ORIGINAL ARTICLE

# No-go trials can modulate switch cost by interfering with effects of task preparation

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**Abstract** It has recently been shown that the cost associated with switching tasks is eliminated following 'no-go' trials, in which response selection is not completed, suggesting that the switch cost depends on response selection. However, no-go trials may also affect switch costs by interfering with the effects of task preparation that precede response selection. To test this hypothesis we evaluated switch costs following standard go trials with those following two types of non-response trials: no-go trials, for which a stimulus is presented that indicates no response should be made (Experiment 1); and cue-only trials in which no stimulus is presented following the task cue (Experiment 2). We hypothesized that eliminating no-go stimuli would reveal effects of task preparation on the switch cost in cue-only trials. We found no switch cost following no-go trials (Experiment 1), but a reliable switch cost in cue-only trials (i.e., when no-go stimuli were removed; Experiment 2). We conclude that no-go trials can modulate the switch cost, independent of their effect on

response selection, by interfering with task preparation, and that the effects of task preparation on switch cost are more directly assessed by cue-only trials.

## Introduction

In task-switching paradigms participants shift between task rules (e.g., "Is a number greater or lesser than five?", "Is a number odd or even?") for the same set of stimuli (e.g., digits 1 through 9). The comparison of trials on which task rules switch with those on which task rules repeat is valuable for investigating those processes that are associated with behavioral control, presumed to be particularly important during task-rule switches. Indeed a difference in performance is typically observed between switch and repeat trials. This *switch cost* has been associated with at least two critical processes of behavioral control: task preparation and response selection.

Task preparation is hypothesized to involve at least partial retrieval of task rules (Allport & Wylie, 1999; de Jong, 2000; Gilbert & Shallice, 2002; Mayr & Kliegl, 2000; Meiran, 1996; Monsell, 1996; Rubinstein, Meyer & Evans, 2001; Sohn & Anderson, 2001; Yeung & Monsell, 2003), referred to as task set reconfiguration (Rogers & Monsell, 1995). This process can be triggered by a cue that indicates the identity (Sohn & Carlson, 2000) or probability (Dreisbach, Haider & Kluwe, 2002) of a subsequent task. Evidence for task preparation comes from the observation that the more information and preparatory time that participants are granted before a task, the better their performance. The benefit of preparation for performance is measured as a function of the cue–stimulus interval (CSI). An increase in its duration produces a reduction in switch cost (RISC; Meiran, 1996; Monsell & Mizon, 2006). More

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recent evidence has shown that priming of cue encoding also contributes to RISC (Logan & Schneider, 2006). In either case, advance cuing appears to prospectively benefit performance during task switching.

Task preparation however does not typically eliminate switch cost, leaving behind a "residual" switch cost. It has been suggested that this residual switch cost can be accounted for by processes that occur at the level of response selection. In particular these processes may contribute to inhibition of irrelevant but competing task sets, which would be expected to interfere with and thus prolong the selection of a response during a subsequent switch but not repetition trial, producing a switch cost. That is, response selection on one trial affects performance on the next. This conclusion is supported by diminished switch cost following trials in which response selection is absent. For instance, Schuch and Koch (2003) measured switch cost following no-go trials, in which a stimulus appeared on screen but a signal instructed participants to withhold their response, and found that switch cost was eliminated on the trial immediately following. In subsequent studies they and others have demonstrated that processes that occur at the level of response-selection, independent of motor execution or inhibition, are the critical factor (Philipp, Jolicoeur, Falkenstein & Koch, 2007; Verbruggen, Liefooghe, Szmalec & Vandierendonck, 2005; Verbruggen, Liefooghe & Vandierendonck, 2006).

Independently measured, task preparation and response selection provide a clear account of behavior control; task rules that are made active in working memory either facilitate or interfere with selection of responses during target onset. However, when considered together, the supporting findings are paradoxical. Specifically, whereas the RISC effect observed on go trials suggests that task-set preparation must have been effective in activating or reconfiguring the task, the complete absence of switch cost following no-go trials suggests the opposite. If task preparation and response-selection processes independently contribute to switch cost then eliminating one should eliminate only that component of the switch cost, not both as observed by Schuch and Koch (2003). During no-go trials, immediately following cue onset, participants are still able to retrieve task rules and even though these are never applied, their retrieval should interfere with subsequent performance. In other words eliminating response selection during no-go trials should eliminate residual switch cost but not RISC. This is contrary to what was observed.

One natural explanation for this paradox is that in this paradigm participants did not in fact retrieve task rules during preparation. If only processes occurring at the level of response selection contributed to the switch cost then only residual switch cost should be present. Accordingly,

eliminating such processes during no-go trials would be expected to eliminate this switch cost, as observed. Consistent with this explanation, in a further exploration of the effects observed by Schuch and Koch (2003), Kleinsorge and Gajewski (2004) demonstrated that as they increased participants' motivation to prepare, RISC effects were increased across trial types. As such the degree to which participants prepare, correlates with the magnitude of subsequent RISC effect. This explanation however is insufficient to account for Schuch and Koch's findings because they, unlike Kleinsorge and Gajewski (2004, "Neutral Context" condition), observed RISC following go trials (e.g., Experiment 1a), suggesting that participants engaged in task preparation. If participants were simply not motivated to engage in task preparation then RISC should have been absent following go trials *as well as* following no-go trials.

Therefore Schuch and Koch's (2003) findings present an interesting puzzle. Why would participants appear to engage in task preparation only following go trials? One intriguing possibility is that processing of no-go trials has the effect of interfering with task preparation. Such interference would be expected to selectively eliminate switch cost following no-go stimuli, as observed. No-go trials may, for instance, trigger a global inhibition signal (Aron & Verbruggen, 2008; De Jong, Coles & Logan, 1995), which has been hypothesized to occur whenever responses need to be stopped quickly (Aron, 2007; Aron & Poldrack, 2006) such as during no-go trials. Beyond its effects on motor responses, such a signal may be expected to also inhibit task rules that are held in working memory. Another possibility is that no-go stimuli reset, rather than inhibit, working memory. For instance, no-go stimuli occur infrequently and are unrelated, in stimuli and responses, to the primary task. As such they may trigger an increase in vigilance that has the side effect of clearing working memory. Indeed such "workspace flushing" has been proposed as a core mechanism that prevents control systems from perseverating on irrelevant response patterns (Gilbert & Shallice, 2002; Logan & Gordon, 2001). More simply, no-go stimuli may also be perceived as a third task, in which case all subsequent go trials would be equivalent to switch trials.[1] Switch cost would not be expected in this case, though responses should be slowed relative to repetition trials. This is consistent with a general slowing of responses following no-go trials relative to go trials (e.g., Kleinsorge & Gajewski, 2004; Schuch & Koch, 2003).

These possibilities clearly demonstrate that no-go trials might have actively interfered with task preparation in Schuch and Koch's (2003) study, which would account for the absence of RISC following these trials but not

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[1] We thank Frederick Verbruggen for pointing out this possibility.

following go trials. If so, then removing no-go trials should reveal effects of task preparation. Such a result would not only help explain Schuch and Koch's paradoxical result, but would also imply that processes occurring at the level of response selection can modulate the efficacy of task preparation. Namely, effects of task preparation can go unnoticed. This hypothesis was the object of the present study.

## Current study

To examine the effect of no-go trials on task preparation, we constructed a variant of the paradigm used by Schuch and Koch (2003, Experiment 1a). Following Schuch and Koch, our participants alternated between number judgments (Is a number odd or even? Is a number greater or lesser than 5?) that were indicated by a cue that preceded each target stimulus. In Experiment 1, a neutral stimulus (@, #, %, !, &) that was not associated with any response was presented on 25% of all trials. During these no-go trials, response selection was absent and therefore any switch cost observed following such trials could only be produced by effects of task preparation during the no-go trial. In Schuch and Koch's study, no such costs were observed. Experiment 1 aimed to replicate this result while controlling for a potentially important confound in Schuch and Koch's original design. Looking ahead briefly, this replication was successful. Experiment 2 therefore investigated further the effect of no-go stimuli on task switching, specifically to test whether the presentation of no-go stimuli might actually interfere with task preparation. To this end, we removed no-go stimuli, transforming no-go trials into "cue-only" trials in which task cues were followed by a blank cue–stimulus interval before the cue for the next trial appeared. We predicted that if no-go stimuli interfere with task preparation, then reliable switch effects and RISC should be observed following these critical cue-only trials.

## Experiment 1

Before examining whether the no-go stimuli interfere with task preparation we first sought to optimize this paradigm for its measurement. In Schuch and Koch's (2003) original design, the length of the cue–stimulus interval was constant across trials within a block. Therefore, long (no-go) preparation intervals were always followed by a long CSI on the subsequent go trial, meaning that participants could potentially "prepare away" any carried-over effects of preparation from the prior trial. The most sensitive condition to evaluate such carry-over effects would be a long (no-go) preparation interval followed by a short CSI on the
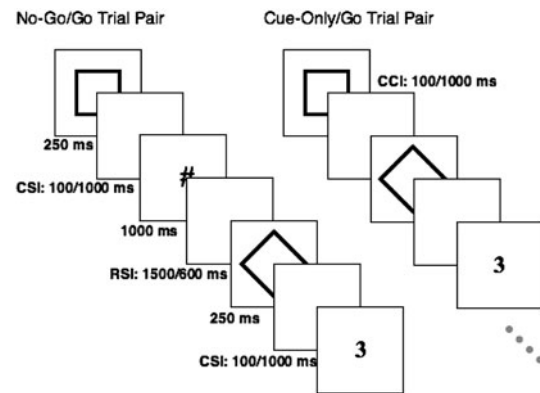


**Fig. 1** In the present study participants alternated between two number judgments (parity and magnitude), that were indicated by a preceding task cue. The trial sequence contained 75% go trials during which a response was required (second trial in each trial pair above), and 25% non-response trials (no-go in Experiment 1 and cue-only trials in Experiment 2). During no-go trials the stimulus was neutral (e.g., #). During cue-only trials there was no stimulus presented between consecutive cues. Switch cost was measured on go trials as a function of preceding trial (go, cue-only, no-go), as well as preparation interval (*CSI* cue–stimulus interval, *CCI* cue–cue interval)

subsequent go trial, maximizing the effects of task-preparation during the no-go trials on performance during the go trial. In Experiment 1 we tested this hypothesis by varying the length of the cue–stimulus interval randomly across trials within blocks. If in the original design the effects of task preparation were prepared away due to blocking of CSI, then randomly varying CSI within a block should produce a significant switch cost for long CSI no-go trials following a short CSI go trial.

Method

### Participants

20 participants were tested (11 females, $M = 20.0$ years old). Participants were recruited across the Princeton University Campus and were paid $10 US or received class credit. This study was approved by the Institutional Review Board at Princeton University. All subjects provided written, informed consent prior to participation.

### Task and stimuli

Participants were presented with single-digit stimuli and were required to make number judgments of either parity (odd–even) or magnitude (higher–lower than 5), depending on a task cue (Fig. 1). All stimuli were presented in white on a black background. Task cues included square and diamond frames, 4.5 cm$^2$ (5.2° of visual angle), respectively cuing parity and magnitude. This assignment was kept constant across participants and manipulations.

The stimulus set included the numbers 1–9 excluding 5. Numbers measured 1 cm in height, 0.3 cm in width (Courier New, 28 point, Bold), subtending 1.2° of visual angle vertically. Both task cues and number stimuli were presented centrally on the screen. The no-go stimuli were neutral characters (@, #, %, !, &) that did not have a corresponding magnitude or parity responses. Left and right arrow responses on a standard keyboard were used for both tasks, producing equal numbers of response–congruent and response–incongruent stimuli.

### Design

We used a within-subject $2 \times 2 \times 2 \times 2$ design. The first three factors were trial type (SWITCH, switch vs. repeat), previous trial go status (prevGO, go vs. no-go on the previous trial), and cue–stimulus interval (CSI: 350 ms vs. 1,250 ms). CSI was manipulated across trials. The fourth variable of interest was previous-trial CSI (prevCSI, 350 ms vs. 1,250 ms). Only go trials were analyzed as no responses were collected for no-go trials, and successive no-go trials were disallowed. The response–stimulus interval (RSI) was kept constant at 1,850 ms by varying the response–cue interval (RCI, 1,500 ms vs. 600 ms) to complement each CSI. Response mappings were counterbalanced across subjects.

Task sequences were constructed randomly within the following constraints (as per Schuch & Koch, 2003, Experiment 1a). No-go trials occurred on 25% of all trials with at least one go-trial between no-go trials. The target stimulus for trial $n$ was always different than for trial $n − 1$ and for the last occurrence of the same task. The sequence contained approximately equivalent number of response repeats and shifts for trial $n$ relative to responses for trial $n − 1$ and $n − 2$. The complete sequence of 768 trials was divided into eight blocks of 96 trials. Within each block there were 48 trials of each task, of which 24 were switch trials and 24 were repeat trials. For each 24, six were no-go trials and 18 were go trials. The first trial of each block was always a go trial.

### Procedure

The task procedure and parameters are illustrated in Fig. 1. A trial started with the presentation of a cue (i.e., diamond or square frame) presented for 250 ms. The cue was replaced by a blank screen for either 100 or 1,000 ms. The blank screen was used to ensure that participants process and internally represent the cue; if the cue remained on screen it may facilitate performance during the target without requiring task preparation (Verbruggen, Liefooghe, Vandierendonck & Demanet, 2007). The CSI was either 350 or 1,250 ms. Following the cue and CSI, a number stimulus was presented and remained on screen until a response was made. On no-go trials the neutral stimulus was displayed until either a button was pressed (erroneously) or until 1,000 ms elapsed.

Participants were instructed to respond as quickly and accurately as possible on go trials and to withhold responses on no-go trials. Incorrect responses were accompanied by feedback presented in red below the number stimulus, stating "Wrong Key" or "Do not press key" for go and no-go trials, respectively. Feedback was presented for 500 ms. An appropriate RCI followed, complementing the subsequent CSI in length for a consistent RSI of 1,850 ms. The screen was blank during the RCI. Subjects were encouraged to take breaks between blocks. The entire session lasted approximately 60 min.

## Results

### Data analysis

The data were analyzed using a repeated-measures analysis of variance (ANOVA) with error rate and RT as dependent measures, and prevCSI, CSI, prevGO and SWITCH as independent variables. The first two trials of each block were excluded. Only trials preceded by two correct trials and for which RT was below 2,000 ms were retained. On average across subjects, we excluded 8% of all trials (SD = 0.06). Only effects that showed at least a trend effect ($p < 0.1$) are reported.

### RT data

As shown in Fig. 2, there was a main effect of SWITCH, $F(1,19) = 27.99$, $p < 0.01$, that interacted with prevGO, $F(1,19) = 19.58$, $p < 0.01$. That is, there was a significant overall switch cost (repeat 761 ms vs. switch 810 ms) that was greater following go trials (80 ms) than following no-go trials (18 ms). Subsequent pairwise comparisons revealed that the switch cost was significant following go trials, (79 ms), $t(19) = 7.36$, $p < 0.001$ (one-tailed), but was a trend following no-go trials, (17 ms), $t(19) = 1.42$, $p < 0.09$ (one-tailed). A planned comparison was conducted for the critical no-go/go sequence in which a long preparation period on the no-go trial was followed by a short preparation interval for the go trial (1,250/350 CSI). This analysis revealed that the observed 23 ms switch cost was not significantly different from zero, $t < 1$.

The overall effect of RISC showed only a trend, SWITCH × CSI, $F(1,19) = 2.45$, $p = 0.13$. As is evident from Fig. 2, switch cost appeared to decrease with a longer CSI following go trials (100 ms vs. 58 ms) but less so following no-go trials (20 ms vs. 15 ms). Although the three-way interaction with prevGO was not reliable, $F(1,19) = 1.15$, $p = 0.24$, we repeated these analyses
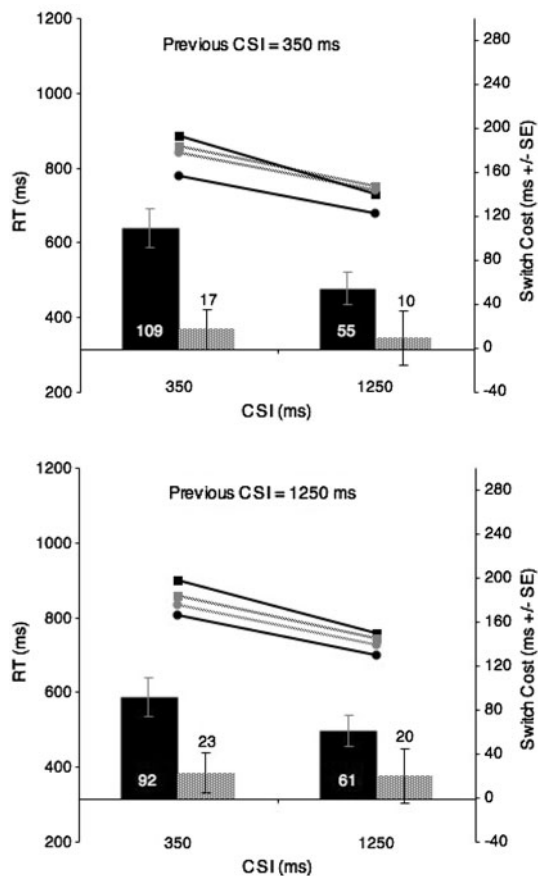
**Fig. 2** Mean reaction time (RT, *lines*) and switch cost (*bars*) for Experiment 1. Data are shown for go trials following go (*black*) and no-go (*grey*) trials, for switch (*squares*) and repeat (*circles*) trials. Switch cost and RISC were significant following go trials. Switch cost was not significant following no-go trials. No effects of prevCSI were observed (top vs. bottom graph)

separately for go and no-go trials. This was done following the protocol of Schuch and Koch (2003) who reported a reliable RISC effect following go trials but not following no-go trials when analyzed separately.[2] Indeed, the interaction between CSI and SWITCH was significant after go trials, $F(1,19) = 6.77$, $p = 0.02$ but not after no-go trials, $F < 1$. Therefore, switch cost was significant and showed a RISC effect after go trials but not after no-go trials.

Finally, there was also a main effect of CSI, $F(1,19) = 93.35$, $p < 0.01$, with mean RT faster for trials with a long CSI (727 ms) than with a short CSI (844 ms), indicating that RT benefited from the preparation interval. An additional interaction, GO × SWITCH, $F(1,19) = 19.58$, $p < 0.001$, reflected a slowing of RT following no-go trials (784 ms) relative to go trials (739 ms) during task repetitions, but not during task alternations (801 ms vs. 818 ms). No other effects were significant.

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[2] The three-way interaction also was not significant in the Schuch and Koch (2003, Experiment 1a) study.

*Error rate*

The overall error rate was 7% (SD = 0.01). The main effects paralleled those for RT. The main effect of SWITCH showed a trend, $F(1,19) = 4.07$, $p = 0.06$, and interacted with prevGO, $F(1,19) = 4.83$, $p = 0.03$. These effects reflected a trend switch cost (repeat 6% vs. switch 7.5%) that was greater following go trials (2.8%) than following no-go trials (0.3%). The overall effect of RISC also showed a trend, SWITCH × CSI, $F(1,19) = 3.75$, $p = 0.07$. Switch cost decreased with CSI (2.6% vs. 0.3%). No other effects were significant.

In contrast to the RT data, there was no main effect of CSI on error rates, $F < 1$. Rather there was a unique three-way interaction between SWITCH, prevGO, and prevCSI, $F(1,19) = 4.56$, $p = 0.05$. This interaction occurred because prevCSI had different effects on switch cost following no-go versus go trials. Switch cost following no-go trials increased with longer prevCSI (−1.3% vs. 1.8%), whereas switch cost following go trials was comparable across prevCSI (2.9% vs. 2.5%). Further post hoc comparisons were not conducted.

## Discussion

The results of this experiment were similar to those of Schuch and Koch (2003) with respect to switch cost, ruling out the possibility that their results were caused by a confound between current and previous CSI present in their blocked-CSI design. Thus, replicating Schuch and Koch's earlier findings, we found that switch costs and RISC were reliable only after go trials, independent of CSI on the prior trial (though we caution that, as in the original study, the three-way interaction between SWITCH, prevGO and prevCSI was not reliable). Importantly, switch cost was also absent in the critical condition in which a long CSI (prepared-for) no-go trial was followed by a short CSI (unprepared) go trial, the condition that should be optimal for observing any interfering effects of prior preparation for an alternative task. Rather, eliminating response selection via no-go stimuli appeared to attenuate subsequent switch cost. Performance during go trials revealed a reduction as CSI increased—that is, there was a reliable RISC effect—suggesting that cue processing contributed to switch cost.

Collectively, these results rule out the possibility that in the original paradigm task preparation was ineffectively measured due to blocking of CSI. In Experiment 2 we therefore addressed the main question of this study, whether no-go trials tend to disrupt ongoing task performance in such a way as to obscure effects of prior preparation that might otherwise be observed.

## Experiment 2

If no-go trials interfered with the effects of task preparation in Experiment 1 (and in the study by Schuch & Koch, 2003), then this effect (e.g., a global inhibition signal) would be expected to occur in response to the no-go stimulus. Therefore, in Experiment 2 we sought to eliminate such interference by removing the no-go stimulus. To do this, we replaced no-go trials with "cue-only" trials that did not include any stimulus following the cue. Rather a cue and appropriate CSI were immediately followed by a cue for the subsequent trial. The CSI was effectively converted to a cue–cue interval (CCI). In this way we aimed to eliminate any potential interference that the no-go stimulus may have produced on task preparation. If such interference was present in Experiment 1 then removal of the no-go stimuli should reveal a reliable switch cost following cue-only trials in Experiment 2.

### Method

#### Participants

We tested 21 participants (9 females, $M = 19.4$ years old).

#### Stimuli, design, procedure

Stimuli and design were identical to Experiment 1 except that no neutral stimulus appeared on no-go trials (Fig. 1, right-hand sequence). Instead, on cue-only trials a cue was presented for 250 ms followed by an interval of either 100 or 1,000 ms. The screen remained blank during this time. The CCI was immediately followed by the cue for the following trial.

### Results

#### Data analysis

Data were screened and analyzed as in Experiment 1, with no-go trials replaced by cue-only trials. For consistency across experiments we retain the use of the terms CSI and prevCSI, although in reference to cue-only trials these terms actually refer to CCI. On average 8% of all trials were excluded from analysis (SD = 0.05).

#### RT data

As in Experiment 1 there was a main effect of SWITCH, $F(1,20) = 75.3$, $p < 0.001$, but unlike Experiment 1 SWITCH did not interact with prevGO, $F < 1$. As shown in Fig. 3 there was an overall switch cost (repeat trials 726 ms vs. switch trials 785 ms) that was significant

following *both* go trials (59 ms), $t(20) = 5.8$, $p < 0.001$, and cue-only trials (58 ms), $t(20) = 7.7$, $p < 0.001$. Indeed, switch cost in the critical CSI condition (1,250/350 CSI) was greater following cue-only trials (113 ms) than following go trials (63 ms). The four-way interaction, SWITCH × prevGO × CSI × prevCSI, was not significant, $F(1,20) = 1.29$, $p = 0.27$. These results suggest that switch cost can be observed in the absence of response selection (i.e., following cue-only trials), contrary to the conclusions of Schuch and Koch (2003).

There was also an effect of RISC, namely the SWITCH × CSI interaction was significant, $F(1,20) = 6.9$, $p = 0.02$, indicating that switch cost was greater with a short CSI (82 ms) than with a long CSI (35 ms). Interestingly this RISC effect interacted with trial type (prevGO), $F(1,20) = 4.69$, $p = 0.04$. A paired $t$ test analysis on mean switch cost revealed a reliable RISC after cue-only trials (94 ms vs. 22 ms), $t(20) = 2.95$, $p < 0.01$
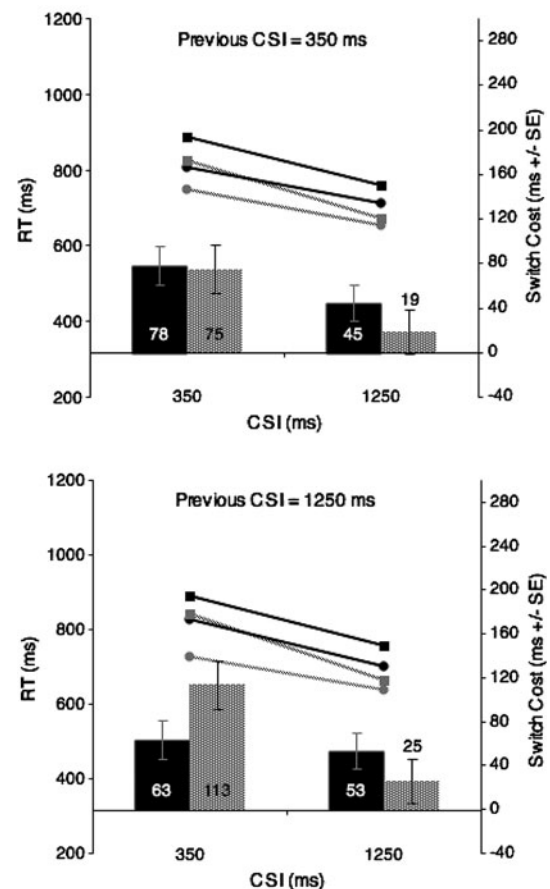


**Fig. 3** Mean reaction time (RT, *lines*) and switch cost (*bars*) for Experiment 2, with no-go replaced by cue-only trials. Data are shown for go trials following go (*black*) and cue-only (*grey*) trials, for switch (*squares*) and repeat (*circles*) trials. Switch cost and RISC were now significant across trial types, and the effect was larger following cue-only trials than following go trials. RT was overall faster following cue-only trials (also see Fig. 4)

(one-tailed), but only a trend following go trials (70 ms vs. 49 ms), $t(20) = 1.23$, $p = 0.13$ (one-tailed). Therefore, RISC was actually reduced following go trials relative to Experiment 1. This finding will be revisited below in the context of between-subject effects (cf., Experiment Effects).

Finally, as in Experiment 1, we found a significant main effect of CSI, $F(1,20) = 65.8$, $p < 0.001$. Participants showed an RT benefit from longer CSI (693 ms vs. 818 ms). Additionally we found a main effect of prevGO, $F(1,20) = 27.7$, $p < 0.001$, which indicated that participants were faster to respond after cue-only trials (719 ms vs. 791 ms). This finding is notable and will also be considered in the between-subject effects analysis below. No other effects were significant.

### Error rate

Average error rate was 9% (SD = 0.09) and the main effects, again, paralleled those in RT data. As in Experiment 1, the main effect of SWITCH showed a trend, $F(1,20) = 4.12$, $p = 0.06$. Switch trials showed slightly more errors than repeat trials (9.9% vs. 8.5%) indicating that the switch cost was in the expected direction. There was also a significant interaction between SWITCH and prevGO, $F(1,20) = 6.6$, $p = 0.02$, with switch costs greater following go trials than following cue-only trials (3.1% vs. 0.02%). The effect of RISC was however not significant, $F(1,20) = 2.27$, $p = 0.15$.

The lack of a switch cost following cue-only trials (0.02%), $t < 1$, contrasted with the RT results (above). However, it is important to note that the switch cost following cue-only trials was zero, but not negative, which would have suggested that a speed-accuracy trade-off could account for the switch cost in RT. The mean switch cost in our condition of interest (1,250/350 CSI), which showed the greatest RT switch cost (113 ms), was 1.1%, also not significantly different from zero, $t < 1$ but, again, not negative.

Finally, accuracy was also higher following cue-only versus go trials, $F(1,20) = 6.73$, $p = 0.02$ (91.5% vs. 90.0%) which, consistent with RT results (above), suggests an overall benefit in performance for trials following cue-only trials. This finding is discussed in the next section.

### Experiment effects

Both RT and error rate analyses revealed that performance was overall better following cue-only trials than following go trials, which was not the case for no-go trials in Experiment 1. We wondered whether a different strategy between experiments could explain the attenuation of RISC
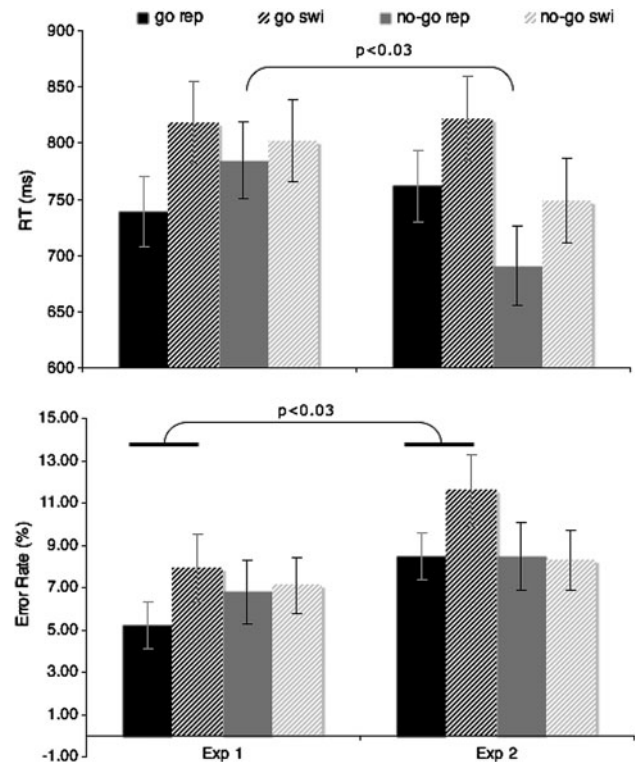


**Fig. 4** Mean reaction time (RT, *top*) and error rate (*bottom*) for Experiments 1 and 2, shown following go (*black*) and no-go/cue-only (*grey*) trials. The difference between switch (*hatched*) and repeat (*solid*) trials clearly shows a switch cost in both RT and error rate following go trials. Following no-go/cue-only trials this effect is absent in error rate, and is present only following cue-only trials in RT. Notably, with removal of no-go stimuli (Experiment 2) RT decreased following cue-only trials and error rate increased following go trials

following go trials. In particular, the omission of no-go stimuli during cue-only trials meant that subsequent cues on these trials were presented at a faster rate then during go trials. A faster pace may speed up responses following such trials (Bertelson, 1961), which may in turn have the side effect of decreasing attention during standard go trials. The consequence would be poorer performance following go trials, potentially attenuating RISC.

We evaluated this possibility by comparing performance across experiments. We conducted a mixed factorial ANOVA separately for error rate and RT. Two within-subject factors were included, prevGO and SWITCH. The latter was included because repeat trials are known to contribute to cue priming effects (Logan & Bundesen, 2003; Mayr & Kliegl, 2003), which would be particularly potent on cue-only trials. Significant interactions with the between-group EXPERIMENT variable were of interest and are shown in Fig. 4.

For the RT data, EXPERIMENT interacted with prevGO, $F(1,39) = 26.19$, $p < 0.01$, and these variables further showed a significant three-way interaction with SWITCH,

$F(1,39) = 10.94$, $p < 0.01$. These interactions indicate first that RT was on average faster in Experiment 2 than in Experiment 1 following no-go/cue-only trials (719 ms vs. 793 ms), $t(39) = 1.79$, $p = 0.09$ (one-tailed), but not following go trials (791 ms vs. 778 ms), $t < 1$. Second this effect was most pronounced for repetition trials (see Fig. 4). Repetition trial responses were significantly faster following cue-only trials in Experiment 2 than following no-go trials in Experiment 1 (690 ms vs. 785 ms), $t(39) = 1.91$, $p = 0.03$ (one-tailed). In other words, as expected, removing stimuli from the no-go trials that were used in Experiment 1 increased response speed following the corresponding cue-only trials in Experiment 2.

For error rates, EXPERIMENT interacted only with prevGO, $F(1,39) = 6.39$, $p = 0.02$. As shown in Fig. 4, following go trials error rate increased from Experiment 1 (6.5%) to Experiment 2 (10%), $t(39) = 1.87$, $p = 0.02$ (one-tailed), but showed no significant change from no-go trials (7%) to cue-only trials (8.5%), $t < 1$. Therefore, removing stimuli from the no-go trials that were used in Experiment 1 increased the error rate selectively following go trials in Experiment 2. These results are consistent with the hypothesis that cue only trials in Experiment 2 hindered performance following go trials, which may have in turn attenuated switch costs following go trials in Experiment 2.

## Discussion

In Experiment 2 we found that removing no-go stimuli revealed an effect of task preparation that occurred during cue-only trials on performance during subsequent go trials. Switch cost and RISC were now reliable following cue-only trials. This finding suggests that switch costs and RISC can occur without response selection, presumably reflecting the influence of prior task preparation, and that the no-go stimuli in Experiment 1 may have interfered with such preparatory effects.

A potential concern with our findings is that removing no-go stimuli (and the response–stimulus interval) in Experiment 2 effectively shortened the time between consecutive cues relative to no-go trials in Experiment 1. Perhaps switch cost emerged because we limited decay of task processing effects between consecutive cues relative to Experiment 1, not because we removed interfering no-go stimuli. However, in other studies in our laboratory we have found that a significant switch cost following cue-only trials may be observed for cue–cue intervals of 2,600 ms (Lenartowicz & Cohen, 2006) and up to 4,000 ms (unpublished results). Therefore, it is unlikely that decay alone can account for the absence of a switch cost in Experiment 1, which had a maximum cue–cue interval of 2,650 ms.

## General discussion

The aim of this study was to evaluate whether no-go stimuli interfere with task preparation, thereby modulating preparatory effects on switch cost during subsequent trials. We first showed that the absence of switch costs in a no-go paradigm is not an artifact of the use of blocked CSIs, and then demonstrated that both switch cost and RISC were significant when no-go stimuli were replaced with cue-only trials. This finding provides evidence that, independent of their effects on response selection, no-go stimuli can interfere with the effects of task preparation. In the remainder of this discussion, we consider the mechanisms by which this interference may occur and the implications of our findings for studying task preparation.

### No-go stimuli and mechanisms of interference

Two plausible mechanisms by which no-go stimuli may interfere with task preparation are inhibition and task reset. The first possibility is that no-go stimuli are interpreted as a stop signal. If so they may be expected to elicit inhibition of the motor response as well as inhibition of recently retrieved task rules. Such a global, non-specific inhibition mechanism has been proposed to operate when responses need to be stopped quickly (Aron & Verbruggen, 2008; Coxon, Stinear & Byblow, 2007; De Jong, Coles & Logan, 1995; Verbruggen, Liefooghe & Vandierendonck, 2006), as may be expected with the occurrence of no-go stimuli. One assumption of this hypothesis is that inhibition at the level of motor responses can spread to representations of task rules. This assumption is not implausible. Spread of inhibition is well documented as a contributing factor in retrieval induced forgetting (Anderson & Neely, 1996; Norman, Newman & Detre, 2007) and in transfer effects within negative priming (Tipper & Driver, 1988; Tipper, MacQueen & Brehaut, 1988). A similar cascade may be initiated by no-go stimuli, with inhibition spreading from motor to rule representations. However, motor inhibition does not automatically spread to rule representations and so it may not necessarily be a factor in the current study. Logan (1983, 1985) showed that stop-signal generated inhibition of motor responses had no effect on the recall of word-pairs associated with that response, counter to the idea of spreading inhibition. The variables that determine whether inhibition spread occurs, and thus whether it was present in our experiment, are unclear. However, one prediction of the inhibition hypothesis is that if task rules were inhibited then the activation level of the task-rule representation should be below baseline. If so, then responses on a subsequent task repetition should be slowed relative to a task switch. The result would be an inverse switch

cost following no-go trials, akin to effects of backwards inhibition (Koch, Gade & Philipp, 2004; Mayr & Keele, 2000). As there was no such slowing following no-go trials (Experiment 1), we suggest that task rules were not inhibited following no-go trials in the current study.

An alternate mechanism by which no-go stimuli could interfere with task preparation is by clearing rule representations that were active in working memory. This could occur because no-go stimuli are unrelated to the task itself and/or because they require an interruption in task flow. Conceptually, this idea is similar to the "flushing" of response counters proposed by Logan and Gordon (2001) in their model of executive control, which was suggested to occur after each response in order to keep working memory open to new inputs and thus prevent perseveration (see also Gilbert & Shallice, 2002). No-go stimuli may have a similar effect in our experiment, but "flushing" all of working memory rather than just response representations. In this sense no-go stimuli may be perceived as a third task that, because it shares no response mappings with others, produces no interference and thus no inhibition (Botvinick, Braver, Barch, Carter & Cohen, 2001; Gade & Koch, 2005). However, it does disrupt processing by clearing working memory. Another potentially related effect of disruption in task switching occurs whenever performance is briefly stopped. Comparing the first trial of a task-switching block to subsequent trials in that block reveals a relative slowing, referred to as the "restart cost" (Allport & Wylie, 2000; Gopher, Armony & Greenshpan, 2000). This pause effect may be similar to that of no-go stimuli in that, following both, activation of the relevant task representation must be rebuilt (Altmann & Gray, 2002; Poljac, Koch & Bekkering, 2009). Consistent with this interpretation, a general slowing has been observed following no-go trials relative to following go trials (Kleinsorge & Gajewski, 2004; Koch & Philipp, 2005; Schuch & Koch, 2003). In the current study such slowing was observed as well, though primarily following repetition trials (Experiment 1). Based on these observations we suggest that the most likely effect of no-go trials is to clear working memory, and as a consequence they eliminate effects of prior task preparation.

Implications for task preparation

Insofar as they may obscure the effects of task preparation, no-go stimuli have direct impact on interpretations regarding the occurrence and scope of preparatory processes. For instance, in Experiment 1, an absence of switch cost following no-go stimuli may be interpreted as evidence that task preparation contributed little if anything to switch cost beyond the effects of response selection. However, such a conclusion would be incorrect because, in Experiment 2, we saw that preparation for cue-only trials clearly modulated subsequent switch cost.

Of perhaps greater significance is whether our result can inform the scope of preparatory processes. In particular, the notion that task preparation involves retrieval of task rules (Allport & Wylie, 1999; de Jong, 2000; Gilbert & Shallice, 2002; Mayr & Kliegl, 2000; Meiran, 1996; Monsell, 1996; Rubinstein, Meyer & Evans, 2001; Sohn & Anderson, 2001; Yeung & Monsell, 2003) has been questioned by the observation that RISC effects may reflect priming of visual encoding of the cue, rather than active preparation of the cued task (Logan & Bundesen, 2003, 2004; Logan & Schneider, 2006). Thus, far we have been agnostic regarding these possibilities, however, our results may be interpreted as evidence for the task-rule retrieval account. Cue priming effects should be most pronounced during short CSI sequences because these trials present the greatest challenge to cue encoding. Accordingly, the greatest switch cost may be expected following cue-only trials in 350/350 CSI-sequences. However, in Experiment 2 (Fig. 3) we found that switch cost following the 1,250/350 CSI-sequence cue-only trials (113 ms) was about 50% greater than following the 350/350 CSI-sequence cue-only trials (75 ms). Though this difference was only a trend, $t(20) = 1.18$, $p = 0.13$, it may suggest that participants engaged in more than cue encoding during the cue-only trials.

Of course this conclusion is based on the assumption that cues were completely encoded within the 350 ms CSI. This assumption may not be appropriate for abstract cues such as those used in our study (Logan & Bundesen, 2004). Stronger evidence would be to show a reliable switch cost, whilst controlling for cue priming. Brass and von Cramon (2004) did exactly that by using multiple cues in a cue-only paradigm similar to that used in the current study. Even with cue priming effects eliminated, they also found a significant switch cost following cue only trials. We also have evaluated switch cost in this paradigm with cue repetitions removed (Lenartowicz & Cohen, 2006) and found switch cost to be significant following cue only trials. Perhaps even more convincing is the finding of Kleinsorge and Gajewski (2004) who demonstrated measurable switch cost and RISC following no-go trials when the probability of a subsequent task repetition was increased to 80%. Apparently, with sufficient motivation, the interfering effects of no-go stimuli can be overcome, implying an active process such as task-set retrieval rather than passive visual priming of cue encoding. Considering these findings, we suggest that switch cost following cue-only trials may be particularly sensitive to the effects of task preparation, and thus task-rule retrieval when it exists.

## Conclusion

The present study demonstrates that no-go trials can interfere with the effects of task-preparation on switch cost, thus accounting for the absence of switch cost following no-go trials in Schuch and Koch's (2003) study. Although the specific mechanism behind this interference is still to be determined, its presence demonstrates that processes at the level of response selection can modulate the efficacy of task preparation.

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