What Determines a Task-Switch Cost After Selectively Inhibiting a Response?

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Abstract

The task-switch cost is one of the most robust phenomena, but it can disappear after nogo trials where the actors decide not to respond to the target. According to the response-selection account, it is the occurrence of response selection that generates a task-switch cost on the following trial. The present study used a variety of selective go/nogo procedures to investigate whether response selection on nogo trials is followed by a switch cost. The first two experiments aimed to replicate previous studies in which go/nogo trials could be distinguished either by the target features or by the responses assigned to the target, but the results were mixed. The subsequent four experiments constrained the conditions so that the actors would need to select a specific response in order to decide whether or not they execute the response. In these experiments, the task-switch cost was consistently absent after selective nogo trials, even when response selection was required on these trials. These results contradict the hypothesis that response selection on nogo trials would be followed by a subsequent switch cost. The results are consistent with the proposal that a task-switch cost might have been established by response selection or other task-related process on nogo trials, but it is abolished because nogo signals interfered with the activated task-set.

Keywords: Cued task switching, go/nogo task, response inhibition, selective inhibition, cognitive control.

Public Significance Statement

The present study investigates the extent to which task performance and response execution determine the effect of task switching upon the efficiency of human performance. The results are potentially relevant to busy life situations where there are rapid changes in the environment.

Task performance is more efficient when people perform the same task repeatedly than when they must switch between different tasks. This advantage of repeating the same task, or the cost of switching between tasks, is observed experimentally in a *cued task-switching procedure* (e.g., Meiran, 1996). In this procedure, two or more tasks are intermixed in an unpredictable sequence, and participants select one of these tasks according to a *task cue* presented at the beginning of a trial indicating which task is required on that trial. Response time (RT) is usually faster when the same task is cued on two consecutive trials (*task repeat trial*) than when different tasks are cued (*task switch trial*). The difference in RT (and in response accuracy) between task-repeat and task-switch trials is termed *task-switch cost* (see Koch, Poljac, Müller, & Kiesel, 2018; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010, for reviews). Although the task-switch cost is one of the most robust effects observed in human task performance, the cost can disappear in rare conditions. In one such condition, cued task-switching is combined with a go/nogo procedure where participants are given an additional nogo signal that informs them of whether or not they should respond to the target on a given trial (Hoffmann, Kiesel, & Sebald, 2003; Schuch & Koch, 2003). It has been found that the task-switch cost is absent, or is reduced substantially to a non-significant level, on trials that immediately follow a nogo trial (i.e., when participants do not perform the cued task on the preceding trial). Given the robustness of task-switch cost, this finding constitutes an important phenomenon that hints where and how the task-switch cost emerges in human task performance.

Several explanations have been offered for this absence of task-switch costs after nogo trials (e.g., Kleinsorge & Gajewski, 2004; Lenartowicz, Yeung, and Cohen, 2011; Schuch & Koch, 2003). Some of the accounts place a strong emphasis on the role of response selection in producing a task-switch cost (e.g., Koch, Gade, Schuch, & Philipp, 2010; Schuch & Koch, 2003). This *response-selection account* proposes that for a task-switch cost to be present, response selection must have taken place on the preceding trial. On a nogo trial, the actor terminates the task before a response is selected, so a switch cost is not obtained on the following trial. Further, if response selection is sufficient to generate a switch cost on the subsequent trial, one might also assume that switch costs should always follow a trial on which selection of a response occurred. Although the account has received support from subsequent studies (e.g., Verbruggen, Liefooghe, & Vandierendonck, 2006), others have also provided evidence that seems to contradict it (Lenartowicz et al., 2011; Wylie, Javitt, & Foxe, 2004). The present study consisted of a series of experiments using different variations of a ‘selective’ go/nogo procedure in which the decision of whether or not to respond on a given trial is determined by task-relevant features of the current target or the response mapped to the feature. This is in contrast to the non-selective nogo procedure whereby the go/nogo decision is made based on a stimulus independent of the cued task (e.g., an additional tone as a go or nogo signal; e.g., Schuch & Koch, 2003). We tested whether a task-switch cost would emerge on trials following a selective nogo trial to examine the role of response selection in generating a task-switch cost.

Where Does the Task-Switch Cost Come From?

Schuch and Koch (2003) incorporated a go/nogo procedure in cued task-switching (also see Hoffmann et al., 2003). In their study, participants performed two different numerical classification tasks. A high or low tone was presented simultaneously with a digit and served as a go or nogo signal on each trial. They found that a task-switch cost was present after go trials but was absent after nogo trials. It was assumed that when a nogo signal was presented, participants could terminate their task without selecting a response, so the lack of a task-switch cost after nogo trials was taken as evidence supporting the idea that response selection is required for a task-switch cost to occur on the following trial. If response selection is responsible for generating a subsequent switch cost, then response selection occurring on a nogo trial should presumably lead to a task-switch cost on the following trial even if the selected response was not executed. In line with this idea, Verbruggen et al. (2006) used a version of the stop-signal task, instead of the go/nogo procedure, that required *selective stopping*: participants withheld responding to the target on a stop-signal trial only when the target required one response but not the other. For example, participants were told to stop responding when the target required pressing a left key but not to stop responding when it required pressing a right key. To stop responding correctly, participants would first select a response according to the target and then decide whether to stop the selected response. They found that switch costs were obtained even when participants had successfully inhibited their response on the preceding trial. In the second experiment, Verbruggen et al. (2006) used another version of selective stopping, in which they presented two different tones that occurred after the target. Participants had to stop responding to the target when one of the tones occurred but to respond if the other tone occurred. This version of selective stopping required perceptually judging as to whether the tone was a stop signal, but it did not require any judgement as to which of the two responses should be made. The researchers found that task-switch cost was absent when participants stopped responding to the target on the preceding trial. These findings are consistent with the idea that a task-switch cost is obtained if response selection has occurred on a preceding (nogo) trial, but it is not obtained if response selection has not occurred on a preceding (nogo) trial, consistent with the response-selection account.

It should be noted that the stop-signal task used by Verbruggen et al. (2006) was somewhat different from a typical go/nogo procedure. In the stop-signal procedure, stop signals generally occur with a variable delay from the target onset, adjusted adaptively according to participants' performance. In contrast, go/nogo signals tend to be coincident with the target stimulus. Philipp, Jolicoeur, Falkenstein, and Koch's (2007) later study, however, used delayed go/nogo signals with two fixed delays (100 ms and 1500 ms), allowing for processing to take place between target onset and “go” or “nogo” decision. The researchers assumed that there would not be enough time for response selection to occur with the short delay (100 ms), but there would be enough time for it to occur with the long delay (1500 ms). The response-selection account would then predict that a task-switch cost should be absent after nogo trials with the short delay, but it should be present after nogo trials with the long delay. The results were consistent with the predicted pattern, but they also found that the task-switch cost was smaller after nogo trials with the long delay than after go trials with the long delay. Philipp et al. concluded that not only response selection but also response execution contributed to task-switch costs. In fact, Verbruggen et al.’s selective stop-signal experiment also showed a smaller task-switch cost when participants successfully stopped responding than when they failed to stop, consistent with Philipp et al.’s findings.

Subsequently, Swainson and Martin (2013) used a procedure designed to test the hypothesis that ‘task judgement’ about a target stimulus, prior to response selection, is sufficient to generate a task-switch cost. In their Experiments 2-5, stimulus-response mappings were not pre-specified but changed across trials. Participants were first presented with a task cue indicating which of the two tasks (color or shape judgement) to perform, followed by a target stimulus. Then, specific stimulus-response mappings were presented after the target stimulus, so participants had to wait for the mapping rules to be presented in order to select the correct response. This delay allowed time for task-based judgements of the target stimulus to be made on all trials (e.g., judging that a red circle was either “red” or a “circle”). On some trials, these mapping rules did not include any features of the target; these trials served as nogo trials. Hence, nogo trials allowed the judgement of the target but not the selection of an overt response. A significant task-switch cost was still obtained after these nogo trials, although the effect was obtained only in error rate, not in RT. These results suggest that processes before response selection may be sufficient to produce a subsequent task-switch cost.

Lenartowicz et al.'s (2011) results support the idea that processes preceding response selection are sufficient to generate task-switch costs. They found that a task-switch cost could be obtained when participants had been presented only with a task cue, and without a target stimulus, on a preceding trial (cue-only trial). Because there is no target stimulus on a cue-only trial, there could be no response selection. Hence, Lenartowicz et al. suggested that task preparation is sufficient, and response selection is not necessary, to produce a task-switch cost on the subsequent trial (also see Swainson, Martin, & Prosser, 2017; Swainson, Prosser, Karavasilev, & Romanczuk, 2021), directly contradicting the response-selection account.

The response-selection account as proposed originally by Schuch and Koch (2003) states that the presence of a task-switch cost depends on the occurrence of response selection on the preceding trial: if response selection has not taken place, there should be no task-switch cost on the subsequent trial. However, subsequent studies have identified other processes that might be responsible for generating a subsequent switch cost, including response execution (Phillip et al., 2007), task-based target judgment (Swainson & Martin, 2013), and task preparation (Lenartowicz et al., 2011). Of these, task preparation and target judgment precede response selection, so when response selection has occurred, these processes must have occurred too. Hence, the presence of a task-switch cost following a completed (or "go") trial could reflect the occurrence of any of these processes, and the absence of a task-switch cost after nogo trials could reflect their non-occurrence.

What Accounts for the Absence of a Task-Switch Cost After Nogo trials?

A number of studies since Schuch and Koch (2003) have examined whether a task-switch cost is obtained when trials are truncated to eliminate some processes that would usually take place in order to perform a cued task (e.g., Kleinsorge & Gajewski, 2004;

Lenartowicz et al., 2011; Los & van der Burg, 2010; Prosser, Yamaguchi, & Swainson, 2023; Swainson et al., 2017; Swainson et al., 2021). The logic of these studies is that when the key stage of processing responsible for generating a subsequent switch cost is missing from a trial as a result of truncating the trial, there should be no switch cost measured on the next trial. However, it is also possible that, although the processes responsible for generating a switch cost have occurred, an additional factor abolishes that cost before it is measured on the next trial. For example, Lenartowicz et al. (2011) suggested that nogo signals might reset the task-set and abolish a task-switch cost (c.f. Los & van der Burg, 2010). In contrast, the aforementioned study of Verbruggen et al. (2006) suggests that it is the occurrence (or non-occurrence) of response selection that determines whether (or not) task-switch cost is obtained on a subsequent trial. Therefore, Verbruggen et al.'s findings from selective stopping are critically important to understanding why a task-switch cost is absent after nogo trials. However, to our knowledge, no study has been carried out to follow up these findings.

A study carried out by Wylie et al. (2004) used a procedure that is somewhat similar to Verbruggen et al.'s selective stopping. They used a version of the go/nogo procedure with cued task-switching, but in their study the go/nogo status of trials was determined by whether the targets were from one stimulus category or the other category. For example, in their vowel-consonant task, participants may have responded to the target if it was a vowel, but they withheld responding if it was a consonant. The procedure was similar to Verbruggen et al.'s Experiment 1 (that required response-based selective stopping) in the sense that both procedures required participants to process the target according to a cued task to decide whether they should respond to it, as opposed to a typical go/nogo experiment where participants could make a go/nogo decision without processing the target. Wylie et al. did not perform a direct test of switch costs after nogo trials, but their results showed little sign of task-switch cost after nogo trials.

To what extent Wylie et al.'s participants processed the cued task on nogo trials is unclear. In their experiment, participants performed an odd/even classification of digits or a vowel/consonant classification of letters and were instructed to respond to one stimulus category of a task while withhold responding to the other stimulus category (e.g., respond to vowels or even digits, but not to consonants or odd digits). To judge whether a response was required on a given trial, participants could have made a task-based judgment about the target without selecting a response (as in the aforementioned experiments by Swainson and Martin, 2013), or they could have selected a response according to the target and inhibited it (as in selective stopping in Verbruggen et al., 2006) if participants had already been instructed on both tasks. In either case, one would expect task-switch costs after nogo trials in this experiment if processes up to response selection are sufficient to generate a task-switch cost.

Furthermore, a more recent study using a similar procedure to Wylie et al.'s experiment showed a significant task-switch cost after nogo trials (Yamaguchi, Wall, & Hommel, 2019). This study was designed to address task switching between two actors in a joint task setting (where two actors performed the tasks together), so there were two alternative responses in each of the two tasks (colour or shape discrimination) that were assigned to two different actors. One actor responded only to one target from each task but ignored the other target that was assigned to their partner, making it a variation of the go/nogo procedure similar in structure to Wylie et al.'s experiment. To decide whether they had to make their response on a given trial, participants might have used the cued task to select a response to the target stimulus and executed the response if it was assigned to them, or they might have identified the target stimulus and judged whether it was assigned to themselves.

Unlike Wylie et al.'s study, Yamaguchi et al.'s (2019) study involved two task cues for each of the two tasks ("COLOUR" and "HUE" for the color task, and "SHAPE" and

"FORM" for the shape task). This separated 'switching task cues' and 'switching tasks' by having three types of trials (Logan & Bundesen, 2003; Mayr & Kliegl, 2003): (1) trials for which the same task cue repeats (so the task also repeats; *cue-repeat trial*); (2) trials for which task cues switch but the same task repeats (*cue-switch trial*); and (3) trials for which both task cues and tasks switch (*task-switch trial*). Yamaguchi et al. found that, after nogo trials, there was no significant difference between cue-repeat and task-switch trials (equivalent to the measure of task-switch cost in Wylie et al.'s and all other studies discussed above), but that there was still a significant difference between cue-switch and task-switch trials, which Logan and Bundesen (2003) suggested to reflect the true cost of task switching. The pattern of the results in their study is unusual because responses on cue-repeat trials are typically no slower than those on cue-switch trials. Yamaguchi et al. explained that the repetition of the same task cue may have falsely triggered a repetition of the same actor to perform the incoming trial when it required a switch to another actor, which slowed responding on a cue-repeat trial. Therefore, although a task-switch cost occurred when participants had selectively stopped responding to some aspect of the incoming task on a preceding nogo trial, the cost might not be observed in designs within which cue-switching never occurred when the same task repeated, as in Wylie et al.'s study and most other studies discussed above.

The Present Study

Most previous studies have asked what processes are necessary to generate a task-switch cost after nogo trials (e.g., Philipp et al., 2007; Schuch & Koch, 2003; Swainson & Martin, 2013), on the assumption that if a cost was not present it had not been generated by the processes occurring on the preceding trial. However, it is not necessarily the case that the absence of a switch cost following a nogo trial meant that no cost had ever been generated: it is also possible that an additional process related to a 'nogo' decision can abolish a task-switch cost that had otherwise been established on nogo trials, one such potential additional process being the inhibition of a selected response (Lenartowicz et al., 2011). Verbruggen et al.'s finding is important as it shows that inhibiting a response does not eliminate task-switch costs completely, but two subsequent studies using similar procedures (Wylie et al., 2004; Yamaguchi et al., 2019) have reported different results from Verbruggen et al.'s in that there was not a significant switch cost after nogo trials. Therefore, the main purpose of the present study was to evaluate whether a task-switch cost would be obtained as long as response selection (and any processes preceding it, including task preparation and target judgment) occurred on the preceding nogo trial. To this end, we carried out a series of six experiments.

Experiments 1 and 2 attempted conceptual replications of Yamaguchi et al. (2019) and Wylie et al. (2004), respectively. Experiment 1 used the color and shape classification tasks as in Yamaguchi et al.'s, whereas Experiment 2 used the vowel/consonant and odd/even tasks as in Wylie et al. In each of these experiments, we included a *selective go/nogo* condition and a *full-task* condition. In the selective go/nogo condition, participants were instructed to make one response if the trial presented a specific target but not to respond if it presented a different target. In the full-task condition (equivalent to the 'choice' condition in Wylie et al.'s; see later), all trials were go trials and therefore participants responded to all targets regardless of the responding hand. The full-task condition was a standard task-switching paradigm, which allowed us to evaluate whether switch costs in the selective go/nogo condition were reduced from the full-task condition, even when a significant task-switch cost was to be obtained after nogo trials. In both experiments, participants would have to make a task judgment about a target feature, at least, or select a response, in order to decide whether they should make a response. Therefore, a task-switch cost would be expected after nogo trials in these experiments.

In these experiments, each task involved two task cues per task, which resulted in three types of trial transitions, *cue-repeat* (“COLOUR” → “COLOUR”), *cue-switch* (“COLOUR” → “HUE”), and *task-switch* (“COLOUR” → “SHAPE”). The performance difference between cue-repeat and cue-switch is the cost of switching task cues (or *cue-switch cost*) without switching the task, and the difference between cue switch and task switch represents the cost of switching tasks (or *task-switch cost*) that discounts the cost of switching task cues (Logan & Bundesen, 2003). Wylie et al.’s study only used one task cue per task, which resulted in two types of task transition that were equivalent to cue-repeat and task-switch in the current experiment, and the difference between these two trial types is the sum of cue-switch and task-switch costs (which we refer to as *total switch cost*). Wylie et al. found no significant total switch cost, and Yamaguchi et al.’s study also showed no significant total switch cost but did show a significant task-switch cost (see the discussion above for the explanation proposed by Yamaguchi et al., 2019).

As in Yamaguchi et al.’s and Wylie et al.’s studies, Experiments 1 and 2 did not constrain the extent to which participants processed the cued task. Hence, regardless of the outcomes, it was not possible to know whether response selection would have occurred on selective nogo trials. Hence, we focused mainly on the replicability of the respective results in Experiments 1 and 2. The subsequent four experiments were designed to impose stronger constraints on participants to process the cued task up to response selection in order for them to decide whether a response was required. In effect, these experiments all intermixed selective go/nogo and full-task conditions in the same blocks of trials, with various other constraints. In Experiment 3, the to-be-stopped hand was fixed within a block of trials (as in Experiments 1 and 2, as well as in Verbruggen et al.’s). In Experiment 4, the to-be-stopped hand changed randomly across go/nogo trials within the same block and was only informed at the beginning of a trial, which prevented participants from preparing a particular response to stop in advance. Experiments 5 and 6 introduced a delay following target onset as in Phillip et al.'s (2007) and Swainson and Martin's (2013) studies. In Experiment 5, the target stayed on display until the end of a trial as in Phillip et al.'s; in Experiment 6 the target stayed only until a go/nogo signal onset as in Swainson and Martin's. We expected that these designs would encourage participants to select a response before go/nogo signals, and the degree of encouragement would increase with later experimental designs, providing progressively stronger tests of the response-selection account. In all of the experiments, we examined whether any of the switch costs (cue-switch, task-switch, or total switch cost) emerged after selective nogo trials.

Experiment 1

The present experiment was a replication of Yamaguchi et al.'s (2019) joint-task experiment but without a co-acting partner performing "nogo" trials. Participants only responded to the target stimulus that required the response assigned to themselves but withheld responding otherwise. This *selective go/nogo* phase was divided into two blocks of trials where participants only used the right hand to respond in one block and they only used the left hand to respond in the other block. Also, in contrast to the previous study, participants performed a *full-task* phase in which they responded to all targets (i.e., all trials were go trials) regardless of the response required on given trials. This full-task phase was included because Wylie et al.'s (2004) study also included such a condition (which they called a 'choice' condition). The inclusion of the full-task phase allowed us to test whether switch costs would be reduced significantly in the go/nogo phase as compared to the full-task phase (also see Philipp et al., 2007; Swainson & Martin, 2013; Verbruggen et al., 2006).

The two tasks involved color discrimination (red vs. green) or shape discrimination (square vs. diamond) on visual stimuli (targets). Participants were assigned two response keys to make responses to these targets. Although cue-switch and task-switch costs have been suggested to represent different processed involved in task switching (Logan & Bundesen, 2003), these different types of costs do not always manifest themselves clearly as several experimental parameters can influence their magnitudes (e.g., Logan & Bundesen, 2004; Monsell & Mizon, 2006). For example, a higher proportion of task-switch trials tends to facilitate responding on these trials and reduce the magnitude of a task-switch cost, whereas a higher proportion of cue-switch trials tends to facilitate responding on these trials and reduce the magnitude of a cue-switch cost (Schneider & Logan, 2006). In the present experiment, the three types of trial transition (cue-repeat, cue-switch, and task-switch) occurred with an equal probability, which should help minimize such biases due to an imbalance in the proportions of the three trial types. For the purpose of the present study, a significant task-switch cost or total switch cost would be taken as evidence for a cost of switching tasks, even when cue-switch cost is not significant. We still report tests of cue-switch cost but place less weights on cue-switch cost in our interpretations of results. If target processing or response selection is sufficient to obtain a cost of switching tasks, we expected that there would be a significant task-switch cost or total switch cost after selective nogo trials in the present procedure.

Method

Participants

Participants were recruited from the Prolific subject pool. All reported having normal or corrected-to-normal vision without color blindness. To match the sample size used in Yamaguchi et al.'s (2019) study, we aimed to recruit 60 participants. The sample size would also be sufficient to achieve a statistical power of .9 to detect a medium effect size (Cohen's f = .25 or η_p^2 = .06) in a fully within-subject design. A total of 70 participants completed the experiment, among which eight participants were excluded due to low response accuracy (below 80% correct response). The data from the remaining 62 participants (34 female and 28 male; mean age = 33.40, SD = 7.40, range = 19-45) were included in the analysis. The experimental protocol was approved by the Research Ethics Committee of the Department of Psychology at the University of Essex.

Apparatus and Stimuli

The experiment was developed and controlled by Inquisit. Participants were required to use either Windows or Macintosh computers, and no mobile devices (e.g., tablet or smartphone) were allowed. The sizes of stimuli varied depending on participants' monitor size. The following measures were based on a screen resolution of 1920 x 1080 in a 13-in laptop monitor. Target stimuli were green and red squares (2 cm inside) and diamonds (the square stimuli tilted 45°), which appeared at the center of the screen. The task cues were the words "COLOUR" and "HUE" for the color task, and "SHAPE" and "FORM" for the shape task. The cues were presented in the Arial font and appeared 3.5 cm above the screen center. Responses were registered by pressing the 'S' and 'L' keys on a keyboard.

Procedure

The experiment was conducted online. The task instructions emphasized both speed and accuracy of responding. Participants performed the *full-task* condition for which they responded to the target on every trial, and the *selective go/nogo* condition for which they responded only to the targets assigned to one response key and withheld responding to the targets assigned to the other response key. There were one block of the full-task condition and two blocks of the selective go/nogo condition; one selective go/nogo block required responding with the left-hand key and the other required responding with the right-hand key. Each block consisted of 180 test trials, and there was a block of 10 practice trials before each test block. Thirty-one participants started with the full-task block, followed by two selective go/nogo blocks later; thirty participants started with the selective go/nogo blocks, followed by the full-task block. The order of the full-task and selective go/nogo blocks were determined randomly. For the selective go/nogo blocks, the order of the blocks requiring different response keys was also determined randomly for each participant.

For both the full-task and selective go/nogo blocks, there were two different tasks (color vs. shape). In the color task, one key was assigned to red stimuli and the other key to green stimuli; in the shape task, one key was assigned to squares and the other key to diamonds. The assignments of the colors and the shapes to the two response keys were counterbalanced across participants. These two tasks were intermixed randomly in each block. One of the tasks was indicated by the task cue at the beginning of each trial; the task cue for the color task was either *COLOUR* or *HUE*, and that for the shape task was either *SHAPE* or *FORM*.

Each trial started with a task cue that stayed on the screen for 400 ms, followed by a 100-ms blank screen. The target stimulus (colored square or diamond) appeared for 2,000 ms or until a response was made. In the full-task blocks, participants had to make a response within the 2000-ms time window after stimulus onset. In the go/nogo blocks, participants were required to respond within the 2000-ms time window only when the target feature assigned to one response key appeared (go trials) but withhold responding until the trial ended when the target feature assigned to the other response key appeared (nogo trials). For full-task and go trials, the message “Correct!” was presented if the correct response was made and stayed on screen for 500 ms; otherwise, an error message was presented for 1,000 ms. The error message was “Error!” for an incorrect response and “Faster!” for no response. For nogo trials, the message was “Correct!” for 500 ms if no response was made, and it was “Don’t respond!” for 1000 ms if a response was made. Response time (RT) was measured as the interval between onset of the target stimulus and a depression of a response key. The next trial started with another task cue.

Data Analysis

The data were analyzed in terms of mean RT and percentage errors (PE) computed for the full-task and selective go/nogo blocks. Only full-task and selective go trials were included in the RT analysis, as there was no RT on selective nogo trials when participants correctly withheld responding: RT was submitted to a 2 (Current Trial: full-task vs. selective go) x 2 (Response Switch; response repeat vs. response switch) x 3 (Trial Sequence: cue-repeat vs. cue-switch vs. task-switch) ANOVA. All three types of trials (full-task, selective go, and selective nogo trials) were included in the PE analysis: PE was submitted to a 3 (Current Trial: full-task vs. selective go vs. selective nogo) x 2 (Response Switch: response repeat vs. response switch) x 3 (Trial Sequence: cue-repeat vs. cue-switch vs. task-switch) ANOVA. All factors were within-subject variables.

Response Switch consisted of response-repeat and response-switch trials: on *response-repeat trials*, the correct response was the same as that on the preceding trial; on *response-switch trials*, the correct response was different from that on the preceding trial. Note that selective go/nogo trials were associated with specific responses. Hence, for selective go trials, response-repeat trials meant that previous trials were also selective go trials (i.e., go-go sequence), whereas response-switch trials meant that previous trials were selective nogo trials (nogo-go sequence). Similarly, for selective nogo trials, response-repeat trials meant that previous trials were also selective nogo trials (i.e., nogo-nogo sequence), and response-switch trials meant that previous trials were selective go trials (go-nogo sequence). Response repeat and switch occurred with an equal probability.

As for Trial Sequence, *cue-repeat trials* were those for which the task cue was the same as that on the preceding trial, and participants performed the same task as the preceding trial. On *cue-switch trials*, the task cue was different from that on the preceding trial, but participants still performed the same task as on the preceding trial. On *task-switch trials*, the task cue was different from that on the preceding trial, and participants performed a task different from the preceding trial. These three types of task transition occurred with an equal probability (.33) in a random order. Because the main purpose of the present experiment was to examine the presence/absence of switch costs, post-hoc multiple comparisons were carried out to follow up significant interactions involving Trial Sequence. Their p-values were Bonferroni-corrected for three comparisons (cue-repeat vs. cue-switch, cue-repeat vs. task-switch, and cue-switch vs. task-switch; i.e., p-values were multiplied by three, as opposed to dividing the alpha by three; where the resulting p-value was greater than 1, it is reported as 1). We report cue-repeat and task-switch costs but omit total switch cost if the task-switch cost was significant; we also report whether a total switch cost was significant when neither the cue-switch nor the task-switch cost was significant.

Transparency and Openness

The raw trial data are available on the OSF project page (https://osf.io/c8hw7/) as well as UK Data Service (link here). We report how we determined our sample size in the Participants section above. The design and its analyses were not pre-registered. All data were collected between February 2022 and March 2022.

Results

Trials were discarded when no response was made or RT was shorter than 200 ms on full-task and go trials, or when the correct response was not made on the immediately preceding trial (6.24% of all trials). Mean RT was computed for correct responses. RT and PE are shown in Figure 1, and the ANOVA results are summarized in Table 1. The main purpose of the analyses was to examine whether significant switch costs were obtained after selective nogo trials.

For RT, all main effects and interactions, except for the interaction between Current Trial and Response Switch, were significant. Responses were generally faster for selective go/nogo trials (M = 519 ms) than for full-task trials (M = 625 ms), and for response repeat (M

= 553 ms) than for response switch (*M* = 591 ms). Responses were also faster for cue-repeat (*M* = 542 ms) than for cue-switch (*M* = 567 ms), and for cue-switch than for task-switch (*M* = 607 ms). These trials were all different from each other (*p*s < .001), reflecting significant cue-switch cost (*M* = 25 ms) and task-switch cost (*M* = 40 ms). The interaction between Current Trial and Trial Sequence indicated that switch costs differed between full-task trials and selective go trials. For full-task trials, cue-switch cost was 25 ms, and task-switch cost was 72 ms (both *ps* < .001); for selective go trials, cue-switch cost was 25 ms (*p* < 001), and task-switch cost was 9 ms (*p* = .370). Thus, the interaction was mainly driven by the differences in task-switch cost. The interaction between Response Switch and Trial Sequence also indicates that switch costs differed between response repeated and response switched. For response repeat, cue-switch cost was 39 ms, and task-switch cost was 61 ms (both *p*s < .001); for response switch, cue-switch cost was 11 ms (*p* = .150), and task-switch cost was 20 ms (*p* = .014).

Most importantly, the 3-way interaction among all three variables implied that switch costs were modulated by Current Trial and Response Switch at the same time. For full-task trials, response repeat produced a cue-switch cost of 38 ms and a task-switch cost of 103 ms (both *p*s < .001). Response switch did not produce a significant cue-switch cost (*M* = 12 ms; *p* = .395) but did produce a significant task-switch cost (*M* = 41 ms; *p* < .001). On selective go trials, response repeat (i.e., selective go trials after a selective go trial) also produced a cue-switch cost of 41 ms (*p* < .001) but not a task-switch cost of 20 ms (*p* = .060). Total switch cost was 60 ms (*p* < .001). However, response switch (selective go trials after a selective nogo trial) did not produce a cue-switch cost (*M* = 9 ms; *p* = .570) or a task-switch cost (*M* = –2 ms; *p* = 1.00), with a non-significant total switch cost of 8 ms (*p* = .910). Therefore, switch costs were absent after selective nogo trials.

For PE, main effects of Current Trial and of Trial Sequence, but not that of Response Switch, were significant. There was very low PE for selective go trials (M = .08%) as compared to full-task trials (M = 6.72%) or to selective nogo trials (M = 5.52%). PE was similar between cue-repeat (M = 2.96%) and cue-switch (M = 3.06%), but it was larger for task-switch (M = 6.30%). Thus, there was no cue-switch cost (p = 1.00), while task-switch cost was significant (M = 3.24%, p < .001). There were also significant interactions between Current Trial and Trial Sequence, between Response Switch and Trial Sequence, and among all three variables. As PE for selective go trials was very low in all conditions, they were not noteworthy. For full-task trials, cue-switch cost was less than 1% and was not significant for response repeat and response switch, while task-switch cost was significant for response repeat (M = 9.43%, p < .001) and for response switch (M = 4.72%, p < .001). For selective nogo trials, cue-switch costs were also less than 1% and were not significant. Task-switch costs were significant for response repeat (i.e., after selective nogo trials; M = 3.86%, p < .001) but not for response switch (after selective go trials; M = 1.64%, p = .818). Nevertheless, total switch cost (the difference between cue-repeat and task-switch trials) was still significant for response switch (M = 2.26%, p = .005). Thus, for selective nogo trials, some forms of switch cost (either task-switch cost or total switch cost) was still significant when the preceding trial was a selective nogo trial.

To summarize the main results, RT showed that switch costs were smaller for response switch than for response repeat. There were smaller switch costs for selective go/nogo trials than for full-task trials, while responses were generally faster and more accurate for the former than the latter. Importantly, for selective go trials, cue-switch and total switch costs remained significant after selective go trials but not after selective nogo trials in RT. For selective nogo trials, switch costs still remained significant after selective nogo trials in PE.

Figure 1

Mean response times (RT; top panels) and percentage errors (PE; bottom panels) as a function of Trial Sequence and Response Switch in full-task and selective go/nogo trials in Experiment 1 (error bars represent one standard error of the means). For RT, the left panel is for full-task trials, and the right panel for selective go trials. For PE, the left panel is for full-task trials, the middle for selective go trials, and the right for selective nogo trials.

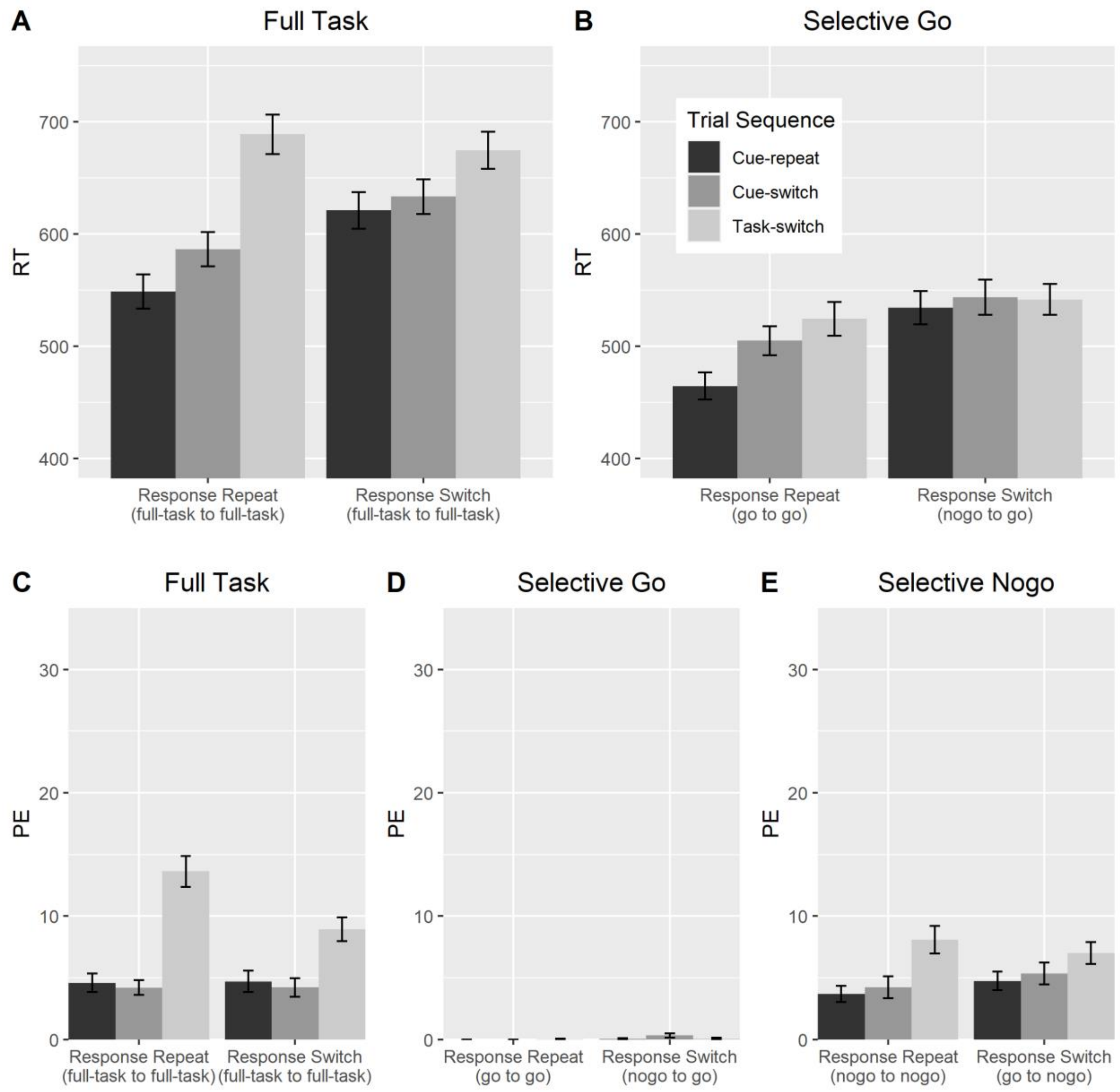

Table 1

ANOVA results for response time (RT) and percentage errors (PE) in Experiment 1.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
			RT		
Current Trial (CT)	**1, 61**	**16066.57**	**131.80**	**< .001**	**.684**
Response Switch (RS)	**1, 61**	**5275.88**	**52.29**	**< .001**	**.462**
Trial Sequence (TS)	**2, 122**	**3072.80**	**87.83**	**< .001**	**.590**
CT x RS	1, 61	2918.58	< 1	.397	.012
CT x TS	**2, 122**	**2601.89**	**31.64**	**< .001**	**.342**
RS x TS	**2, 122**	**2317.44**	**32.89**	**< .001**	**.350**
CT x RS x TS	**2, 122**	**1663.88**	**4.33**	**.015**	**.066**
			PE		
CT	**1, 61**	**85.32**	**54.53**	**< .001**	**.472**
RS	1, 61	19.18	1.74	.192	.028
TS	**2, 122**	**21.23**	**63.13**	**< .001**	**.509**
CT x RS	**1, 61**	**18.46**	**5.33**	**.006**	**.080**
CT x TS	**2, 122**	**18.48**	**27.09**	**< .001**	**.307**
RS x TS	**2, 122**	**13.93**	**12.46**	**< .001**	**.170**
CT x RS x TS	**2, 122**	**13.44**	**4.11**	**.003**	**.063**

Note: Bold represents a significant effect.

Discussion

The present experiment yielded non-significant switch costs in RT after selective nogo trials, which seem to agree with Wylie et al.'s (2004) results, but unlike Yamaguchi et al.'s (2019) results that still showed a significant task-switch cost. Interestingly, however, there was still a significant total switch cost (the sum of task-switch and cue-switch cost) in PE on selective nogo trials that followed another selective nogo trial, which means that participants tended to make responses when they should not, more so when the task switched than when the task repeated. Swainson and Martin (2013) also found a significant task-switch cost in PE after nogo trials with delayed go/nogo signals, although this was only examined on go trials. Before we consider possible factors that might have contributed to these results, we first report Experiment 2 and consider inferences from the two experiments together.

Experiment 2

Experiment 2 now replaced the color and shape discrimination tasks, used in Yamaguchi et al.'s (2019) study, with the consonant-vowel and odd-even classification tasks similar to those used in Wylie et al.'s (2004) experiment. We did not intend to replicate all details of Wylie et al.'s design. Instead, the design of the present experiment followed that of Experiment 1 closely, except for the use of the consonant-vowel and odd-even tasks that were modelled after Wylie et al.'s. Both of these two tasks involved four target stimuli for each response category, as opposed to a single target for each response category in the color and shape discrimination tasks used in Experiment 1. Thus, the current tasks might be more difficult than Experiment 1, and the mappings between specific stimuli (digits and letters) and responses (keypresses) may be mediated by more general stimulus categories (odd/even and consonant/vowel). As there were more stimuli, the present experiment also excluded immediate repetitions of the same stimuli on two consecutive trials, which would not have been possible with the color and shape tasks in Experiment 1. We did not have a specific prediction as to which of these task parameters would determine the eventual outcomes, but as Wylie et al.'s results show no switch cost after nogo trials with these tasks, we expected that we would also find no switch cost after nogo trials in the present experiment if the results of Wylie et al.'s study depended on the tasks.

Method

Participants

A new group of 72 participants from the Prolific subject pool completed the experiment. Nine participants yielded an overall error rate greater than 20% and were excluded from the analysis, leaving a total of 63 participants (37 females, 26 males; mean age = 32.46, SD = 7.16, range = 19-45). All participants were recruited with the same recruitment criteria as in Experiment 1.

Apparatus, Stimuli, and Procedure

The apparatus was the same as Experiment 1. The design of the experiment was also similar but involved the digit task (judging whether a digit was an even or odd number) and the letter task (judging whether a letter was a vowel or consonant). Target stimuli were “2, 4, 6, 8” for even and “3, 5, 7, 9” for odd in the digit task, and “A, E, I, U” for vowels and “G, K, M, R” for consonants in the letter task. The task cues for the digit task were *DIGIT* and *NUMBER*; the task cues for the letter task were *LETTER* and *ALPHABET*. On each trial, a task cue appeared at the screen center, and a letter and a digit appeared 2 cm above or below the screen center. The letter and digit were not allowed to repeat on consecutive trials. There were two blocks of full-task trials and two blocks of selective go/nogo trials for each participant. The procedure followed Experiment 1 in all other respects.

Results

The data were filtered as in Experiment 1, and 8.18% of trials were discarded. RT and PE were analyzed in the same manner, and are shown in Figure 2 and Table 2.

For RT, all main effects and interactions were significant. Responses were generally faster for selective go trials (M = 732 ms) than for full-task trials (M = 807 ms), and for response repeat (M = 755 ms) than for response switch (M = 785 ms). Responses were also faster for cue-repeat (M = 741 ms) than for cue-switch (M = 761 ms), and for cue-switch than for task-switch (M = 807 ms), yielding significant cue-switch and task-switch costs (ps < .001). The advantage of response repeat was larger for selective go trials (Ms = 708 ms for response repeat and 757 ms for response switch) than for full-task trials (Ms = 801 ms for response repeat and 814 ms for response switch). The effect of Trial Sequence was larger for full-task trials than for go trials, and for response repeat than for response switch. Namely, cue-switch and task-switch costs were 22 ms and 69 ms for full-task trials (both ps < .007) and 18 ms and 21ms for selective go trials (*p*s < .02); these costs were 21 ms and 67 ms for response repeat (*p*s < .01) and 19 ms and 23 ms for response switch (*p*s < .02).

The 3-way interaction among all three factors reflected the following outcomes: For full-task trials, cue-switch cost was not significant (*M* = 17 ms, *p* = .280) but task-switch cost was significant (*M* = 113 ms, *p* < .001) for response repeat, whereas cue-switch cost was significant (*M* = 26 ms, *p* = .018) but task-switch cost was not (*M* = 25 ms, *p* = .099) for response switch. For selective go trials, cue-switch cost (*M* = 24 ms, *p* = .023), but not task-switch cost (*M* = 22 ms, *p* = .059), was significant for response repeat (go-go sequence). Total switch cost was 46 ms (*p* < .001). For response switch (nogo-go sequence), neither cue-switch cost (*M* = 12 ms, *p* = .459) nor task-switch cost (*M* = 21 ms, *p* = .187) were significant, although the total switch cost (*M* = 33 ms, *p* = .009) was still significant.

For PE, all main effects and interactions were also significant. Responses were least accurate for full-task trials (*M* = 8.80%), intermediate for selective nogo trials (*M* = 6.08%), and most accurate for selective go trials (*M* = .15%). Responses were also most accurate for cue-repeat (*M* = 3.85%), intermediate for cue-switch (*M* = 4.14%), and least accurate for task-switch (*M* = 7.04%); cue-switch cost was not significant (*M* = .29%, *p* = .95), while task-switch cost was (*M* = 2.91%, *p* < .001). These switch costs depended on Current Trial, Response Switch, and both of these variables at the same time: For full-task trials, task-switch cost (*M* = 8.54%, *p* < .001), but not cue-switch cost (*M* = 0.48%, *p* = 1.000), was significant for response repeat. Also, for response switch, task-switch costs (*M* = 3.03%, *p* = .043), but not cue-switch cost (*M* = .14%, *p* = 1.00), was significant. As in Experiment 1, PE for selective go trials was too low to consider any meaningful inference. For selective nogo trials, task-switch costs were significant for response repeat (*M* = 4.04%, *p* = .002) and for response switch (*M* = 1.69%, *p* = .027), whereas cue-switch costs were not significant for both response repeat and response switch (*M*s = .21% and .56%, *p*s = 1.000).

Therefore, the results of Experiment 2 were similar to those of Experiment 1 in most respects, but for RT, the total switch cost remained significant after nogo trials, although neither cue-switch nor task-switch cost was significant. This is inconsistent with the absence of a total switch cost following nogo trials in Wylie et al.'s (2004) data. The experiment also showed significant task-switch costs in PE on nogo trials after nogo trials, as observed in Experiment 1.

Figure 2

Mean response times (RT; top panels) and percentage errors (PE; bottom panels) as a function of Trial Sequence and Response Switch in full-task and selective go/nogo trials in Experiment 2 (error bars represent one standard error of the means). For RT, the left panel is for full-task trials, and the right panel for selective go trials. For PE, the left panel is for full-task trials, the middle for selective go trials, and the right for selective nogo trials.

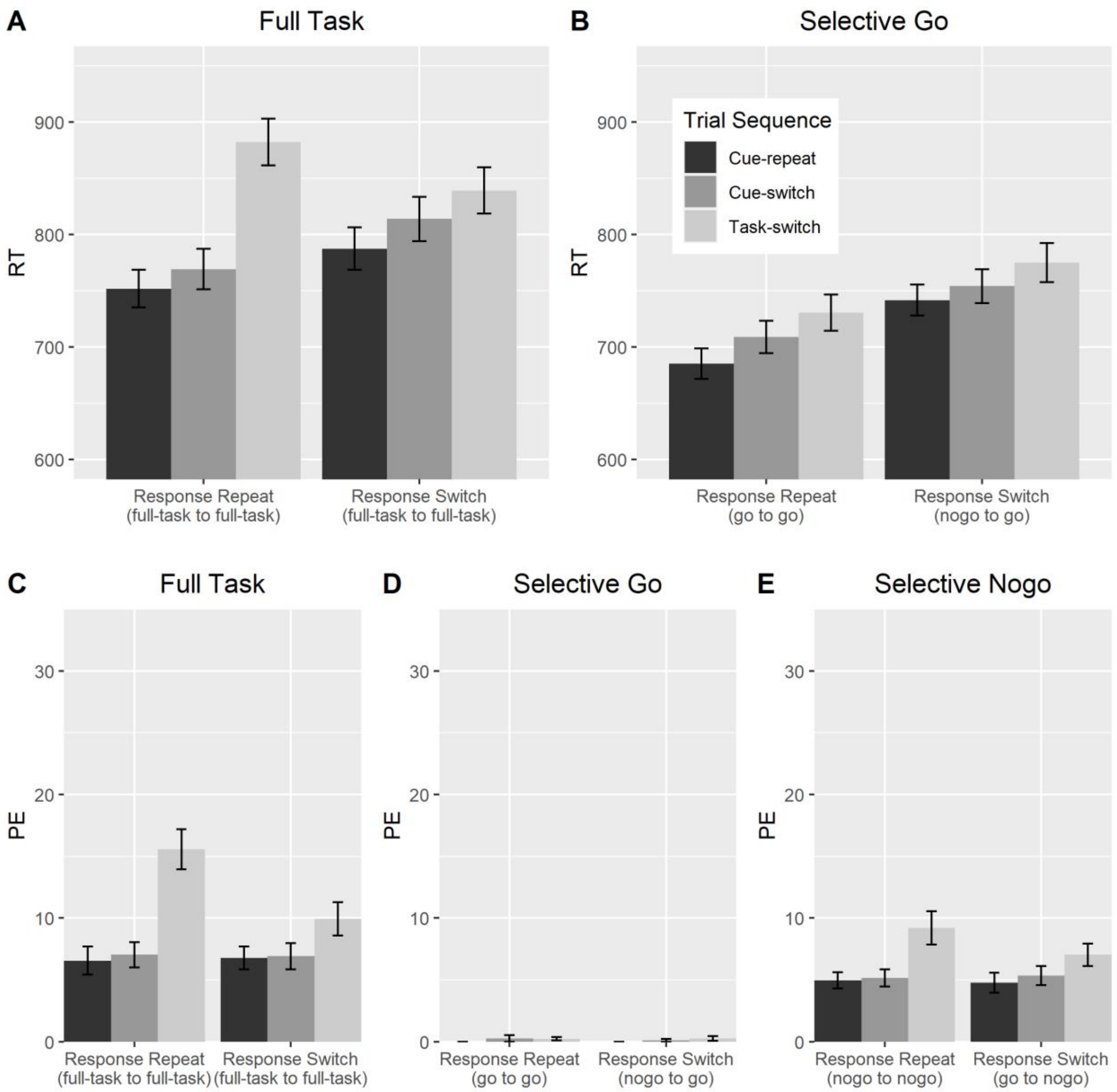

Table 2

ANOVA results for response time (RT) and percentage errors (PE) in Experiment 2.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
			RT		
Current Trial (CT)	**1, 62**	**21450.11**	**49.32**	**< .001**	**.443**
Response Switch (RS)	**1, 62**	**4305.56**	**41.24**	**< .001**	**.399**
Trial Sequence (TS)	**2, 124**	**6839.11**	**41.23**	**< .001**	**.399**
CT x RS	**1, 62**	**4105.94**	**15.28**	**< .001**	**.198**
CT x TS	**2, 124**	**3447.83**	**15.06**	**< .001**	**.195**
RS x TS	**2, 124**	**2915.62**	**14.42**	**< .001**	**.189**
CT x RS x TS	**2, 124**	**2460.23**	**13.26**	**< .001**	**.176**
			PE		
CT	**1, 62**	**129.52**	**57.18**	**< .001**	**.480**
RS	**1, 62**	**29.81**	**7.20**	**.009**	**.104**
TS	**2, 124**	**36.78**	**32.13**	**< .001**	**.341**
CT x RS	**1, 62**	**20.84**	**3.72**	**.027**	**.057**
CT x TS	**2, 124**	**29.33**	**11.97**	**< .001**	**.162**
RS x TS	**2, 124**	**24.56**	**8.55**	**< .001**	**.121**
CT x RS x TS	**2, 124**	**18.20**	**4.95**	**< .001**	**.074**

Note: Bold represents a significant effect.

Discussion

The results of Experiment 2 were consistent with those of Experiment 1 in showing that task-switch costs were significant after selective nogo trials in PE. However, task-switch cost was significant in RT in Experiment 2 whereas it had not been in Experiment 1. An important finding in these experiments is that switch costs were still obtained after selective nogo trials (on selective nogo trials) in PE. This appears to be consistent with Swainson and Martin's (2013) results, but the experimental setups were different in many aspects. Swainson and Martin's study did not involve selectively stopping according to target features or the required response, and their go trials were similar to full-task trials that in the present experiments were separated from the selective go/nogo trials. Despite these differences, the significant switch costs after selective nogo trials in these experiments may suggest that task judgment about target features is sufficient to produce switch costs in PE, but not in RT. These observations would deserve further investigations in future studies.

Another important finding is that the results of Experiments 1 and 2 disagree with their counterpart studies: Experiment 1 was similar in design to Yamaguchi et al.'s (2019) study, but the results disagreed with that study because none of the switch costs following selective nogo trials were significant in RT in Experiment 1. Experiment 2 were similar in design to Wylie et al.'s (2004) study, but the results disagreed with that study because total switch cost following selective nogo trials was significant in RT in Experiment 2. Experiments 1 and 2 differed in the types of tasks, which were also reflected in the differences between Yamaguchi et al.'s and Wylie et al.'s studies. There were two major differences between these types of tasks. First, Experiment 2 and Wylie et al. used multiple stimuli per response category, which excluded stimulus repetitions across trials, which may play a central role in producing switch costs as proposed by a recent theory (Schmidt, Liefooghe, & De Houwer, 2020). Second, multiple stimuli per response category in the consonant-vowel and odd-even tasks also made it more difficult to learn particular stimulus-response associations than one stimulus per response category in Experiment 1. Response selection may also be mediated by abstract concepts ('odd' or 'vowel'), so particular stimuli might not be associated directly with responses. Although any of these differences could have contributed to the discrepancies, the results of the present experiments imply that they are not reliable determinants of the presence or absence of switch costs after selective nogo trials.

A possible reason for the discrepancies between these experiments is that these experimental setups allowed different participants to adopt different strategies to perform the tasks. For example, some participants might have been able to judge whether to make responses based only on target features without selecting the assigned responses, whereas others might have made that judgement only after selecting responses. According to the response-selection account, the former group would not generate subsequent switch costs, but the latter group would still produce subsequent switch costs. The proportions of participants who adopted different strategies could determine the overall outcome, leading to the inconsistent results. If this is the case, it is necessary to test switch costs after selective nogo trials in a condition that prevents stopping without response selection. This was attempted in Experiments 3 and 4.

It is also worth considering what constitutes response selection. In a dual-task study, Hommel (1998) suggested that *response activation* can occur automatically and concurrently for two separate tasks, but the final 'selection' only occurs for one task at a time, resulting in dual-task interference, known as the psychological refractory period effect (slowing of the second of the two concurrent tasks for short intervals between the tasks). Some participants may be able to make a go/nogo judgment at the stage of response activation before the final response selection occurs, whereas others may require the final selection to do so. Similarly, with a variation of the go/nogo procedure in task switching, Philipp et al. (2007) also suggested that processes subsequent to response selection (e.g., response execution) contribute to switch costs after go trials. They also found that switch costs were present but were substantially larger when there had been a long delay between the target and nogo signal onsets on the preceding trial, as compared to when there had been a short delay. Therefore, the degree to which response selection and subsequent processes have completed may determine switch costs on the following trial, and response selection alone might not be sufficient to produce reliable switch costs. This *depth of processing* could be examined by introducing a delay between the target onset and a go/nogo signal onset (Philipp et al., 2007; Swainson & Martin, 2013). We used this manipulation in Experiments 5 and 6.

Considering these possible reasons for the discrepancy between the first two experiments (and between the previous studies these experiments modelled), we designed the next four experiments, so as to increase the chance that response selection would occur on selective nogo trials. If the occurrence of response selection determines the presence of a task-switch cost in RT after selective nogo trials, we expected that task-switch cost (or total switch cost, at least) should occur in these experiments. However, if the task-switch cost is found to be absent after selective nogo trials, one could conclude that something other than response selection is responsible for determining the presence of switch costs. That is, response selection or processes prior to it might establish switch costs, but the costs could be abolished by another process (e.g., inhibition of a task-set; Lenartowicz et al., 2011).

Experiment 3

In Experiments 1 and 2, selective go/nogo trials were separated from full-task trials in different blocks, and the to-be-stopped response was fixed within a given block of selective go/nogo trials. This meant that only one response (a keypress with, say, the right index finger) would need to be used for the whole block of trials. Participants might have been able to remember particular targets or target categories that were associated with the to-be-stopped response and this might have allowed them to stop responding without selecting the response when these targets were presented. For instance, a participant might have looked for the relevant target feature/category (e.g., the colour red, or odd numbers) and responded when they saw it, and they might have done nothing when they found the other target feature/category. In those experiments, participants made almost no response errors and substantially faster responses on selective go trials than on full-task trials, which seem to imply that participants did indeed make simple detection responses to the relevant targets without selecting between alternative responses. To increase participants' propensity to perform response selection on go/nogo trials, Experiment 3 intermixed full-task and go/nogo trials within the same block of trials. This would prevent participants from simply looking for the relevant target feature to judge whether a response was required on the trial.

To this end, a grey square frame that signalled a selective go/nogo trial was added on a subset of trials. Participants then had to judge whether the target required the to-be-stopped response, which was predetermined for a given block of trials as in Experiments 1 and 2. Unless the grey square frame appeared, it was the same as a full-task trial in Experiments 1 and 2, and participants had to respond to all targets including the ones that were otherwise assigned to selective nogo trials. By intermixing go/nogo and full-task trials, this design also allowed comparing full-task trials that followed selective go/nogo trials and those that followed full-task trials. As discussed in the Introduction, the response-selection account would predict that a task-switch cost should depend on whether response selection occurred on the preceding trial (Schuch & Koch, 2003), but others argue that nogo signals interfere and abolish the task-switch cost generated on the preceding trial (Lenartowicz et al., 2011). We expected that a task-switch cost would be obtained after selective nogo trials if the presence of the switch cost depends only on whether response selection (or processes preceding response selection) has occurred on the preceding nogo trial. However, a task-switch cost would be absent after selective nogo trials if nogo trials abolish the switch cost that might be generated by response selection (or processes preceding response selection).

Method

Participants

Sixty-five participants completed the experiment online, but six participants yielded response accuracy less than 70% and were excluded (we used a lower cut-off in this experiment than in Experiments 1 and 2 because error rates were generally higher in this experiment due to the additional complexity of judging whether it was a full-task trial or a selective go/nogo trial). This left with 59 participants (33 females, 25 males, 1 other; mean age = 33.00, SD = 7.55, range = 19-45).

Apparatus, Stimuli, and Procedure

The present experiment used the same stimuli as those from Experiment 1. The procedure was also similar to Experiment 1, with the main change being that full-task and go/nogo trials were intermixed and occurred randomly within the same blocks. The two tasks were the color and shape classifications, as in Experiment 1. There were two phases, each consisting of one block of 15 practice trials and three blocks of 120 test trials. Half of the test trials were full-task trials where participants responded to the target regardless of the required response. The other half were go/nogo trials where a grey square frame was presented around the target. On such trials, participants responded to the target only if the target required a designated response (selective go trials) and withheld responding to the target that required the other response (selective nogo trials). In one phase, the designated response was the left response, and in the other phase, it was the right response. The order of the designated responses was randomly determined for each participant.

Results

The analyses focused on RT and PE on full-task trials. The number of selective go/nogo trials was not sufficiently large to warrant separate analyses, so we report the analyses of selective go and nogo trials for this and subsequent experiments in supplemental materials. Mean RT for correct responses and PE on full-task trials were computed as in Experiments 1 and 2 (12.9% of trials were discarded) and were submitted to 3 (Previous Trial: full-task vs. selective go vs. selective nogo) x 2 (Response Switch: response repeat vs.

response switch) x 3 (Trial Sequence: cue-repeat vs. cue-switch vs. task-switch) ANOVAs[1]. Figure 3 and Table 3 summarise the results.

For RT, all main effects and interactions were significant. Responses were fastest after full-task trials (*M* = 729 ms), intermediate after selective go trials (*M* = 776 ms), and slowest after selective nogo trials (*M* = 807 ms). Responses were also faster for response repeat (*M* = 755 ms) than for response switch (*M* = 786 ms) in general, but whereas response repeat was faster than response switch after full-task (*M*s = 698 ms vs. 760 ms) and selective go (*M*s = 697 ms vs. 855 ms), the reverse was true after selective nogo (*M*s = 871 ms vs. 742 ms). This reversed effect of response repetition was presumably because the required response was inhibited on the preceding nogo trial, which incurred the cost of repeating the inhibited response. In general, cue-switch cost did not reach significance (*M* = 16 ms, p = .053), while task-switch cost (*M* = 59 ms, $p < .001$) was significant. Nevertheless, these effects were modulated by Response Switch: as in Experiments 1 and 2, switch costs were generally smaller for response switch (cue-switch cost = 6 ms; task-switch cost = 27 ms) than for response repeat (cue-switch cost = 25 ms; task-switch cost = 91 ms). Previous Trial further modulated this interaction: After full-task trials, both cue-switch cost (*M* = 40 ms) and task-switch cost (*M* = 159 ms) were significant for response repeat (both *p*s < .001), whereas only task-switch cost (*M* = 30 ms, p = .039), but not cue-switch cost (*M* = 17 ms, p = .244), remained significant for response switch. After selective go trials, cue-switch cost was no longer significant (*M* = 28 ms, p = .277), but task-switch still remained significant (*M* = 98 ms, $p < .001$), for response repeat. For response switch, neither cue-switch cost (*M* = 0 ms, *p*

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[1] Note that in the selective go/nogo blocks of Experiments 1 and 2, the sequence of different trial types (go vs. nogo) was confounded with response repeat/switch. For example, on selective nogo trials, response repeat meant that the preceding trial was also a selective nogo trial, and response switch meant that the preceding trial was a selective nogo trial. This confound could not be avoided because go/nogo was defined in terms of the response required on a given trial. In the present experiment, response repeat/switch was de-confounded from previous trial type because both selective-go and selective-nogo trials could be followed by a full-task trial that required either of the two alternative responses.

= 1.00) nor task-switch cost (*M* = 42 ms, *p* = .122) were significant, but the total switch cost still reached significance (*M* = 40 ms, *p* = .050). After selective nogo trials, no switch costs were significant, regardless of response repeat or switch; cue-switch costs were 8 ms and 0 ms for response repeat and response switch, and task-switch costs were 16 ms and 11 ms for response repeat and response switch (all *p*s > .6). Total switch costs were not significant for response repeat (*M* = 24 ms, *p* = .670) or for response switch (*M* = 11 ms, *p* = 1.00).

For PE, responses were more accurate for response switch (*M* = 7.33%) than for response repeat (*M* = 6.28%), but this outcome depended on Previous Trial. After full-task trials, PE was similar between response repeat and response switch (*M*s = 6.50% and 6.67%); after selective go trials, responses were more accurate for response repeat than for response switch (*M*s = 6.68% vs. 7.59%); but responses were less accurate for response repeat than for response switch (*M*s = 8.80% vs. 4.58%) after selective nogo trials. As in RT, these outcomes showed a reversed effect of Response Switch after selective nogo trials, suggesting that response was inhibited on a preceding nogo trial for response repeat. In general, cue-switch cost was not significant (*M* = .26%, *p* = 1.00), but task-switch cost was (*M* = 4.10%, *p* < .001), as reflected by the significant main effect of Task Sequence. None of the interactions involving Trial Sequence reached significance. However, when switch costs were examined separately after full-task, selective go, and selective nogo trials, task-switch cost was significant after full-task trials (*M* = 6.11%, *p* < .001) and selective go trials (*M* = 6.07%, *p* < .001) when response repeated. When response switched, task-switch cost was still significant after full-task trials (*M* = 4.93%, *p* < .001); after selective go trials, task-switch cost was not significant (*M* = 3.28%, *p* = .109), although total switch cost remained significant (*M* = 4.61%, *p* = .012). After selective nogo trials, neither task-switch cost nor total switch cost were significant regardless of whether response repeated or switched, all *p* > .17.

Figure 3

Mean response times (RT) and percentage errors (PE) as a function of Trial Sequence and Response Switch on full-task trials in Experiment 3 (error bars represent one standard errors of the means).

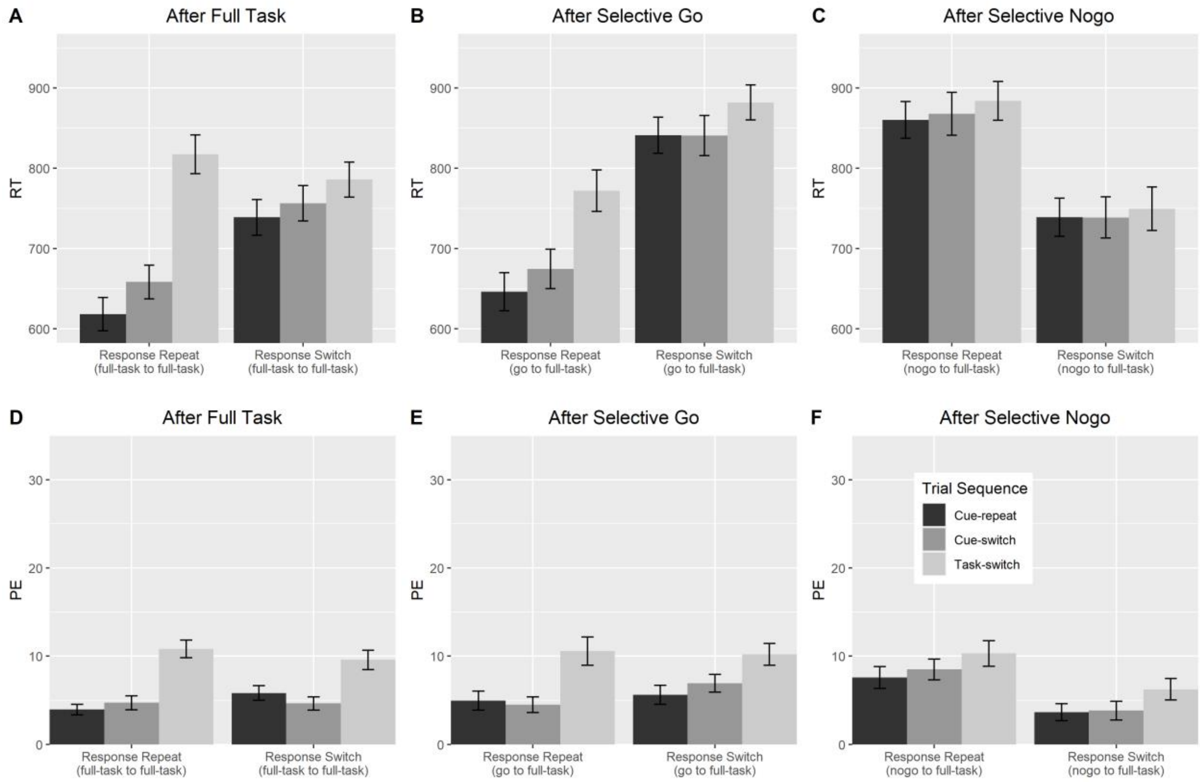

Table 3. ANOVA results for response time (RT) and percentage errors (PE) on full-task trials in Experiment 3.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
			RT		
Previous Trial (PT)	**2, 116**	**13545.53**	**39.75**	**< .001**	**.407**
Response Switch (RS)	**1, 58**	**8426.95**	**29.03**	**< .001**	**.334**
Trial Sequence (TS)	**2, 116**	**12984.82**	**42.36**	**< .001**	**.422**
PT x RS	**2, 116**	**9546.63**	**196.29**	**< .001**	**.772**
PT x TS	**4, 232**	**6216.50**	**15.03**	**< .001**	**.206**
RS x TS	**2, 116**	**7929.45**	**21.30**	**< .001**	**.269**
PT x RS x TS	**4, 232**	**6750.91**	**6.49**	**< .001**	**.100**
			PE		
PT	2, 116	58.84	< 1	.608	.009

RS	**1, 58**	**53.64**	**5.38**	**.024**	**.085**
TS	**2, 116**	**59.97**	**35.36**	**< .001**	**.379**
PT x RS	**2, 116**	**65.53**	**10.40**	**< .001**	**.152**
PT x TS	4, 232	45.52	2.37	.054	.039
RS x TS	2, 116	41.97	1.18	.311	.020
PT x RS x TS	4, 232	47.73	.92	.454	.016

Note: Bold represents a significant effect.

Discussion

The present experiment differed from the first two experiments in that full-task and selective go/nogo trials occurred randomly within the same block. As the to-be-stopped response was fixed within a given block, participants could anticipate and prepare for inhibiting a response, but that response was still required on full-task trials. Hence, there appeared to be strong propensity to respond on nogo trials, given the increased error rate on these trials (which indicated that participants often failed to inhibit responding) as compared to other trial types within the experiment as well as to nogo trials in the first two experiments. There was also evidence that responses were slower and less accurate when the current full-task trial required the response that was inhibited on the preceding selective nogo trial (i.e., response repeat) than when it required the other response (response switch). These reversed effects of Response Switch seem to indicate that response selection did occur on a selective nogo trial, but the selected response was inhibited, leading to the higher error rate when the inhibited response was required on the next full-task trial. Consequently, response selection is more likely to have occurred in the present experiment than in Experiments 1 and 2, providing a stronger test of the response-selection account.

For RT, the results were clear with respect to the influences of previous trial type on switch costs. For full-task trials, switch costs were substantially reduced for response switch as compared to those for response repeat, but task-switch cost remained significant after full-task and selective go trials when response repeated. However, no significant switch cost was obtained after selective nogo trials regardless of whether response repeated or switched. The PE data corroborated the RT data in that no significant switch cost was obtained after selective nogo trials regardless of whether response repeated. The results are consistent with the idea that a task-switch cost might have been established (because of response selection or process preceding it) but was abolished on selective nogo trials.

Experiment 4

By mixing full-task and go/nogo trials, Experiment 3 became more similar to the selective stopping experiment of Verbruggen et al.'s (2006), and we expected that participants were strongly encouraged to initiate response selection in order to decide whether to stop responding on selective nogo trials. The absence of switch costs after selective nogo trials in Experiment 3 raises a question as to whether response selection determines the presence of task-switch cost after nogo trials. However, one may still argue that in Experiment 3, participants could judge 'nogo' based on the target alone without selecting a response because the to-be-stopped response was fixed within a given block. We think that this is unlikely because there was a reversed effect of response switch after selective nogo, which seems to imply that the to-be-stopped response was actually selected and was inhibited on the preceding selective nogo trial. The inhibition would then presumably interfere with responding on the next response repeat trial, reversing the cost of response switch after selective nogo trials. Nevertheless, it is also possible that the reversed response-switch effect following selective nogo trials reflects negative priming of the target feature associated with the to-be-stopped response rather than an inhibition of the response itself, and as such might not constitute evidence of response selection having taken place on selective nogo trials. Therefore, we decided to carry out a stronger manipulation to encourage response selection on selective nogo trials in Experiment 4.

The present experiment introduced two different nogo signals that indicated which hand to use (or stop) on a given nogo trial. Participants were presented with a letter “L” or “R” on a subset of trials, which indicated the response key that could be pressed on a given trial. For example, if the letter “L” appeared, participants were to respond if the target required the left response but to stop responding if the target required the right response. As these nogo signals occurred randomly, participants could not prepare for a to-be-stopped response prior to the trial, so it was unlikely that they would only have processed the target without selecting a response, in order to decide whether to stop responding to it. Therefore, if response selection determines the presence of a subsequent switch cost, it was expected that switch costs would be obtained even after selective nogo trials in the present experiment. Alternatively, the absence of switch costs after selective nogo trials would support the idea that switch costs are abolished when a response is inhibited even though a task-switch cost had been established by response selection (or processes preceding it).

Method

Participants

Seventy-four participants completed the present experiment, but 14 participants yielded an overall accuracy lower than 70% and were excluded from the analysis, leaving 60 participants (38 females, 22 males; mean age = 32.05, SD = 6.36, range = 20-45).

Apparatus, Stimuli, and Procedure

The experiment modified Experiment 3 in such a way that the responding hand on selective nogo trials varied on a trial-by-trial basis within the same block. The tasks were the same color and shape classification tasks, and full-task trials were the same as those in Experiment 3. On selective go/nogo trials, a letter “L” or “R” was superimposed on the target (which appeared as if there was a white cavity on the target). When the letter was “L”, participants were to respond to the target if the target required the left response (selective go trials), but to withhold responding if it required the right response (selective nogo trials); when the letter was “R”, the role of the left and right responses were reversed. Each participant performed two blocks of 16 practice trials, followed by six blocks of 120 test trials. Half of these trials were full-task trials, one quarter were selective go trials, and the other quarter were selective nogo trials.

Results

Trials were filtered in the same manner as in the preceding experiments, resulting in 15.2% of trials being discarded. Mean RT and PE for full-task trials were submitted to the same ANOVAs as in Experiment 3. The results are summarised in Figure 4 and Table 4 (see the supplemental materials for the analyses of selective go and nogo trials).

For RT, all main effects and interactions were significant. Responses were fastest after full-task trials (M = 769 ms), intermediate after selective go trials (M = 816 ms), and slowest after selective nogo trials (M = 854 ms). Responses were also faster for response repeat (M = 805 ms) than for response switch (M = 854 ms). As in Experiment 3, the advantage of response repeat was found after full-task trials (M s= 747 ms vs. 791 ms for response repeat and switch, respectively) and after selective go trials (Ms = 794 ms vs. 838 ms), but it was reversed after selective nogo trials (Ms = 872 ms vs. 836 ms), implying repeating the inhibited response on the preceding trial slowed response as compared to switching to the other response. There was both a cue-switch cost (M = 15 ms, p = .019) and a task-switch cost (M = 50 ms, p < .001). Cue-switch and task-switch costs were still significant for response repeat (cue-switch cost = 26 ms, p = .029; task-switch cost = 80 ms, p < .001), but they were no longer significant for response switch (cue-switch cost = 5 ms, p = 1.00; task-switch cost = 19 ms, p = .281). However, when the previous trial types were considered, cue-switch and task-switch costs were significant for response repeat (Ms = 41 ms and 149 ms; both ps < .001), whereas task-switch cost (M = 51 ms, p = .001) but not cue-switch cost (*M* = 13 ms, *p* = .312) remained significant for response switch, after full-task trials. There were also significant task-switch cost (*M* = 94 ms, $p < .001$) but not cue-switch cost (*M* = 21 ms, *p* = .683) for response repeat after selective go trials; cue-switch cost (*M* = -9 ms), task-switch cost (*M* = 11 ms), and total switch cost (*M* = 3 ms) were all non-significant for response switch after selective go trials (all *p*s = 1.00). Similarly, none of these costs were significant for response repeat or switch after selective nogo trials; cue-switch and task-switch costs were 15 ms and –2 ms for response repeat, and they were 9 ms and –6 ms (all *p*s = 1.00). Total switch cost was 13 ms and 3 ms (both *p*s = 1.00) for response switch. Therefore, as in Experiment 3, switch costs emerged after full-task and selective go trials at least when response repeated, but there was no sign of switch cost after selective nogo trials regardless of whether response repeated or switched.

For PE, there were main effects of Previous Trial and of Trial Sequence, and these factors interacted. The main effect of Response Switch was not significant, but it interacted with Trial Sequence. PE was higher after selective nogo trials (*M* = 7.28%) than after full-task (*M* = 5.32%) or selective go (*M* = 5.95%). There was task-switch cost (*M* = 3.84%, $p < .001$) but not cue-switch cost (*M* = -.58, *p* = .600), which were true for response repeat (cue-switch cost = -.20, *p* = 1.00; task-switch cost = 5.17%, $p < .001$) and for response switch (cue-switch cost = -.96%, *p* = .498; task-switch cost = 2.55%, *p* = .001), although the costs were generally larger for the former than for the latter. Cue-switch cost was not significant after full-task (*M* = -.07%, *p* = 1.00) or after selective go (*M* = -1.19%, *p* = .599), but task-switch costs were significant both after full-task (*M* = 5.72%, $p < .001$) and after selective go trials (*M* = 6.48%, $p < .001$). Cue-switch and task-switch costs were not significant after selective nogo trials (*M*s = -.61% and -.69%; both *p*s = 1.00), which corroborate the results of RT.

Figure 4

Mean response times (RT) and percentage errors (PE) as a function of Trial Sequence and Response Switch on full-task trials in Experiment 4 (error bars represent one standard errors of the means).

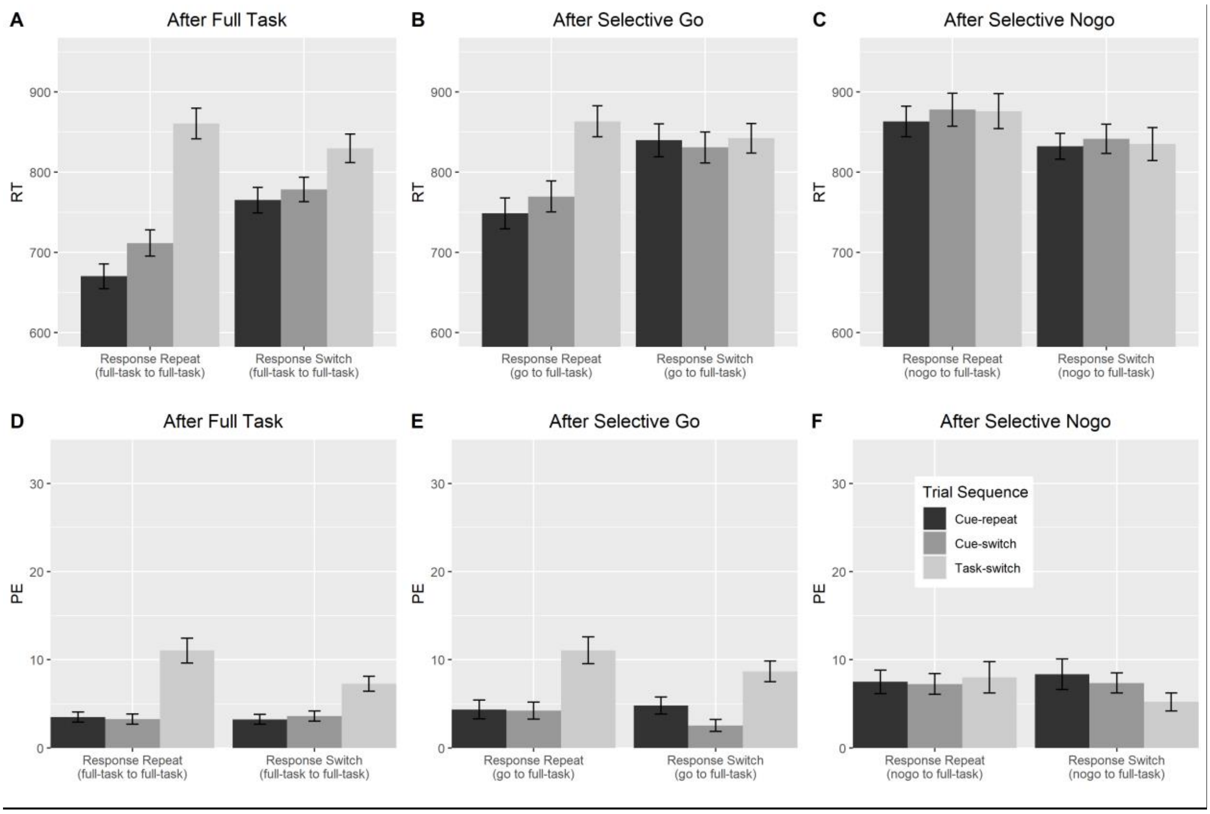

Table 4. ANOVA results for response time (RT) and percentage errors (PE) on full-task trials in Experiment 4.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
			RT		
Previous Trial (PT)	**2, 118**	**12770.93**	**51.18**	**< .001**	**.465**
Response Switch (RS)	**1, 59**	**11284.50**	**6.96**	**.011**	**.106**
Trial Sequence (TS)	**2, 118**	**9969.21**	**41.41**	**< .001**	**.412**
PT x RS	**2, 118**	**7306.03**	**26.23**	**< .001**	**.308**
PT x TS	**4, 236**	**7723.84**	**16.72**	**< .001**	**.221**
RS x TS	**2, 118**	**8553.61**	**19.41**	**< .001**	**.248**
PT x RS x TS	**4, 236**	**6296.43**	**5.30**	**< .001**	**.082**
			PE		
PT	**2, 118**	**49.74**	**7.29**	**.001**	**.110**
RS	1, 59	88.72	3.11	.083	.050

TS	**2, 118**	**54.11**	**28.45**	**< .001**	**.325**
PT x RS	2, 118	61.82	< 1	.843	.003
PT x TS	**4, 236**	**63.40**	**9.95**	**< .001**	**.144**
RS x TS	**2, 118**	**59.19**	**4.67**	**.011**	**.073**
PT x RS x TS	4, 236	41.91	< 1	.653	.010

Note: Bold represents a significant effect.

Discussion

In the present experiment, to-be-stopped responses were cued randomly across trials. This prevented participants from associating specific target features with the to-be-stopped response and made it impossible for them to prepare stopping the response before a nogo signal occurred, ensuring that a response was selected before participants decided to stop on a nogo trial. The results showed no sign of switch costs after selective nogo trials, indicating that the occurrence of response selection does not result in a significant task-switch cost. Hence, response selection could not determine the presence of task-switch cost after selective nogo trials, again supporting the idea that task-switch cost may be established but was abolished on nogo trials. To reinforce the present conclusion, Experiments 5 and 6 introduced a delay between the target and a go/nogo signal (Philipp et al., 2007; Swainson & Martin, 2013). These experiments examined the idea that the depth of processing (i.e., the extent to which response is activated or selected) determines whether a task-switch cost is obtained after selective nogo trials.

Experiment 5

Although Verbruggen et al.’s (2006) selective stopping study found switch costs even after participants successfully inhibited a response on the preceding trial, switch costs were substantially smaller after selective stopping (16 ms) than after selective go (invalid signal trials; 76 ms) or selective stopping where participants failed to stop (76 ms). Philipp et al.

(2007) found a similar result and suggested that, in addition to response selection, response execution also plays a role in producing task-switch costs. Unlike Verbruggen et al.'s study, our Experiment 4 did not produce switch costs on full-task trials after selective nogo trials. A possible reason for the discrepancy may be that there was a signal delay after the target onset in the stop-signal procedure whereas there was no delay in the go/nogo procedure of Experiment 4. The delay in the signal onset could have allowed response selection to occur to a greater degree (e.g., to the final selection stage; Hommel, 1998), which then made switch costs more resistant against interference from other factors (e.g., response switch, trial type switch). Philipp et al. (2007) used a delayed signal with non-selective nogo procedure and found that switch costs emerged after nogo trials with a long delay. Swainson and Martin's Experiment 1 (2013) used even a shorter delay of 400 ms, and they also found switch cost after non-selective nogo trials. Therefore, Experiment 5 examined whether switch costs emerged on full-task trials after selective nogo trials when there was a delay in the onset of go and nogo signals.

The present experiment was essentially the same as Experiment 4, but there was a 400 ms delay in the onset of go and nogo signals after the target onset. This delay allowed participants to start processing the target and selecting (or activating) a response before the selective go/nogo signals occurred. Given that a non-selective nogo procedure yielded task-switch costs with a delayed signal in the previous studies (Philipp et al., 2007; Swainson & Martin, 2013), there should be a greater chance of obtaining a significant task-switch cost in the present experiment than in Experiments 3 and 4, if response selection determines the presence of switch cost after selective nogo trials.

Method

Participants

Seventy-four participants completed the experiment online. Nineteen participants yielded an overall accuracy lower than 70% and were excluded from the analysis, leaving 55 participants (40 females, 15 males; mean age = 30.35, SD = 7.65, range = 18-45).

Apparatus, Stimuli, and Procedure

The experiment was similar to Experiment 4. The only change was that there was a 400-ms delay between the target and signal. Selective go/nogo signals were the same as those used in Experiment 4 (the letters “L” and “R” to indicate which of the responses was relevant on the trial). For full-task trials, there was a delayed signal (“Go”) superimposed on the target to prompt the response required by the target, which also occurred 400 ms after the target onset. The target stayed on display for 2000 ms or until a response was made. RT was the interval between the onset of one of these signals and a keypress. When participants pressed a response key before a signal occurred, RT was recorded as a negative value, although participants still saw the same feedback messages for correct (“Correct”) or error responses (“Error”) on these responses as they would have for a response that followed the signal. In Swainson and Martin’s (2013) study, participants were discouraged from responding too early (before the go signal) by flashing the screen, but we avoided warning participants because that might encourage participants to withhold response selection until a signal occurred. Trials for which participants responded before a go signal were excluded from the analysis. There were three blocks of 12 practice trials, followed by six blocks of 120 test trials. The procedure followed Experiment 4 closely in other respects.

Results

Trials were filtered in the same manner as in the preceding experiments, except that the cut-off for short RT was now removed, because of the delayed go signal made RT much shorter than those in the preceding experiments; instead, trials for which a response occurred before the go or nogo signal were excluded. In total, 17.0% of all trials were discarded for being trials following an error trial or having no response. Mean RT and PE were calculated and submitted to the same ANOVAs as in Experiment 4. The results are summarised in Figure 5 and Table 5.

For RT, all effects but the main effect of Response Switch were significant. Responses were fastest after full-task trials (*M* = 552 ms), intermediate after selective nogo trials (*M* = 610 ms), and slowest after selective nogo trials (*M* = 623 ms). Responses for response repeat and response switch were similar (*M*s = 596 ms and 595 ms for response repeat and response switch), but Response Switch interacted with Previous Trial: there were advantages for response repeat after full-task trials (*M*s = 539 ms vs. 565 ms) and after selective go trials (*M*s = 600 vs. 620 ms), but this effect was reversed after selective nogo trials (*M*s = 647 ms vs. 599 ms). Cue-switch cost (*M* = 15 ms, $p = .011$) and task-switch cost (*M* = 27 ms, $p = .001$) were both significant, and Trial Sequence interacted with Response Switch: For response repeat, cue-switch cost (*M* = 27 ms, $p = .001$) and task-switch cost (*M* = 38 ms, $p < .001$) were significant, but for response switch, they were both non-significant (*M*s = 3 ms and 15 ms, both *p*s > .2; total switch cost = 18 ms, $p = .10$). These outcomes were further modulated by Previous Trial: The patterns of cue-switch and task-switch costs were similar for full-task and selective go trials, in that both costs were significant for response repeat after full-task (cue-switch cost = 25 ms, $p = .013$; task-switch cost = 86 ms, $p < .001$) and after selective go (cue-switch cost = 33 ms, $p = .021$; task-switch cost = 41 ms, $p < .022$), and cue-switch cost was reduced to a non-significant level for response switch after full-task trials (*M* = –1 ms, $p = 1.00$) and after selective go trials (*M* = 4 ms, $p = 1.00$). Task-switch cost remained significant after full-task trials (*M* = 23 ms, $p = .042$) but was not significant after selective go trials (*M* = 23 ms, $p = .32$). After selective nogo trials, no switch costs were obtained (all *p*s > .3); cue-switch and task-switch costs were 22 ms and –14 ms for response repeat, and they were 6 ms and 0 ms for response switch. Total switch cost was 8 ms for response repeat and 6 ms for response switch (both *p*s = 1.00). These outcomes echoed with those of Experiment 4.

For PE, significant results included a main effect of Trial Sequence and its interaction with Previous Trial and with Response Switch. Cue-switch cost was not significant (M = .17%, p = 1.00), but task-switch cost was still significant (M = 3.45%, p < .001). These results were true for response repeat (cue-switch cost = 1.04%, p = .342; task-switch cost = 4.26%, p < .001) and for response switch (cue-switch cost = -.70%, p = .870; task-switch cost = 2.65%, p = .023), and after full-task trials (cue-switch cost = .46%, p = .100; task-switch cost = 5.31%, p < .001) and after selective go trials (cue-switch cost = 1.13%, p = .700; task-switch cost = 4.95%, p < .001). There were neither cue-switch cost (M = 1.17%, p = .97) nor task-switch cost (M = .10%, p = 1.0) after selective nogo trials (total switch cost = 1.27%, p = .76).

Figure 5

Mean response times (RT) and percentage errors (PE) as a function of Trial Sequence and Response Switch on full-task trials in Experiment 5 (error bars represent one standard errors of the means).

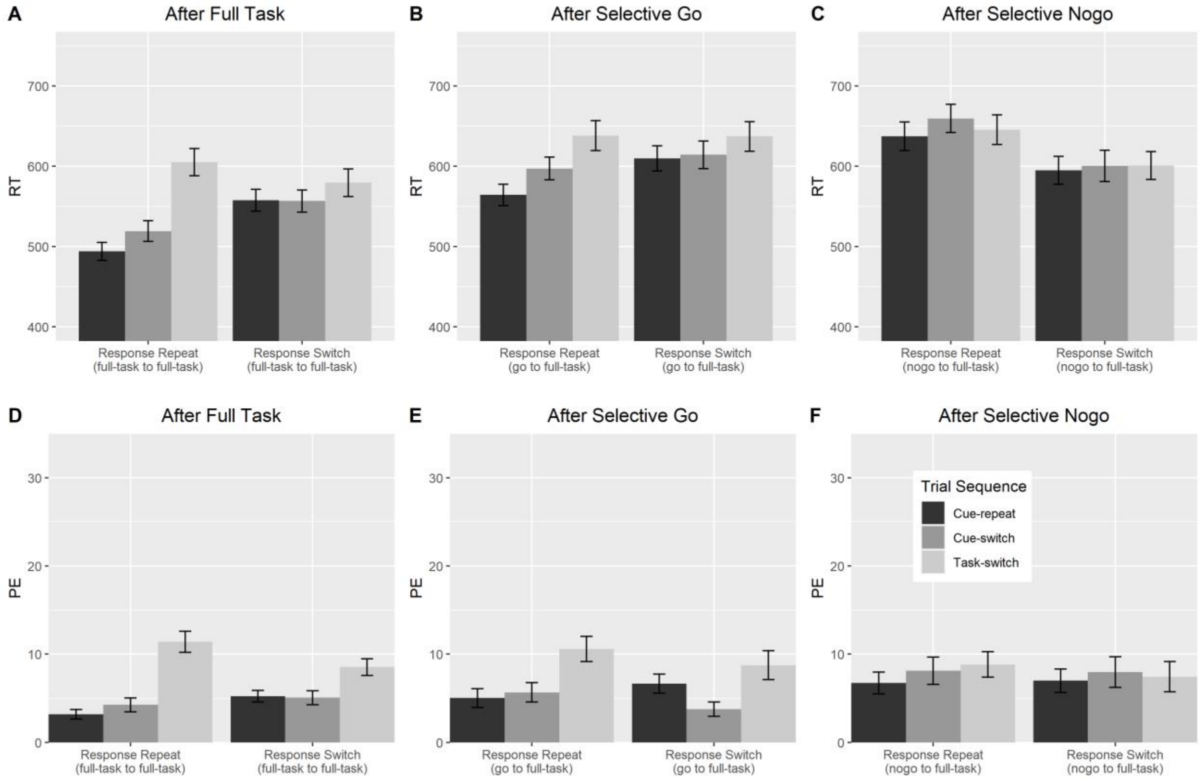

Table 5. ANOVA results for response time (RT) and percentage errors (PE) on full-task trials in Experiment 5.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
			RT		
Previous Trial (PT)	**2, 108**	**8937.84**	**53.05**	**< .001**	**.496**
Response Switch (RS)	1, 54	8387.20	< 1	.867	< .001
Trial Sequence (TS)	**2, 108**	**6865.29**	**21.22**	**< .001**	**.282**
PT x RS	**2, 108**	**5945.75**	**23.81**	**< .001**	**.306**
PT x TS	**4, 216**	**4103.52**	**8.57**	**< .001**	**.137**
RS x TS	**2, 108**	**4876.52**	**9.00**	**< .001**	**.143**
PT x RS x TS	**4, 216**	**4953.66**	**3.18**	**.015**	**.056**
			PE		
PT	2, 108	76.97	2.18	.118	.039
RS	1, 54	94.98	< 1	.546	.007
TS	**2, 108**	**61.15**	**22.55**	**< .001**	**.295**
PT x RS	2, 108	62.07	< 1	.850	.003

PT x TS	**4, 216**	**50.86**	**5.39**	**< .001**	**.091**
RS x TS	**2, 108**	**58.40**	**3.97**	**.022**	**.068**
PT x RS x TS	4, 216	56.76	< 1	.575	.013

Note: Bold represents a significant effect.

Discussion

The present experiment introduced a 400-ms delay in the onset of a go or nogo signal after the target, which should have encouraged participants to process the target and start response selection at an early point in time. In general, RT (as measured from the onset of a go/nogo signal) was about 200 ms faster in the present experiment than in Experiment 4, implying that the readiness of responding at the onset of these signals was higher than in Experiment 4. Nevertheless, the results replicated the major outcomes of Experiment 4. Thus, even though response selection could have occurred to a greater degree in the present experiment, it did not determine the presence of switch costs after selective nogo trials.

Experiment 6

The results of Experiment 5 showed no significant switch costs after selective nogo trials. These outcomes were in contrast to the previous studies that used a delayed signal procedure. Interestingly, while Verbruggen et al. (2006) and Philipp et al. (2007) found substantially smaller switch costs after non-selective nogo trials with delayed signals, Swainson and Martin (2013) found in Experiment 1 that the switch cost after non-selective nogo trials was as large as that after go trials. In retrospect, we noticed a major difference in the methods of these studies, which was that the target stayed present in the display when a go or nogo signal appeared in the former two studies whereas the target was erased and replaced by a go or nogo signal in the latter. The short presentation duration of the target in the Swainson and Martin study possibly forced participants to process the target and start response selection more quickly than when the target was still present after a go/nogo signal occurred. This might have led to the “full-blown” switch cost even after nogo trials in that study. To test whether the duration of target presentation is an important factor in this procedure, Experiment 6 erased the target after 400 ms when a signal occurred.

Method

Participants

Seventy-six participants completed the experiment online, but 20 participants yielded response accuracy lower than 70% and were excluded from the analysis. This left 56 participants (32 females, 22 males, 2 others; mean age = 31.63, SD = 7.96, range = 18-45).

Apparatus, Stimuli, and Procedure

This experiment was essentially the same as Experiment 5, except that targets were erased and replaced by a signal ("Go" for full-task trials and "L" or "R" for selective go/nogo trials) that lasted for 1600 ms. The signal was now presented in black. The procedure followed Experiment 5 in all other respects.

Results

Trials were filtered in the same manner, and mean RT and PE were submitted to the same ANOVAs as in Experiment 5 (13.5% of all trials were discarded). The results are summarised in Figure 6 and Table 6.

For RT, the results were very similar to those of Experiment 5. All main effects and interactions, except for the main effect of Response Switch, were significant. Responses were fastest after full-task trials (M = 547 ms), intermediate after selective go trials (M = 610 ms), and slowest after selective nogo trials (M = 613 ms). Responses were somewhat faster for response repeat (M = 543 ms) than for response switch (M = 552 ms) after full-task trials, but this advantage for response repeat disappeared after selective go trials (Ms = 611 ms vs. 608 ms) and reversed after selective nogo trials (Ms = 628 ms vs. 598 ms). There was no cue-switch cost (M = 3 ms, p = 1.00) or task-switch cost (M = 10 ms, p = .058), although total switch cost was still significant (M = 14 ms, p = .014). For response repeat, task-switch cost was significant (M = 21 ms, p = .002), but cue-switch cost was not (M = 9 ms, p = .312); for response switch, cue-switch cost (M = -3 ms), task-switch cost (M = 0 ms), or total switch cost (M = -3 ms) were all non-significant (all ps = 1.00). When aggregated across response repeat and switch, there were cue-switch costs (M = 15 ms, p = .007) and task-switch costs (M = 40 ms, p < .001) after full-task trials, but neither cue-switch nor task-switch costs were significant after selective go or selective nogo trials (all ps > .1). When response repeat and switch were examined separately, task-switch cost was significant for both response repeat (M = 23 ms, p = .020) and response switch (M = 57 ms, p < .001) after full-task trials, but cue-switch cost was significant only for response repeat (M = 26 ms, p = .003) but not for response switch (M = 4 ms, p = 1.00). After selective go trials, neither cue-switch nor task-switch costs were significant for response repeat or response switch, but total switch cost was significant for response repeat (M = 35 ms, p = .004) but not for response switch (M = -23 ms, p = .151). After selective nogo trials, there were no cue-switch or task-switch cost; cue-switch and task-switch costs were –20 ms and –6 ms for response repeat, and they were 2 ms and –17 ms for response switch (p > .3). Total switch cost was –26 ms for response repeat (p = .300) and –15 ms (p = .570) for response switch.

For PE, the only significant effect was a main effect of Trial Sequence and its interaction with Previous Trial. There was a significant task-switch cost after full-task trials (M = 4.16%, p < .001), but not cue-switch cost (M = .31%, p = 1.00). After selective go trials, there was also a significant task-switch cost (M = 5.89%, p < .001) but not cue-switch cost (M = -1.22%, p = .384). After selective nogo trials, cue-switch cost (M = .68%, p = 1.00), task-switch cost (M = 1.28%, p = .678), and total switch cost (M = 1.96%, p = .086) were all non-significant.

Figure 6

Mean response times (RT) and percentage errors (PE) as a function of Trial Sequence and Response Switch on full-task trials in Experiment 6 (error bars represent one standard errors of the means).

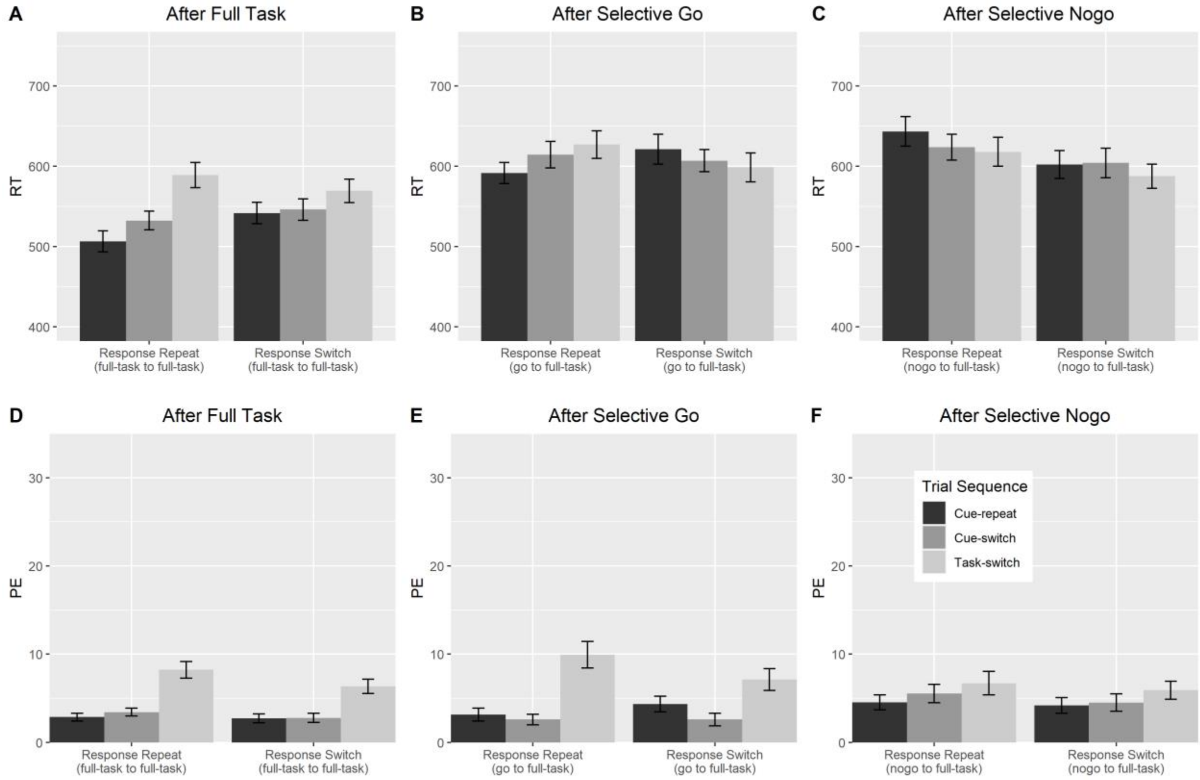

Table 6. ANOVA results for response time (RT) and percentage errors (PE) on full-task trials in Experiment 6.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
			RT		
Previous Trial (PT)	**2, 110**	**7620.64**	**60.68**	**< .001**	**.525**
Response Switch (RS)	1, 55	5150.06	2.79	.101	.048
Trial Sequence (TS)	**2, 110**	**3282.36**	**5.27**	**.007**	**.087**
PT x RS	**2, 110**	**3903.13**	**9.21**	**< .001**	**.143**
PT x TS	**4, 220**	**3448.19**	**12.50**	**< .001**	**.185**
RS x TS	**2, 110**	**3496.01**	**7.12**	**.001**	**.115**
PT x RS x TS	**4, 220**	**3315.85**	**3.62**	**.007**	**.062**
			PE		
PT	2, 110	32.49	1.89	.156	.033
RS	1, 55	37.66	3.50	.060	.067

TS	**2, 110**	**62.07**	**25.63**	**< .001**	**.318**
PT x RS	2, 110	39.30	< 1	.941	.001
PT x TS	**4, 220**	**29.91**	**5.53**	**< .001**	**.091**
RS x TS	2, 110	44.70	2.03	.136	.036
PT x RS x TS	4, 220	37.85	< 1	.594	.013

Note: Bold represents a significant effect.

Discussion

Although a previous study with a non-selective nogo procedure suggested that switch costs could be as large after nogo trials as after go trials with a signal delay when the target was presented only briefly (Swainson & Martin, 2013), the present experiment provided little sign of any switch cost after selective nogo trials. The outcomes were largely consistent with those obtained in Experiments 4 and 5 and provided little support for the "depth of processing" explanation of switch cost after selective nogo trials. The design of the present experiment was the strongest of all the experiments in the present study, as it included multiple factors that should have encouraged response selection on every trial, but there was little support that response selection determines the presence of switch cost after selective nogo trials. The results are consistent with the idea that task-switch cost might be established but was abolished on selective nogo trials.

General Discussion

The response-selection account has suggested that the occurrence of response selection determines whether a task-switch cost is obtained on the subsequent trial (Schuch & Koch, 2003), but it has been challenged by a proposal that a task-switch cost could be established even before response selection takes place and be abolished by a nogo signal (Lenartowicz et al., 2011). Support for the response-selection account came from a study that combined a cued task-switching paradigm with a selective stop-signal task (Verbruggen et al., 2006), which showed that switch costs could be obtained after stop-signal trials when stopping required selecting a response, but not when stopping only required perceptual judgment of a signal without selecting a response. However, Wylie et al. (2004) and Yamaguchi et al. (2019) used procedures similar to Verbruggen et al.'s selective stopping, and neither study found significant (total) switch costs, although Yamaguchi et al. still found a task-switch cost, after selective nogo trials. Therefore, the role of response selection in determining the presence of a task-switch cost after nogo trials still remained unclear. The present study addressed this issue by using various selective go/nogo procedures.

As in Yamaguchi et al.'s (2019) experiment, participants in Experiment 1 performed the color/shape clarification tasks with a go/nogo procedure in which a nogo trial was defined by the target/response on a given trial. This condition required participants to process the relevant target attribute, and possibly select the required response, to decide whether they should respond on the trial. For RT, switch costs were obtained after selective go trials but not after selective nogo trials, although there were still switch costs after selective go and nogo trials for PE. Experiment 2 replaced the color/shape classification tasks with the odd/even and vowel/consonant tasks used in Wylie et al.'s (2004) experiment. Switch costs were obtained after selective nogo trials both for RT and PE. These experiments indicated that switch costs can be obtained after selective nogo trials, but both experiments showed that switch costs were much smaller after selective nogo trials than after full-task trials, and they were not consistently significant (e.g., for RT in Experiment 1). It was also not clear to what extent participants processed the cued task in these experiments since it was possible that participants decided to stop responding only by judging the target. To evaluate the role of response selection, the subsequent four experiments used conditions that encouraged response selection more strongly to decide whether or not to make a response, and the degree of encouragement was progressively increased across the experiments.

Experiment 3 intermixed full-task trials and selective go/nogo trials to encourage participants to prepare for an upcoming task more fully and to increase the chance that response selection occurred. Consistent with this aim, this experiment produced more errors on selective nogo trials where participants responded to the target when they should not have done, as compared to the preceding two experiments. This implied that participants had greater difficulty stopping their responses on selective nogo trials. Switch costs were obtained after full-task and selective go trials, but they were still absent after selective nogo trials. To encourage response selection further, Experiment 4 cued a to-be-stopped response only at the beginning of selective go and nogo trials. Because participants could not predict the to-be-stopped response in advance, they could not associate a particular target feature to the to-be-stopped response, which would force them to select a response to judge whether to respond or stop on a given trial. The results were similar to Experiment 3, in that switch costs were not obtained after selective nogo trials. Experiments 5 and 6 introduced a delay in the selective go/nogo signal onset, so as to allow for response selection (or response activation) to start before participants could judge whether to respond or stop. In these experiments, responses were substantially faster than in the preceding experiments, implying that task processing started before a signal onset in these experiments. Nevertheless, both experiments showed little sign of switch costs after selective nogo trials[2]. These results indicate that the occurrence of response selection (or of processes preceding response selection) does not determine the presence of a task-switch cost after selective nogo trials.

These results add to the previous findings where task-switch costs were reduced significantly but were still significant when response selection occurred without response

[2] In addition to these main results, we also reported the analyses of RT and PE on selective go/nogo trials in Experiments 3-6 in the supplemental materials. We have to acknowledge that the number of trials for these analyses was too small, but it may be noteworthy that there were some indications of switch costs in PE on selective nogo trials following a nogo trial in Experiment 5, while they only appeared numerically in Experiment 6. Therefore, there was little evidence that task-switch cost was obtained reliably after nogo trials in these analyses.

execution (Philipp et al., 2007; Verbruggen et al., 2006). These previous findings suggest that processes occurring after response selection (i.e., response execution) contribute to task-switch costs, but they also showed that task-switch costs could still be obtained when response selection occurred without response execution. Therefore, they do not fit with the strong version of the response-selection account proposed by Schuch and Koch (2003), which placed the sole responsibility of producing a task-switch cost on response selection, but nevertheless they are still consistent with the idea that processes up to and including response selection are sufficient to produce a subsequent task-switch cost. However, in the present study, even when response selection occurred on a nogo trial, a subsequent task-switch cost was not consistently obtained – this result is most convincing in the later experiments where response selection seems very likely to have taken place on nogo trials. Hence, this study provides evidence that response selection, and the processes leading up to it, do not determine the presence of a switch cost on the next trial.

A possible explanation for the absence of task-switch cost after nogo trials is motivational, as proposed by Kleinsorge and Gajewski (2004). They argued that the inclusion of nogo trials discouraged participants from engaging in the preparation of a cued task upon onset of a task cue because participants experience their efforts being wasted when a nogo signal occurs on a substantial number of trials. If so, participants might withhold activation of a cued task-set until a go signal occurs along with the target, and the preparation of a task-set would never run to completion on a nogo trial. Thus, the elimination of the task-switch cost after nogo trials could reflect a lack of advance preparation. Although this account might explain the absence of task-switch cost after non-selective nogo trials, it is unlikely that it also explains the absence of task-switch cost after selective nogo trials in the present study. Selective stopping required processing the target to the extent that participants could judge whether the required response was to be stopped. For this to occur, task preparation as well as the subsequent processes required to identify the required response had to have occurred on nogo trials, so the lack of advance preparation cannot explain the absence of task-switch cost after selective nogo trials in the present results.

An alternative explanation of the absence of task-switch costs after nogo trials was proposed by Lenartowicz et al. (2011). Whereas the response-selection account suggested that the absence of task-switch cost after nogo trials was due to the non-occurrence of response selection, Lenartowicz et al. suggested that nogo trials actively interfered with the task-set that was activated on nogo trials. Thus, a task-set was activated upon an onset of a task cue, but it was either inhibited or reset when a nogo signal occurred. This would eliminate the benefit of task repeat over task switch because the repeated task needs to be reactivated after nogo trials. Verbruggen et al.'s (2006) finding that the task-switch cost was still significant after successful stopping in their selective stopping experiment could be considered to contradict this alternative explanation. However, it should be noted that Verbruggen et al. also found that the task-switch cost was much reduced after successful stopping, as compared to no-stop trials or unsuccessful stopping trials. Philipp et al. (2007) extended the response-selection account and suggested that the reduced task-switch cost after successful stopping in Verbruggen et al.'s experiment or after nogo trials with a long delay in their own experiment was due to the lack of response execution. It is also possible that nogo signals in these studies did not interfere with the activated task-set sufficiently well to remove completely the established task-switch cost in these experiments. If there are several processes that could generate a subsequent task-switch cost, including task preparation (Lenartowicz et al., 2011), target judgment (Swainson & Martin, 2013), and response selection (Schuch & Koch, 2003), it may be more difficult to interfere with the activated task-set as more processes have completed on nogo trials.

While we suggest that the results of the present study are more consistent with the notion that a nogo signal or decision interferes with the activated task-set, the present experiments are not designed to evaluate possible mechanisms by which a nogo signal or decision interferes with the task-set. Lenartowicz et al. (2010) put forward two possible mechanisms. First, they proposed that the activated task-set might be inhibited on a nogo trial. Nevertheless, Koch and Philipp (2005) showed that performing a nogo trial on a preceding trial did not slow responding on a subsequent trial when there was only a single task to perform, suggesting that a nogo signal/decision does not necessarily inhibit the task-set at least when there is a single task-set possibly used in the context. Whether this finding is also relevant to the situation where two possible task-sets compete is still subject to a further investigation. It could be that a nogo signal/decision does not inhibit the activated task-set when only a single task-set is possible, but it inhibits the activated task-set if more than one task-set is possible. Second, instead of actively inhibiting the task-set, a nogo trial/decision might reset working memory and the task-set maintained there. This possibility may be able to accommodate the reduced N-2 repetition cost after a nogo trial (e.g., Philip et al., 2007; Schuch & Koch, 2003). If the inhibition of a task-set producing the repetition cost relies on a control setting maintained in working memory, the repetition cost should be reduced or eliminated if the control setting is reset by a nogo signal or decision.

A more recent model of cued task-switching ascertains that there are multiple sources of contextual features that contribute to the eventual task-switch cost obtained on any given trial (the Parallel Episodic Processing, or PEP, model; Schmidt et al., 2020). These contextual features include, but are not limited to, target or non-target stimuli, the task cue, and the response. The sequences of the contextual features can differ for different types of trial, and priming of a prior trial episode by these contextual features could explain major patterns of cued task-switching performance. For example, in the present study, we used two task cues for each of the two tasks, in order to separate the effect of switching task cues from the effect of switching tasks. We have also separated trials for which the same response repeated from the previous trial and trials for which the response switched. As can also be seen in the present results, these contextual features have significant impact on the performance of the subsequent task (e.g., Logan & Bundesen, 2004; Proctor, Koch, Vu, & Yamaguchi, 2008), and the PEP model predicts these results without assuming an underlying cognitive control setting. At the same time, other researchers also proposes that the influence of response sequence reflects a bias to switch the task when the response switches (Kleinsorge, 1999) or an inhibition of the response on a previous trial (Hübner & Druey, 2006). A recent study has indicated that both episodic retrieval (as proposed by the PEP model) and response inhibition both contribute to the effect of response sequence (Koch, Frings, & Schuch, 2018). In the present study, we pointed out that response repetition resulted in slower responses after a selective-nogo trial, and suggested that it reflected response inhibition. However, we should note that there were also indications as shown in the supplemental analyses of selective go/nogo trials in Experiments 3-4 (see the supplemental materials) that switch costs are reduced when the type of trial (full-task vs. go/nogo) changed (e.g., switch costs were smaller on selective go trials following a full-task trial, as compared to the costs on selective go trials following a selective go trial). When any contextual features other than the task itself switches, the benefit of repeating the same task decreases. Schmidt et al.'s (2020) PEP model demonstrated a complicated interplay among multiple factors that can either repeat or switch in cued task switching. The presence of a task-switch cost might also depend to a large extent on the combinations of changes in several aspects of the task context, rather than the occurrence of a particular process. Further evaluations of the roles of contextual switch/repetition in switch costs after nogo trials are required in future investigations.

Concluding Remarks

The finding that such a robust phenomenon as task-switch cost is absent in a certain condition provides an important clue as to how the cognitive system operates control of human behavior. The response-selection account of switch costs states that it is the selection of a response on one trial that generates a switch cost measured on the next trial. This proposal has been challenged by a number of subsequent findings. For example, merely presenting a task cue is sufficient to obtain a task-switch cost on the next trial (Lenartowicz et al., 2011), and the task-switch cost following response selection is much reduced compared with that following response execution (Philipp et al., 2007). To extend these findings, the present study showed that the task-switch cost is absent even when response selection has occurred on the preceding nogo trial. Across six experiments, progressively stronger constraints were imposed on participants to perform response selection in order for them to decide whether a trial required a response. However, task-switch costs were not obtained after those selective nogo trials on which response selection should most reliably have occurred. The results are consistent with the proposal that a task-switch cost might be generated by response selection or by processes that precede response selection (e.g., task preparation or target judgment), but that the cost can be abolished when a nogo signal or decision not to respond interferes with the activated task-set. The present study only assessed a limited number of contextual features that repeated or alternated across trials (e.g., task cue and responses), and the contributions of contextual repetition or alternation should be evaluated more systematically in future studies.

Constraints on Generality

The authors acknowledge possible limits of generality of the results for participants, materials, and data acquisition procedures. The data were collected through a cloud-sourcing platform (Prolific) with a specific age range (healthy young adults who were at the age of 18-45 years old) and extrapolating the results beyond this population (e.g., young children, older adults, individuals with a history of neurological disorders) would require some caution. The authors also acknowledge that the results might to some extent be associated with the data collection context as well as the materials used in the present study (e.g., color and shape discrimination tasks).

Author Credits

MY conceptualised the study, designed and programmed the experiments, carried out data analyses, created figures, and wrote the original draft. MY and RS reviewed and edited the manuscript, and contributed to funding acquisitions.

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