriguingly, in introspective estimates of RT2 (IRT2) this PRP effect was either completely absent (Bryce & Bratzke, 2014; Corallo et al., 2008; Marti et al., 2010) or extremely small and accompanied by the same effect on IRT1 (Bryce & Bratzke, 2015). This introspective lack of the PRP effect has been observed irrespective of the method used to assess IRTs (Bryce & Bratzke, 2015, 2017).

The reason for the apparent unawareness of the PRP effect is still under debate. Some have proposed that it results from a unified attentional processing bottleneck that encompasses not only response selection but also conscious perception (Marti et al., 2010; Marti, Sigman, & Dehaene, 2012; see also Tombu et al., 2011). According to this view, the PRP effect is not reflected in IRTs because central processing (e.g., response selection) of Task 1 blocks the conscious access to Task 2. In our previous work, we have argued that this misperception of dual-task costs actually results from limited timing abilities in this highly demanding situation, which tempt participants to draw potentially mistaken

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inferences about the temporal processing demands (Bratzke & Bryce, 2016; Bratzke et al., 2014; Bryce & Bratzke, 2014, 2017). We stipulate that these two accounts are not mutually exclusive and that both may play an important role in introspection about one's own performance, even though their contribution may differ depending on the specific task and context.

As mentioned before, concurrent task performance as in the PRP paradigm constitutes only one pole of the multitasking continuum. Little is yet known about introspection at the other pole of the continuum, that is, when people switch between different tasks without any temporal overlap. Since the pioneering study of Jersild (1927), a large number of studies using a variety of different experimental paradigms have consistently demonstrated that switching between tasks entails costs in terms of response slowing and error proneness (see Monsell, 2003). A number of active task-set reconfiguration as well as passive interference processes have been suggested to be involved in task-switching performance (for reviews see Kiesel et al., 2010; Vandierendonck, Liefoghe, & Verbruggen, 2010). The finding that switch costs usually reduce with increasing preparation time has been taken as evidence that parts of these processes (e.g., active task-set reconfiguration) can take place in advance of a task switch (Rogers & Monsell, 1995).

Investigating introspection in task switching may not only provide an answer to the very basic question of how people experience their task switching performance but may also contribute to our understanding of the underlying cognitive mechanisms at play in different multitasking contexts (i.e., concurrent vs. sequential multitasking). That is, switch costs in task-switching paradigms and dual-task costs in the PRP paradigm have been suggested to arise from the same (or at least similar) underlying processing limitations (Band & van Nes, 2006; Lien, Schweickert, & Proctor, 2003; Oriet & Jolcœur, 2003; Pashler, 2000; Sigman & Dehaene, 2006). For example, Oriet and Jolcœur (2003) provided empirical evidence that task-set reconfiguration can be a bottleneck process

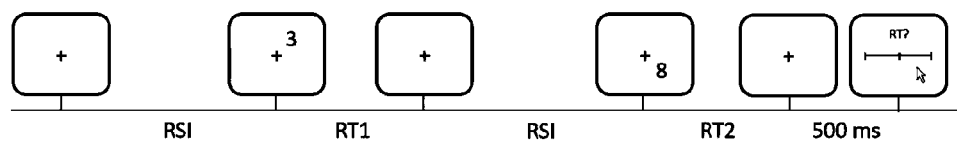
(as response selection is in the PRP paradigm), though this conclusion has been challenged on both methodological (Gilbert, 2005) and empirical grounds (Mackenzie & Leuthold, 2011). If indeed the two types of multitasking costs (dual-task costs and switch costs) arise from (at least partly) the same processing mechanisms, and if these mechanisms give rise to the introspective limitations in the PRP paradigm, one would expect that people can also not accurately introspect about their task-switching performance.

The Present Study

In the present study, we investigated people's introspection about their task-switching performance by extending the introspective RT approach (i.e., the method of quantified introspection; Corallo et al., 2008) to two different standard task-switching paradigms, the alternating-runs (AR) paradigm (Experiments 1a and 1b; e.g., Rogers & Monsell, 1995) and the task-cuing paradigm (Experiment 2; e.g., Meiran, 1996). To assess introspective RTs we used the visual analogue scales that have been used in most previous introspective RT studies (Bryce & Bratzke, 2014, 2015; Corallo et al., 2008; Marti et al., 2010). We modified both task-switching paradigms so that participants always performed a sequence of two tasks (Task 1 and Task 2) within a trial and subsequently provided IRTs for the tasks (only for Task 2 in Experiment 1a and for both tasks in Experiments 1b and Experiment 2; see Figure 1 for an illustration of a trial in each paradigm).

Regarding objective RT performance we expected to find the standard result pattern in these paradigms, that is, switch costs and a reduction of switch costs with increasing preparation time. Regarding introspection, we hypothesized that task-set reconfiguration may constitute a bottleneck that can block conscious access to another task (as does response selection in the dual-task context). Accordingly, in the extreme case participants might be completely

Experiment 1a/b: Alternating-Runs Paradigm



Experiment 2: Task-Cuing Paradigm

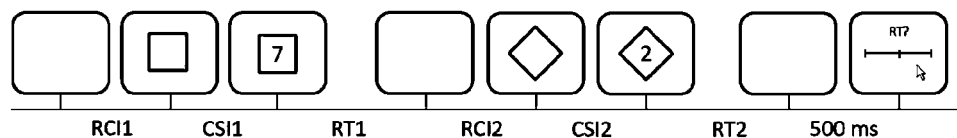


Figure 1. Time course of an experimental trial in the task-switching paradigms used in Experiment 1 and 2. In the alternating-runs paradigm, the stimuli appeared in a clockwise fashion around the fixation cross (the first position was chosen at random on each trial), and the position indicated which task to perform (e.g., parity task in upper positions, size task in lower positions). The response-stimulus interval (RSI) was the same for the two tasks within a trial. In the task-cuing paradigm, frames of different shapes (square vs. diamond) served as cues for which task to perform. The response-cue interval (RCI) and the cue-stimulus interval (CSI) varied independently for the two tasks. In both paradigms, after each sequence of two tasks, participants provided on a visual analogue scale (VAS) an estimate of their response time (RT) for the second task (Experiment 1a) or separately for the first and then the second task (Experiments 1b and 2).

unaware of their switch costs and the reduction of switch costs with increasing preparation time. To investigate these hypotheses, we analyzed the data in two different ways. First, as in previous introspective multitasking studies we conducted separate analyses for mean RT and IRT. Second, to explore the basis of introspective RTs in this context, we also analyzed RT and IRT and their relationship on a trial-by-trial basis. To anticipate the results, participants did not show the same unawareness of switch costs that has been previously observed for dual-task costs. Instead, participants were able to report their switch costs, even though IRTs were not an unbiased reflection of RTs also in task switching.

Experiment 1

In Experiment 1, we used the AR paradigm, in which the stimuli appear in a clockwise cycle in four locations and the locations serve as cues for the two tasks. That is, for each participant two adjacent locations are associated with one of the two tasks (Task A) and the other two locations are associated with the other task (Task B). This procedure leads to a predictable sequence of alternating task repetitions (or nonswitch) and task switches (AABBAAABB . . .). Additionally, to provide the participant with more or less time to prepare for each task, in the AR paradigm the response-stimulus interval (RSI) is manipulated.

In our modified version of the AR paradigm, we used the clockwise procedure but used only pairs of tasks within each trial. As in the study by [Oriet and Jolcœur \(2003\)](#), the stimuli were the digits 1 to 9 (excluding 5), and participants had to either judge the parity (P: odd or even) or the size (S: smaller or larger than 5) of the digit's numerical value. In contrast to the standard AR paradigm the position of the first stimulus within a trial was randomly selected from the four possible positions, so that each trial could comprise a nonswitch (PP or SS) or a switch (PS or SP) sequence. The RSI was manipulated between blocks since in the AR paradigm a reduction of switch costs has been observed under blocked but not under mixed RSI conditions ([Rogers & Monsell, 1995](#)). In Experiment 1a we collected IRTs only for Task 2, in Experiment 1b for Task 1 and Task 2.

Experiment 1a

Method

Participants. Forty-eight volunteers (34 women, mean age = 25.1 years) participated in one session lasting about 1 h. Participants reported normal or corrected-to-normal vision. The data of three participants were replaced by the data of new participants because of excessive error rates (>50% trials with at least one error in the two tasks).

Apparatus and stimuli. The experiment was run in a sound-attenuated, dimly illuminated experimental booth. The experiment was programmed in Matlab using the Psychophysics Toolbox extension ([Brainard, 1997](#); [Pelli, 1997](#)) Version 3.0.8. Participants sat in front of a CRT computer screen (150 Hz) with a viewing distance of about 50 cm. All stimuli were presented in black against a gray background. A fixation cross (0.7 × 0.7 cm) was presented during the whole trial. The digits 1 to 9, excluding 5, served as target stimuli (0.7 × 1.0 cm). In each trial, two digits (each selected at random with replacement) were presented se-

quentially at two adjacent quadrants of an imaginary 2 × 2 matrix centered at fixation (with a distance of 2 cm between adjacent positions). The position of the first stimulus was randomly chosen from the four possible positions with the restriction that all positions were selected equally often over the course of the experiment. The *C* and the *M* keys of a standard German keyboard were used to record responses with the left and right index finger. The VAS for collection of introspective RTs (22 cm) was marked every 250 ms and labeled at the left end (0 ms), at the middle (1,000 ms) and the right end (2,000 ms). The range of the VAS was chosen to approximately cover the range of typical RTs in task switching.

Procedure and design. Participants started each trial by pressing the space key. After one of two possible RSIs (50 vs. 600 ms) the first digit appeared at one of the four possible locations (randomly selected for each trial). The digit remained on the screen until the participant's response. After another RSI (within a trial, the two RSIs were always the same), the second digit appeared at the next position of the matrix in a clockwise fashion. After the participant's response the digit disappeared. Then, after 500 ms the VAS appeared on the screen and participants provided their introspective RT for Task 2 by clicking with the mouse on the scale (a small black dot was presented for 500 ms at the respective position). In case of an erroneous response in Task 1 and/or Task 2, a feedback message (indicating in which of the two tasks an error had been made) appeared on the screen above the VAS.

There were two tasks, a parity task (odd or even) and a size task (greater or less than 5). The assignment of the two tasks to the four possible target locations as well as the stimulus-response mapping for the two tasks followed [Oriet and Jolcœur \(2003\)](#). That is, for one half of the participants the parity task was assigned to the two target locations above the fixation cross, and the size task to the locations below. The other half of participants had to judge the parity when the digit appeared at one of the two locations to the left of the fixation cross, and judge the size when the digit appeared to the right of the fixation cross. The S-R mapping was completely balanced across participants. That is, one quarter of the participants had to respond according to one of the four following S-R mappings: odd/less – *C*, even/greater – *M*; odd/greater – *C*, even/less – *M*; even/less – *C*, odd/greater – *M*; even/greater – *C*, odd/less – *M*. Participants were instructed to respond as fast and as accurately as possible. They were also encouraged to use the predictability of the task sequence within each trial to prepare for Task 2.

The two RSI conditions (50 vs. 600 ms) were tested in different halves of the experiment. Half of the participants started with the short and the other half with the long RSI blocks. Each half of the experiment comprised one initial practice block (36 trials) and four experimental blocks (36 trials). Accordingly, there were 72 experimental trials per participant for each combination of task sequence and RSI.

Results

Separate analysis of variances (ANOVAs) including the within-subject factors task sequence (switch vs. nonswitch) and RSI (50 vs. 600 ms) were performed for mean RTs (RT1 and RT2), percentage errors (PE1 and PE2) and mean IRT2. For RT and IRT analyses, first all trials that included an error in Task 1 and/or Task 2 (13.7%), and then all trials in which RT1 and/or RT2 deviated

more than ± 2.5 SDs from the individual mean per experimental condition (5.7% of correct trials) were discarded. To explore which information forms the basis of introspective RTs, we conducted a more-in-depth trial-by-trial analysis. That is, a linear-mixed effects model was fitted with IRT2 as outcome variable and RT2, task sequence and RSI as predictor variables (see also Desender, Van Opstal, & Van den Bussche, 2017; Questienne, Atas, Burle, & Gevers, 2018), using the R package lme4 (Bates, Mächler, Bolker, & Walker, 2015). For this analysis, unaggregated RT2s and IRT2s were z-transformed. The fitted model included all main effects and interactions in the fixed effect structure and random intercepts per participant as well as random effects/slopes per participant for each predictor in the random effects structure (see Barr, Levy, Scheepers, & Tily, 2013). Likelihood ratio tests were used to assess significance of fixed main and interaction effects by comparing each reduced model with the more complex model. For example, to test the main effect of task sequence, the model including all main effects (but no interactions) was compared with the same model reduced by the main effect of task sequence. For all figures, SEs for within-subject designs were calculated according to Morey (2008).

Task 1 performance (RT1 and PE1). RT1 was on average much longer than RT2 (1,263 vs. 633 ms). Unexpectedly, there was an effect of task sequence on RT1. That is, participants responded slower to the first digit in switch (1,301 ms) than in nonswitch (1,226 ms) sequences, $F(1, 47) = 17.62, p < .001, \eta_p^2 = .27$. Participants also responded slower when the RSI was short (1,323 ms) than when it was long (1,203 ms), $F(1, 47) = 8.80, p = .005, \eta_p^2 = .16$. There was no interaction of task sequence and RSI on RT1, $F(1, 47) = 0.03, p = .861, \eta_p^2 < .01$. In line with the main effect of task sequence on RT1, participants also made more errors in Task 1 in switch sequences (4.5%) than in nonswitch sequences (3.8%), $F(1, 47) = 6.06, p = .018, \eta_p^2 = .11$. There was no significant effect of RSI on PE1, $F(1, 47) = 1.68, p = .201, \eta_p^2 = .03$, and also no significant interaction of task sequence and RSI, $F(1, 47) = 0.23, p = .636, \eta_p^2 < .01$.

Task 2 performance (RT2 and PE2). Task 2 performance showed the standard RT pattern in the AR paradigm (see left panel

of Figure 2). RT2 was 226 ms longer in switch (746 ms) than in nonswitch sequences (520 ms), $F(1, 47) = 194.48, p < .001, \eta_p^2 = .81$, and these switch costs were reduced with increasing RSI (267 vs. 185 ms), $F(1, 47) = 20.36, p < .001, \eta_p^2 = .30$. There was also a significant main effect of RSI on RT2, $F(1, 47) = 7.06, p = .011, \eta_p^2 = .13$, with longer RT2 at short RSI (656 ms) compared with long RSI (610 ms). Switch costs in Task 2 were also reflected in error rate. PE2 was higher in switch (11.2%) than in nonswitch (7.5%) sequences, $F(1, 47) = 56.82, p < .001, \eta_p^2 = .55$. Concerning PE2, there was neither a significant main effect of RSI, $F(1, 47) = 0.34, p = .561, \eta_p^2 = .01$, nor a significant interaction of task sequence and RSI, $F(1, 47) = 3.19, p = .081, \eta_p^2 = .06$.

Introspection about Task 2 (IRT2). As can be seen in the right panel of Figure 2, both the objective switch costs in Task 2 as well as their reduction with increasing RSI were reflected in introspective RT2. Accordingly, the ANOVA for IRT2 revealed a significant main effect of task sequence, $F(1, 47) = 68.01, p < .001, \eta_p^2 = .59$, and a significant interaction of task sequence and RSI, $F(1, 47) = 14.34, p < .001, \eta_p^2 = .23$. The introspective switch costs were 139 ms at short RSI and 93 ms at long RSI. This reduction of the introspective switch costs with increasing RSI by one-third (33%) is comparable with the reduction of the objective switch costs (31%). In contrast to the objective pattern, the RSI effect on IRT2 did not reach significance, $F(1, 47) = 3.06, p = .087, \eta_p^2 = .14$. Participants even indicated that they responded more slowly in trials with the long RSI (671 ms) than in trials with the short RSI (644 ms), which is the opposite of what was observed for objective RTs.

To explore which factors contributed to IRT2, we plotted IRT2 against RT2 (divided into three bins) as a function of task sequence and RSI (see Figure 3). As one can see, there was a clear positive relationship between RT2 and IRT2. Additionally, participants provided overall longer IRT2s in long than in short RSI trials, as indicated by the parallel vertical shift of the RT2-IRT2 function. Furthermore, there was a small shift of the RT2-IRT2 function between switch and nonswitch trials, indicating that participants provided relatively longer IRT2s in switch than in nonswitch trials. Accordingly, linear mixed-effects model analysis with IRT2 as

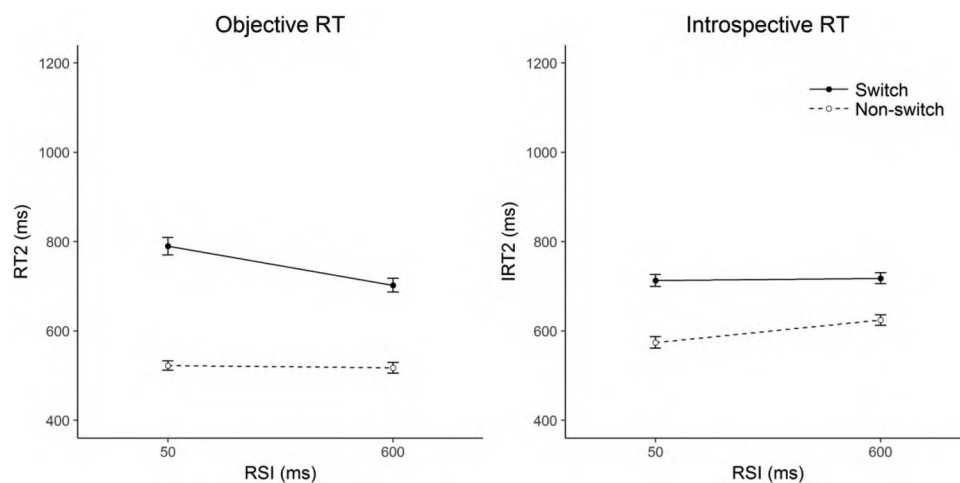


Figure 2. Objective and introspective reaction time (RT) in Task 2 (RT2 and IRT2) as a function of task sequence and response-stimulus interval (RSI) in Experiment 1a. Error bars represent ± 1 within-subject SE.

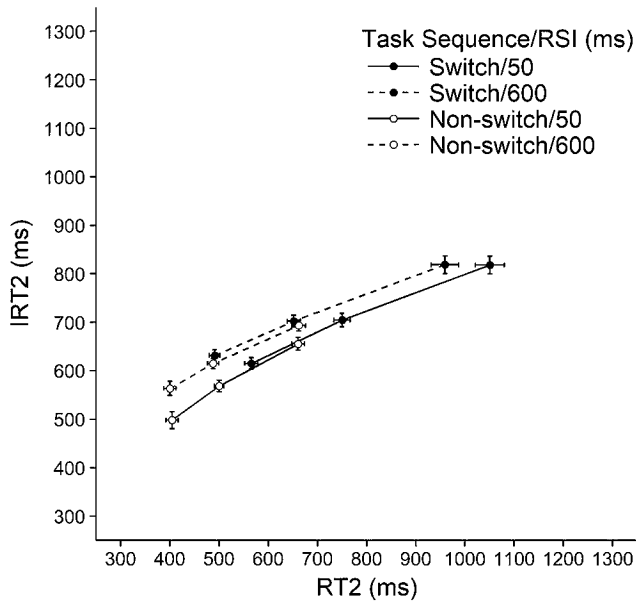


Figure 3. The relationship between objective and introspective RT in Task 2 (RT2 and IRT2) in Experiment 1a. Introspective RT2 is plotted against RT2 (divided into three bins) as a function of task sequence and response-stimulus interval (RSI). Error bars represent ± 1 within-subject *SE*.

dependent variable and RT2 as additional fixed factor revealed significant main effects of RT2, $\chi^2(1) = 66.60, p < .001$, RSI, $\chi^2(1) = 9.15, p = .002$, and task sequence, $\chi^2(1) = 8.93, p = .003$. There were also significant interactions between RT2 and task sequence, $\chi^2(1) = 61.04, p < .001$, and between RT2 and RSI, $\chi^2(1) = 6.62, p = .010$, and a significant three-way interaction, $\chi^2(1) = 5.19, p = .023$. These interactions indicate different slopes of the RT2-IRT2 function as a function of task sequence and RSI. For example, Figure 3 suggests that the function is slightly steeper for nonswitch than for switch trials. The interaction between task sequence and RSI was not significant, $\chi^2(1) = 0.16, p = .693$.

Discussion

Experiment 1a revealed the standard RT pattern of the AR paradigm, that is, switch costs and a reduction of these costs with longer preparation time. Moreover, participants seemed to be aware not only of their switch costs but also of the reduction of these costs when more preparation time was provided by a long RSI. Nevertheless, introspection about task-switching performance was not perfect since participants did not indicate the overall beneficial effect of increasing RSI on Task 2 performance.

The trial-by-trial analysis revealed a clear positive relationship between introspective and objective RT2s. This indicates that participants were sensitive to their RT2 variations not only between but also within experimental conditions. However, the effect of task sequence on IRT2 was not solely a consequence of this positive RT2-IRT2 relationship, as the whole RT2-IRT2 function was slightly shifted toward longer IRT2s for switch compared with nonswitch trials. In other words, participants slightly overestimated the effect of task sequence on RT2 relative to other trial-

by-trial variations in RT2. The trial-by-trial analysis also showed that the null-effect of RSI on IRT2 resulted from an overall tendency to overestimate RT2 in long relative to short RSI trials. There were also some interactions including RT2, suggesting different slopes of the RT2-IRT2 function across conditions. Since these effects, however, were rather negligible (see Figure 3), we refrain from interpreting them in terms of introspective sensitivity.

While the focus of the present study was on Task 2 performance, there were also two results regarding Task 1 performance that deserve further consideration. First, there was an effect of task sequence also on Task 1 performance. It should be noted that the position of the first digit in each trial was randomly selected, and only this starting position determined whether the current trial was a switch or a nonswitch trial. Thus, this effect on Task 1 performance likely reflects prospective preparation of Task 2 even during Task 1 processing (see also Meiran, Chorev, & Sapir, 2000; Reissland & Manzey, 2016). Second, Task 1 performance showed large overall RT costs in comparison with Task 2 performance. These costs might reflect so-called restart costs (e.g., Gopher, Armony, & Greenshpan, 2000), or might be caused by the higher overall preparation demands in Task 1 compared with Task 2 (because Task 1 was not predictable). Another possibility, more related to the introspective approach of the present study, is that because participants had to introspect about their Task 2 performance, they may have allocated fewer resources to Task 1. In Experiment 1b, we replicated the same basic paradigm as in Experiment 1a but collected introspective RTs for both tasks.

Experiment 1b

Method

Participants. Forty-eight volunteers (40 women, mean age = 22.5 years) participated in one session lasting about 1 h. Participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus and stimuli were the same as in Experiment 1a.

Procedure and design. The procedure and design were identical to Experiment 1a with the following modifications. After each trial, participants provided introspective RTs for Task 1 and Task 2. To this end, two separate but otherwise identical VAS (ranging from 0 to 2,000 ms) were presented subsequently, one for each task. Following the procedure of previous introspective PRP studies, participants had to provide their introspective RT always first for Task 1 and then for Task 2.

Results

Data analysis followed the procedure of Experiment 1a. Accordingly, trials including an error in Task 1 and/or Task 2 (10.8%), trials in which participants provided IRTs outside of the VAS range ($< 0.1\%$), and trials with an RT outlier in Task 1 and/or Task 2 (5.3% of remaining trials) were excluded from RT and IRT analyses. ANOVAs for Task 1 and Task 2, and linear mixed-effects model analysis for Task 2 followed the procedure of Experiment 1a.

Task 1 performance (RT1 and PE1). The overall RT1 level (1,027 ms) was somewhat lower than in Experiment 1a (1,275 ms).

However, RT1 was still substantially longer than RT2 (641 ms). There was again a significant effect of task sequence on RT1, $F(1, 47) = 5.90, p = .019, \eta_p^2 = .11$, even though the effect was much smaller than in Experiment 1a (19 vs. 119 ms). Experiment 1b also replicated the RSI effect on RT1, $F(1, 47) = 5.17, p = .028, \eta_p^2 = .10$. Participants were slower in trials with the short RSI (1,064 ms) than in trials with the long RSI (991 ms). There was again no significant interaction between task sequence and RSI on RT1, $F(1, 47) = 0.15, p = .703, \eta_p^2 < .01$. The PE1 pattern slightly deviated from Experiment 1a. In contrast to Experiment 1a, there was no significant effect of task sequence on PE1 (switch: 5.3% vs. nonswitch: 5.2%), $F(1, 47) = 1.25, p = .269, \eta_p^2 < .03$. Also in contrast to Experiment 1a, we observed a significant main effect of RSI on PE1, $F(1, 47) = 8.31, p = .006, \eta_p^2 = .03$. Participants made more errors in Task 1 when the RSI was long (6.2%) than when it was short (4.6%). Consistent with Experiment 1a, there was no interaction between task sequence and RSI on PE1, $F(1, 47) = 1.64, p = .207, \eta_p^2 < .03$.

Introspection about Task 1 (IRT1). It appeared that participants were aware of the overall RT costs and the task sequence effect on Task 1 performance. Accordingly, IRT1 was on average longer than IRT2 (883 vs. 688 ms) and participants indicated switch costs of 26 ms, $F(1, 47) = 23.43, p < .001, \eta_p^2 = .33$. Similar to the misperception of the RSI effect on RT2 in Experiment 1a, participants did not correctly introspect about the RSI effect on RT1. Whereas participants responded faster in long than in short RSI trials, they indicated the opposite in their IRT1s (896 vs. 870 ms), even though the main effect of RSI on IRT1 was not significant, $F(1, 47) = 1.80, p = .186, \eta_p^2 = .04$. There was no significant two-way interaction on IRT1, $F(1, 47) = 0.52, p = .475, \eta_p^2 = .01$.

Task 2 performance (RT2 and PE2). Task 2 performance again showed the standard RT pattern in the AR paradigm (see left panel of Figure 4). We observed switch costs of 219 ms, $F(1, 47) = 189.23, p < .001, \eta_p^2 = .80$, and these switch costs decreased with increasing RSI (252 vs. 186 ms), $F(1, 47) = 24.36, p < .001, \eta_p^2 = .34$. Also, RT2 was again longer at short RSI (662 ms) than at long RSI (619 ms), $F(1, 47) = 9.15, p = .004, \eta_p^2 = .16$. Again,

only the switch costs were reflected in error performance (switch: 8.0% vs. nonswitch: 3.9%), $F(1, 47) = 49.93, p < .001, \eta_p^2 = .52$. Both the main effect of RSI on PE2, $F(1, 47) = 0.55, p = .463, \eta_p^2 = .01$, and the interaction between task sequence and RSI on PE2, $F(1, 47) = 2.77, p = .103, \eta_p^2 = .06$, were not significant.

Introspection about Task 2 (IRT2). As in Experiment 1a, both the objective switch costs in Task 2 and their reduction with increasing RSI were reflected in IRT2 (see right panel of Figure 4). Accordingly, there was a significant main effect of task sequence, $F(1, 47) = 131.56, p < .001, \eta_p^2 = .74$, and a significant interaction of task sequence and RSI on IRT2, $F(1, 47) = 17.33, p < .001, \eta_p^2 = .27$. The introspective switch costs were 132 ms at short RSI and 86 ms at long RSI. This reduction of the introspective switch costs with increasing RSI by about one-third (35%) was again comparable to the reduction of the objective switch costs (27%). Although IRT2 was slightly longer at long (693 ms) than at short RSI (682 ms), there was no significant RSI effect on IRT2, $F(1, 47) = 0.42, p = .520, \eta_p^2 = .01$.

Figure 5 depicts IRT2 plotted against RT2 (divided into three bins) as a function of task sequence and RSI. As in Experiment 1a, there was a positive relationship between RT2 and IRT2 and a clear shift of the RT2-IRT2 function depending on RSI, with longer IRT2s in long than short RSI trials. In contrast to Experiment 1a, however, the RT2-IRT2 functions for switch and non-switch trials virtually coincided with each other, indicating that task sequence did not influence IRT2 beyond the RT2-IRT2 relationship. Accordingly, linear mixed-effects model analysis revealed significant main effects of RT2, $\chi^2(1) = 65.48, p < .001$, and RSI, $\chi^2(1) = 7.39, p = .007$, but no significant effect of task sequence, $\chi^2(1) = 1.08, p = .299$. The interaction results were similar to Experiment 1a, with the exception that the interaction between RT2 and RSI was not significant, $\chi^2(1) = 0.93, p = .335$. There was again a significant interaction between RT2 and task sequence, $\chi^2(1) = 20.44, p < .001$, and a significant three-way interaction, $\chi^2(1) = 7.52, p = .006$. The interaction between task sequence and RSI was not significant, $\chi^2(1) = 0.93, p = .335$.

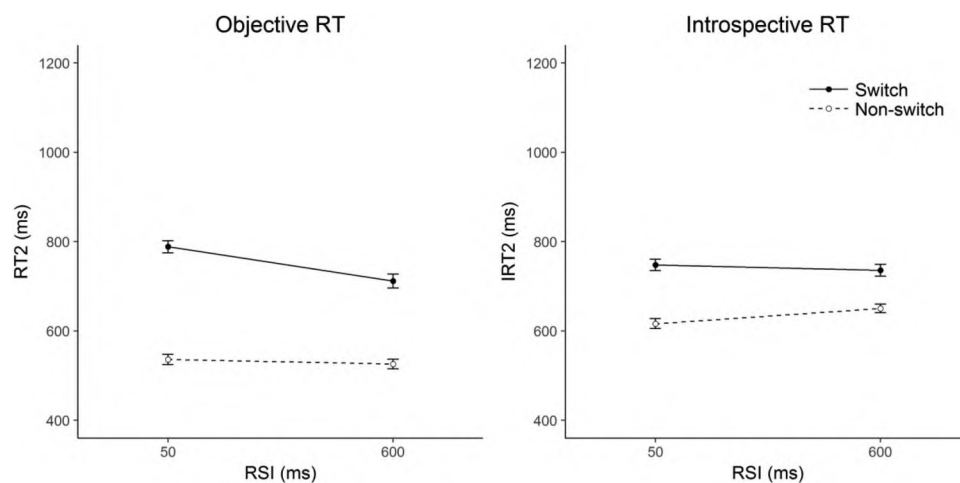


Figure 4. Objective and introspective RT in Task 2 (RT2 and IRT2) as a function of task sequence and response-stimulus interval (RSI) in Experiment 1b. Error bars represent ± 1 within-subject SE.

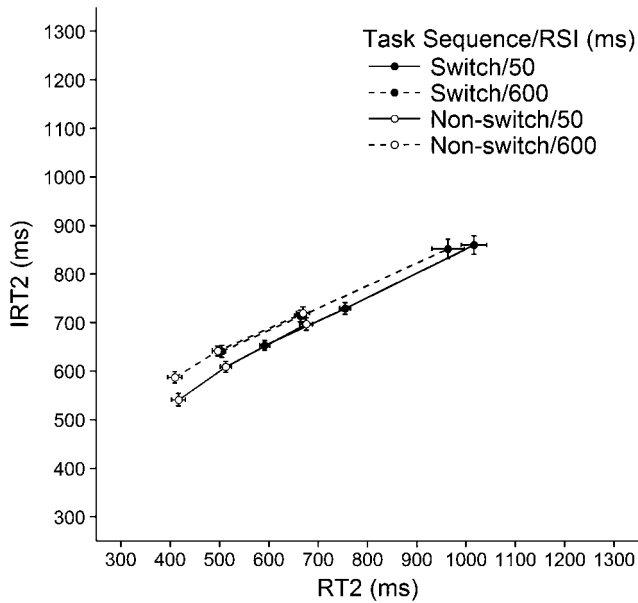


Figure 5. The relationship between objective and introspective RT in Task 2 (RT2 and IRT2) in Experiment 1b. Introspective RT2 is plotted against RT2 (divided into three bins) as a function of task sequence and response-stimulus interval (RSI). Error bars represent ± 1 within-subject SE.

Discussion

Experiment 1b replicated the basic results of Experiment 1a. That is, Task 2 performance again showed the standard RT pattern in the AR paradigm. There was also again an effect of task sequence on Task 1 performance even though the effect was much smaller than in Experiment 1a. This suggests that the special emphasis on Task 2 in Experiment 1a may have exaggerated the prospective switch costs observed in Task 1. Consistent with this suggestion, the overall RT costs in Task 1 were also lower than in Experiment 1a. As in Experiment 1a, longer preparation time led to a general response speed up in both tasks.

The objective and subjective Task 2 result patterns were very similar to Experiment 1a. Again, some but not all objective effects were reflected in IRTs. It appears that participants were indeed aware of switch costs and their reduction with increasing RSI. An interesting find was that participants indicated switch costs in their IRTs not only for Task 2 but also for Task 1. The trial-by-trial analysis again revealed a clear positive relationship between RT2 and IRT2. In contrast to the results of Experiment 1a, there was no effect of task sequence on IRT2 beyond this relationship. As in Experiment 1a, participants showed a tendency to overestimate their RTs in long compared with short RSI trials, with the consequence that they did not report the general beneficial effect of longer preparation time on their RT performance (numerically the effects were again in the opposite direction of the objective pattern).

Experiment 2

In Experiment 2, we investigated whether the results of Experiment 1 would generalize to another task-switching paradigm and examined in more detail participants' introspection about the im-

port of task preparation on their task-switching performance. To this end, we applied the introspective RT approach to the so-called task-cuing paradigm, in which different components of task preparation can be distinguished. In this paradigm, there is no regular and predictable task sequence as in the AR paradigm but instead a cue indicates which task should be executed. This procedure divides the single preparation interval of the AR paradigm (i.e., the RSI) into two preparatory intervals, the response-cue interval (RCI) and the cue-stimulus interval (CSI). Usually, it is assumed that these intervals reflect different components of preparation, both of which play a role in the reduction of switch costs: passive dissipation of the previous task set during the RCI and active preparation of the new task set during the CSI (e.g., Meiran et al., 2000). An assessment of IRTs in the task-cuing paradigm thus enables further specification regarding which parts of switch costs are accessible to introspection, those caused by passive interference or by active task-set reconfiguration or both. Given the previous suggestion that task-set reconfiguration can be a bottleneck process as is response selection in the PRP paradigm (e.g., Oriet & Jolcœur, 2003) as well as the observed unawareness of the PRP effect, one could hypothesize that only the passive component is reflected in IRTs. Under this hypothesis, one would expect that participants only report the reduction of switch costs with increasing RCI, but not the reduction with increasing CSI.

Method

Participants. Twenty-four volunteers (21 women, mean age = 24.7 years) participated in a session lasting about 75 min. Participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus was the same as in Experiment 1. All stimuli were presented in black against a gray background. As in Experiment 1, the digits 1 to 9, excluding 5, served as target stimuli (0.7×1.0 cm). A square and a diamond frame (3.8×3.8 cm) served as task cues for the parity and the size task, respectively. The response keys and VASs used for collection of IRTs were the same as in Experiment 1.

Procedure and design. As in Experiment 1, each trial comprised two tasks. Frames of different shapes served as cues for which type of task (parity vs. size task) should be executed (as in Koch & Allport, 2006). A square frame indicated the parity task (odd or even), and a diamond frame the size task (greater or less than 5). Participants started each trial by pressing the space key. For each task, first a cue was presented at the center of the screen after a variable RCI (50 vs. 600 ms), and then a digit appeared within the cue after a variable CSI (50 vs. 600 ms). Each cue and digit remained on the screen until the participant's response. After two such tasks (500 ms after the second response), IRTs were collected for Task 1 and Task 2 using separate VASs as in Experiment 1b.

For each trial, two digits were randomly drawn from the eight possible digits without replacement so that the same digit could not be repeated within the same trial. The RCIs and CSIs for the two tasks (separately for each task), and the two types of tasks varied randomly between trials, with all combinations of these variables being equally frequent across the experiment. The experiment comprised one initial practice block (64 trials) and five experimental blocks (64 trials). Accordingly, there were 40 experimental

trials per participant for each combination of task sequence, RCI and CSI.

Results

Data analysis followed the procedure of Experiment 1. Accordingly, trials including an error in Task 1 and/or Task 2 (14.8%), and trials with an RT outlier in Task 1 and/or Task 2 (5.1% of correct trials) were excluded from RT and IRT analyses. Separate ANOVAs including the within-subject factors task sequence (switch vs. nonswitch), RCI (50 vs. 600 ms) and CSI (50 vs. 600 ms) were performed for mean RTs (RT1 and RT2), mean IRTs (IRT1 and IRT2) and percentage error (PE1 and PE2). Since RCI and CSI varied independently between the two tasks, analyses were conducted with the RCI and CSI associated with the respective task (i.e., RCI1 and CSI1 for Task 1, and RCI2 and CSI2 for Task 2). For the linear mixed-effects model analysis, RT2s and IRT2s were again z-transformed. The fitted model included all main effects and interactions in the fixed effect structure, and random intercepts per participant as well as random effects/slopes per participant for each main effect in the random effects structure of the model.

Task 1 performance (RT1 and PE1). Overall mean RT1 was 763 ms. The ANOVA on RT1 revealed significant main effects of RCI, $F(1, 23) = 12.98, p = .001, \eta_p^2 = .36$, and CSI, $F(1, 23) = 103.45, p < .001, \eta_p^2 = .82$, and a significant interaction between RCI and CSI, $F(1, 23) = 5.53, p = .028, \eta_p^2 = .19$. As one would expect, increasing preparation time reduced RT1. Specifically, an increase of CSI resulted in a stronger reduction (183 ms) than an increase of RCI (30 ms). Participants provided the fastest responses to Task 1 when both CSI and RCI were long (879 ms) and the slowest responses when both intervals were short (667 ms). Responses were still relatively fast when the CSI was long and the RCI was short (676 ms), and relatively slow when the CSI was short and the RCI was long (829 ms). As one would also expect because of the unpredictability of task sequence in the cuing paradigm, the main effect of task sequence and all interactions including task sequence were not significant, all $F_s < 1$.

The overall error rate in Task 1 was 7.9%. The ANOVA on PE1 revealed a significant main effect of CSI, $F(1, 23) = 5.60, p = .027, \eta_p^2 = .20$, and a significant interaction of RCI and CSI, $F(1, 23) = 5.25, p = .031, \eta_p^2 = .19$. In line with the RT1 result pattern, PE1 was higher in short than in long CSI trials (8.6 vs. 7.1%). PE1 was highest in trials with a long RCI and a short CSI (9.4%), followed by the two short RCI conditions (7.9% for the short CSI and 7.4% for the long CSI), and lowest when both intervals were long (6.8%). The main effect of task sequence and all interactions including the factor task sequence were not significant, all $p_s > .292$.

Introspection about Task 1 (IRT1). In contrast to the objective RT1 pattern, IRT1 was slightly longer in switch (797 ms) than in nonswitch trials (773 ms), $F(1, 23) = 20.56, p < .001$. However, consistent with the objective RT1 pattern, participants indicated longer IRT1s in short than in long RCI trials (777 vs. 748 ms), $F(1, 23) = 9.54, p = .005, \eta_p^2 = .29$. Even though IRT1 was also slightly longer in short than in long CSI trials (791 vs. 779 ms), the main effect of CSI was not significant, $F(1, 23) = 2.07, p = .164, \eta_p^2 = .08$. The interaction between RCI and CSI did also not reach significance, $F(1, 23) = 3.14, p = .090, \eta_p^2 = .12$. All interactions including the factor task sequence were not significant, $p_s > .120$.

Task 2 performance (RT2 and PE2). Reaction time performance in Task 2 is depicted in the left panel of Figure 6. RT2 showed overall switch costs of 149 ms, $F(1, 23) = 189.23, p < .001, \eta_p^2 = .80$. These switch costs were greatly reduced when more preparation time was provided during the CSI (198 vs. 100 ms), $F(1, 23) = 28.40, p < .001, \eta_p^2 = .55$. The switch costs were also reduced, although to a smaller degree, when the RCI was prolonged (173 vs. 120 ms), $F(1, 23) = 189.23, p < .001, \eta_p^2 = .80$. There were also significant main effects of RCI and CSI on RT2. Whereas an increase of CSI reduced RT2 by 182 ms, $F(1, 23) = 189.23, p < .001, \eta_p^2 = .80$, an increase of RCI reduced RT2 by only 31 ms, $F(1, 23) = 14.41, p = .001, \eta_p^2 = .39$. The interaction between CSI and RCI and the three-way interaction were not significant, both $F_s < 1$.

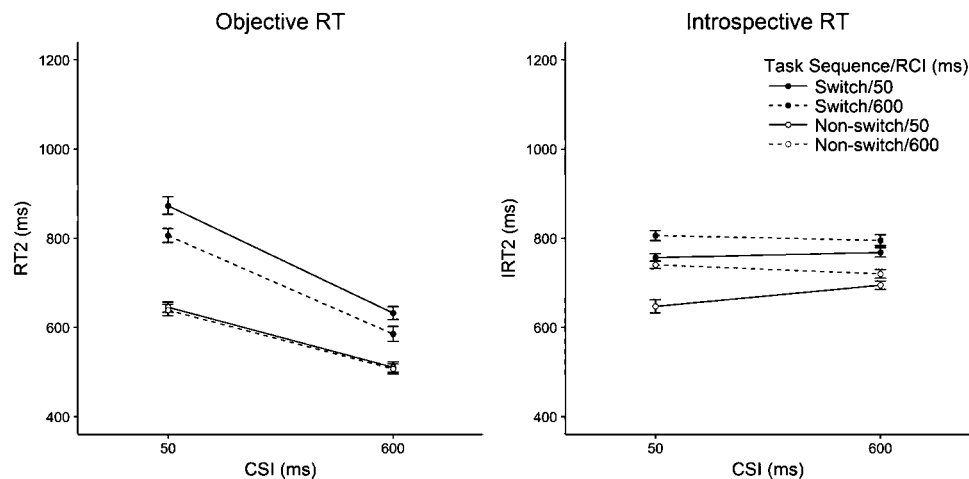


Figure 6. Objective and introspective RT in Task 2 (RT2 and IRT2) as a function of task sequence, response-cue interval (RCI), and cue-stimulus interval (CSI) in Experiment 2. Error bars represent ± 1 within-subject SE.

The pattern of PE2 was very similar to the RT2 performance. The overall error rate in Task 2 was 7.6%. Participants made more errors in switch (9.7%) than in nonswitch trials (5.5%), $F(1, 23) = 42.18, p < .001, \eta_p^2 = .65$. These switch costs were significantly smaller when the CSI was long (2.2 percentage points) than when it was short (6.2 percentage points), $F(1, 23) = 10.64, p = .003, \eta_p^2 = .32$. An increase of RCI also reduced the switch costs in PE2 (5.3 vs. 3.1 percentage points); this, however, was not significant, $F(1, 23) = 2.82, p = .107, \eta_p^2 = .11$. Participants made overall fewer errors in trials with long CSI (6.3%) than in trials with short CSI (9.0%), $F(1, 23) = 16.97, p < .001, \eta_p^2 = .42$. The main effect of RCI as well as the other interactions were not significant, $ps > .315$.

Introspection about Task 2 (IRT2). Introspective RT2 can be seen in the right panel of Figure 6. As in Experiment 1, objective switch costs were reflected in introspective IRTs. Participants indicated overall switch costs of 81 ms, $F(1, 23) = 36.03, p < .001, \eta_p^2 = .61$. They also correctly indicated that these switch costs were reduced from the short to the long RCI (92 vs. 70 ms), $F(1, 23) = 6.87, p = .015, \eta_p^2 = .23$. The interaction between task sequence and CSI was not significant, $F(1, 23) = 1.33, p = .261, \eta_p^2 = .05$, even though participants also indicated a small reduction of switch costs with increasing CSI (87 vs. 75 ms). There was also a significant three-way interaction, $F(1, 23) = 5.48, p = .028, \eta_p^2 = .19$, suggesting that participants indicated a reduction of switch costs caused by an increase of RCI when the CSI was short (44 ms) but not when the CSI was long (-2 ms). The ANOVA also revealed a significant main effect of RCI on IRT2, $F(1, 23) = 28.15, p < .001, \eta_p^2 = .55$. Participants indicated longer IRT2s in long than in short RCI trials (766 vs. 717 ms), a pattern that is opposite to the effect of RCI on objective RT2. In contrast to the objective RT2 pattern, there was no significant main effect of CSI on IRT2 (short CSI: 745 ms; long CSI: 738 ms), $F(1, 23) = 1.47, p < .238, \eta_p^2 = .06$. The significant interaction between RCI and CSI on IRT2, $F(1, 23) = 1.47, p < .238, \eta_p^2 = .06$, suggests that the effect of RCI on IRT2 was more pronounced when the CSI was short (71 ms) than when the CSI was long (26 ms).

Figure 7 depicts IRT2 plotted against RT2 (divided into three bins) as a function of task sequence and RCI (left panel), as a function of task sequence and CSI (middle panel), and as a function of RCI and CSI (right panel). As one can see in all panels of the figure, there was again a clear positive relationship between RT2 and IRT2. Inspection of the left and the middle panel of the figure suggests that IRT2 was affected by all other factors beyond the RT2-IRT2 relationship, with relatively stronger effects of RCI and CSI compared with the effect of task sequence. Accordingly, all main effects were significant in the linear mixed effects model analysis, task sequence: $\chi^2(1) = 5.82, p = .016$, RCI: $\chi^2(1) = 30.21, p < .001$, CSI: $\chi^2(1) = 28.46, p < .001$.

A comparison of the left and the middle panel suggested that the shift of the RT2-IRT2 function related to the factor task sequence was differently affected by RCI and CSI. Whereas the shift appeared to be relatively independent of RSI (left panel), there seemed to be a larger shift in long than in short CSI trials (middle panel). Nevertheless, significant interactions were observed between task sequence and RCI, $\chi^2(1) = 4.24, p = .040$, and between task sequence and CSI, $\chi^2(1) = 11.19, p < .001$. Furthermore, the three-way interaction between task sequence, RCI and CSI was not significant, $\chi^2(1) = 1.74, p = .187$. Of the remaining interactions including the factor task sequence, only the two-way interaction between task sequence and RT2 was significant, $\chi^2(1) = 11.52, p < .001$, all other $ps > .116$.

The right panel of Figure 7 shows the interactive influence of the two preparatory intervals on the RT2-IRT2 function. It can be seen that the longer the total preparation interval (i.e., the sum of RCI and CSI), the more the function was shifted toward longer IRT2s. However, the shift was stronger from the shortest to the two intermediate RSIs (50 ms RCI/600 ms CSI and 600 ms RCI/50 ms CSI) than from the intermediate to the longest RSI. Accordingly, there was a significant interaction between RCI and CSI, $\chi^2(1) = 20.93, p < .001$. There were also significant two-way interactions between RCI and RT2, $\chi^2(1) = 7.54, p = .006$, and between CSI and RT2, $\chi^2(1) = 4.06, p = .044$, and a significant three-way interaction between RCI, CSI, and RT2, $\chi^2(1) = 12.50, p < .001$.

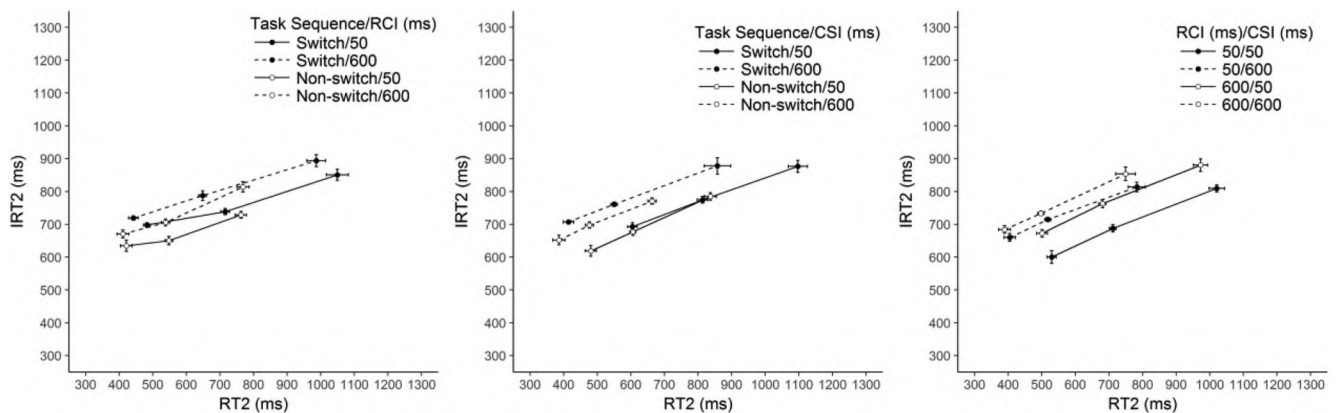


Figure 7. The relationship between objective and introspective RT in Task 2 (RT2 and IRT2) in Experiment 2. Left panel: IRT2 as a function of RT2 (divided into three bins), task sequence, and response-cue interval (RCI); middle panel: IRT2 as a function of RT2, task sequence, and cue-stimulus interval (CSI); right panel: IRT2 as a function of RT2, RCI, and CSI. Error bars represent ± 1 within-subject SE.

Discussion

In Experiment 2, we again observed typical task-switching performance, namely switch costs and a reduction of switch costs with increasing preparation time (RCI and CSI). As in Experiment 1, participants were able to report their switch costs. The hypothesis that participants might have introspective access only to the passive part of task preparation (during the RCI) but not to the active (during the CSI) was only partly supported. Even though the IRT2 results showed a three-way interaction (i.e., participants indicated a reduction of their switch costs caused by one of the preparation intervals only when the other interval was short), participants overall indicated a numerically larger reduction of their switch costs with an increase of the RCI than with an increase of the CSI. Additionally, only the reduction of switch costs caused by an increase of the RCI reached significance. This is especially remarkable because an increase of the CSI was much more effective in reducing the objective switch costs than an increase of the RCI. Consistent with the results of Experiment 1, participants did not accurately report the general beneficial effect of increased preparation time on their Task 2 performance. More specifically, they reported no effect of CSI and even a reversed effect of RCI. In the trial-by-trial analysis, we again observed that all factors influenced IRT2s beyond the positive RT2-IRT2 relationship. Specifically, participants tended to provide longer IRT2s in switch than in nonswitch trials and also when either preparatory interval was long, which enhanced the introspective switch costs in the former case, and led to a reduced or even reversed preparation effect in the latter case.

Analysis of introspection about Task 1 performance in Experiment 2 also revealed some remarkable effects. For the first time, the beneficial effect of increased preparation time on objective RT was reflected in IRTs. However, the awareness of the preparation effect was restricted to the effect of RCI, even though the objective RT advantage was much greater for the CSI than the RCI. Moreover, participants also reported switch costs in Task 1 even though there were no objective switch costs in Task 1 performance. This suggests that, when both IRTs are collected at the end of the trial, introspective reports of Task 1 can be influenced by introspection about Task 2.

General Discussion

In the present study, we explored introspection about task-switching performance using the method of quantified introspection in modified versions of two standard task-switching paradigms: the AR paradigm and the task-cuing paradigm. Based on previous evidence suggesting that participants are unaware of their dual-task costs in the PRP paradigm, we hypothesized that participants might also be unaware of their switch costs. The present study clearly does not support this hypothesis as switch costs were reflected in IRTs. Thus, in contrast to the previously observed unawareness of the PRP effect, participants seem to be aware of their switch costs.

Nevertheless, introspection was not entirely accurate. First, participants did not correctly report the overall beneficial effect of longer preparation time on RTs (with the exception of Task 1 performance in Experiment 2). Second, while in the AR paradigm the reduction of switch costs with increasing preparation time was reflected in IRTs, in the task-cuing paradigm this was only partly

the case. That is, even though an increase of the “active” compared with the “passive” preparation interval (i.e., CSI vs. RCI) resulted in a much larger reduction of switch costs, participants reported the reduction to be numerically larger for the RCI than for the CSI, and only the former effect was statistically reliable. This pattern is consistent with the hypothesis that active task preparation can act as a bottleneck process, which leads both to switch costs and delayed conscious access to the target stimulus. According to this interpretation, the switch costs that are reported by participants would predominantly reflect the passive source of switch costs. The trial-by-trial analysis, however, did not provide support for this interpretation. The conscious bottleneck account assumes that when the target stimulus is presented before task-set reconfiguration is finished, participants misperceive the stimulus onset and, therefore, underestimate their RT. This would result in a downward-shifted RT2-IRT2 function, for example for switch compared with nonswitch trials. In fact, in all three experiments there was either no shift or the function was shifted upward for switch compared with nonswitch trials.

Instead, the present results provide strong evidence that participants utilize various cues, some of which are valid and some of which are invalid, to give their IRTs (see also the cue-utilization account of metacognitive judgments, e.g., [Koriat, 2007](#)). The clear positive relationship between objective and introspective RTs indicates that RT is indeed an important basis for IRT. However, there was also evidence for the utilization of other cues, as indicated by parallel shifts of the RT2-IRT2 function. Task sequence can be considered a valid cue in this context as the upward-shift in switch compared with nonswitch trials (with the exception of Experiment 1b) is in line with the objective switch costs. The preparation intervals (RSI, RCI, and CSI), however, turned out to be invalid cues since the RT2-IRT2 function was shifted toward longer IRTs when either preparation interval increased, leading to the objective task preparation effects being either cancelled out or even reversed in IRT2. This evidence of utilization of cues other than RT for IRT is consistent with previous results from introspective PRP studies ([Bratzke & Bryce, 2016](#); [Bratzke et al., 2014](#); [Bryce & Bratzke, 2014](#)). For example, in a PRP study in which we used a temporal comparison task to assess IRTs (i.e., participants had to compare their RT2s with comparison intervals), participants almost exclusively utilized the distribution of the comparison intervals for their judgments ([Bratzke & Bryce, 2016](#)).

The present evidence of cue-utilization supports the view that the timing of internal processing probably relies more on retrospective inference than on prospective timing mechanisms ([Bratzke & Bryce, 2016](#); [Bratzke et al., 2014](#); [Bryce & Bratzke, 2014](#); see also [Klein & Stolz, 2018](#)). In this respect, although participants are asked to estimate the speed of their responses, they probably also utilize accuracy-related cues for their IRTs. Specifically, the feeling of difficulty and its objective counterpart, error performance, may be important cues for IRTs ([Bryce & Bratzke, 2014](#)). How precisely these cues contribute to IRTs remains an open issue. What seems clear, however, is that ratings of subjective difficulty depend not only on RT but are also influenced by other task-related cues ([Desender et al., 2017](#)), as are IRTs in the present study. This suggests that the feeling of difficulty that participants experience within each trial and their reported IRTs are very closely related, if not identical (but see [Questienne, van Dijck, & Gevers, 2018](#), for evidence that subjective feelings can be spe-

cific). Additionally, performance accuracy might be one of the factors that contribute to IRT beyond the trial-by-trial RT-IRT relationship. For example, in the present study, implicit or explicit knowledge about the higher error rate in switch than in nonswitch trials might have led participants to provide generally longer IRTs in switch trials.

The result that participants were aware of their switch costs represents a clear dissociation from the previously observed unawareness of dual-task costs in the PRP paradigm. There are at least two possible reasons for this dissociation. First, whereas a processing bottleneck that encompasses not only central processing but also conscious perception (e.g., Marti et al., 2012; Tombu et al., 2011) might play a major role in the emergence of the PRP effect, its role may be less prominent in task switching. A second reason relates to the above-mentioned cue-utilization account and our suggestion that participants utilize also accuracy-related cues for their IRTs. In particular, whereas dual-task costs in the PRP paradigm often occur only in RT (e.g., Kamienkowski & Sigman, 2008; Pashler, 1989), switch costs are usually observed in both RT and error rate (e.g., Kiesel et al., 2010). Additionally, as ratings of the feeling of difficulty are only very slightly affected by the temporal overlap of the two tasks in the PRP paradigm (Bryce & Bratzke, 2014), it appears likely that there is a similar dissociation between the PRP effect and switch costs regarding the subjective experience of difficulty.

A pertinent question emerges from these findings regarding the potential function of introspection in multitasking. Whether we have introspective access to the costs of multitasking or not might be crucial for top-down controlled behavioral adaptations in such paradigms. The assumption that subjective experience is an important factor for the deployment of cognitive control (for a related view on the function of consciousness, see, e.g., Baars, 1988; Dehaene & Naccache, 2001) has recently received empirical support from conflict studies (Desender, Van Opstal, & Van den Bussche, 2014; Questienne, Van Opstal, van Dijk, & Gevers, 2018). For example, Desender et al. (2014) provided evidence that trial-by-trial conflict adaptation in a masked-priming task was driven by the subjective experience of conflict rather than by the objective conflict. Dynamic behavioral adaptations have also been observed in task-switching performance (e.g., Brown, Reynolds, & Braver, 2007; Dreisbach & Haider, 2006; Goschke, 2000). For example, Dreisbach and Haider (2006) reported smaller switch costs in blocks with a high probability of task switches (75% switches) than in blocks with a high probability of repetitions (75% repetitions) and concluded that task preparation can be dynamically adjusted to the task requirements. In their study, the task requirements were explicitly cued (either before each block or before each trial). Whether such dynamic adaptations in task switching could also be triggered by the subjective experience of one's own performance remains an open question for future research.

The present results are also of interest regarding the question of how people adjust their behavior under less externally controlled task-switching conditions, as in the voluntary task-switching paradigm. Various findings from this paradigm suggest that participants might take into account their switch costs when choosing to switch or not. In the classic version of this paradigm, in which participants are instructed to perform the two tasks equally often and in random order, a tendency to more frequently repeat than

switch between tasks is usually observed (i.e., a repetition bias; e.g., Arrington & Logan, 2004). This repetition bias is even more pronounced when repeating the same task without any restrictions is permitted (e.g., Kessler, Shencar, & Meiran, 2009). One simple explanation for the repetition bias, which is in line with the present results, is that participants avoid the (consciously accessible) costs of switching between tasks (for discussions and alternative accounts, see Arrington & Logan, 2004, 2005; Mittelstädt, Dignath, Schmidt-Ott, & Kiesel, 2018; Vandierendonck, Demanet, Liefoghe, & Verbruggen, 2012). A very recent study by Mittelstädt, Miller, and Kiesel (2018) used an adaptive approach to investigate in more detail the conditions under which people choose to switch between tasks. In their paradigm, two stimuli were presented within each trial and the repetition stimulus was increasingly withheld (i.e., an increasing SOA) when participants chose to repeat the task. As a result, participants tended to switch between the tasks when the SOA was approximately equivalent to their switch costs. While all these results may indicate that participants consider their switch costs in adapting their behavior, whether participants are really aware of their switch costs in voluntary task switching and whether such adaptive behavior is under conscious control remain open questions.

Conclusion

The present study revealed that participants' introspection about their task-switching performance is rather accurate as they were aware not only of their switch costs but, at least partly, also of the reduction of the switch costs with increasing preparation time. By demonstrating that introspection about multitasking performance is not always as limited as in concurrent dual-task paradigms, an important dissociation between the subjective experiences of multitasking at the different poles of the multitasking continuum has been highlighted. Hence, the fact that people often take the risk of multitasking cannot be solely attributed to a limit of introspection that leaves them blind to all kinds of multitasking costs. Nevertheless, the present study also revealed introspective limitations in task-switching performance. Participants did not report the reduction of their switch costs caused by an increase of "active" preparation time, and did not report the overall beneficial effect of longer preparation time on their RT. More generally, the present study suggests that introspective RTs do not provide an unbiased reflection of objective RT performance because participants utilize a variety of cues for generating introspective RTs.

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