Excessive Response-Repetition Costs Under Task Switching: How Response Inhibition Amplifies Response Conflict

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The size of response-repetition (RR) costs, which are usually observed on task-switch trials, strongly varies between conditions with univalent and bivalent stimuli. To test whether top-down or bottom-up processes can account for this effect, we assessed in Experiment 1 baselines for univalent and bivalent stimulus conditions (i.e., for stimuli that are associated with either 1 or 2 tasks). Experiment 2 examined whether the proportion of these stimulus types affects RR costs. As the size of RR costs was independent of proportion, a top-down explanation could be excluded. However, there was an increase in RR costs if the current stimulus induced a response conflict. To account for this effect, we proposed an amplification of response conflict account. It assumes that the basic mechanism that leads to RR costs amplifies response conflict, which, in turn, increases RR costs. Experiment 3 confirmed this bottom-up explanation by showing that the increase in RR costs varies with previous-trial congruency, which is known to affect RR costs. Experiment 4 showed that the increase can also be found with univalent stimuli that induce response conflict. Altogether, the results are in line with a response inhibition account of RR costs. Implications for alternative accounts are also discussed.

Keywords: response repetition, response inhibition, task switching, response conflict

Intentional behavior requires the flexible selection of an appropriate action in response to a relevant stimulus. This selection is a significant challenge if the required action changes frequently (Houghton & Tipper, 1996). In such highly demanding contexts, cognitive control is necessary not only for selecting relevant information but also for diminishing interference from representations that have been activated on the last trial. Such control processes have been widely studied in task-switching studies (for overviews see Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010). In these studies, information about mechanisms underlying the control can be extracted from effects caused by the repetition of task components from one situation to the next. Among the various components that can repeat, the present study is concerned with response repetition (RR).

In task switching, RRs usually produce benefits if the task repeats but costs if it switches (e.g., Druey & Hübner, 2008a; Hübner & Druey, 2006, 2008; Kleinsorge & Heuer, 1999; Koch, Schuch, Vu, & Proctor, 2011; Meiran, 2000a; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995; Schuch & Koch, 2004). Several mechanisms have been proposed to account for this interaction between task switching and RR (cf. Rogers & Monsell, 1995). However, which one is valid is still under debate (e.g., Schuch & Koch, 2010). What might be informative for differentiating between the accounts is the fact that RR costs vary considerably between conditions (cf. Altmann, 2011) and that they are more stable and pronounced in error rates (ERs) than in response times (RTs). Consequently, the aim of the present study was to examine which factors modulate the size of RR costs. The results should provide some insight into the mental mechanism underlying RR costs.

Our starting point was the finding that RR costs are larger for bivalent than for univalent stimuli (i.e., larger for stimuli that activate stimulus categories of two tasks and their corresponding responses; e.g., Hübner & Druey, 2006). To account for this valency effect it has been speculated that bivalent stimuli increase the risk of perseveration and that response inhibition is controlled by a top-down strategy in dependence of this risk (Hübner & Druey, 2006). However, contrary to this idea, the outcome of our first two experiments in the present study indicated that the valency effect on RR costs is the result of bottom-up (i.e., stimulus-driven) mechanisms. In two subsequent experiments we found further evidence for this hypothesis. These findings put new constraints on models of RR costs, as will be discussed in detail in the General Discussion.

Because our reasoning in this study was based on the idea of response inhibition, we first describe this concept before we report the objective of the present study and the experiments in detail.

Response Inhibition

The response-inhibition account (e.g., Cooper & Marí-Beffa, 2008; Hübner & Druey, 2006) assumes that mental representations involved in response selection remain activated for some time after responding (for a closely related idea, see Juvina & Taatgen, 2009) and that this produces a bias toward repeating the last response. Because such a perseverative bias is unfavorable if responding

must be flexible, as in task switching, it is counteracted by inhibiting the last response. Hence, RR costs reflect an inhibition-induced bias toward a response shift (RS) that is strategically implemented and affects task-switch and task-repetition trials alike (Marí-Beffa, Cooper, & Houghton, 2012).

On task-repetition trials this bias is usually not observed as RR costs (but see e.g., Cooper & Marí-Beffa, 2008; Steinhauser, Hübner, & Druey, 2009), because other features of the previous trial repeat as well on these trials. Thus, not only the pure effects of RR are observed but also positive effects of category priming (cf. Pashler & Baylis, 1991) or of episodic matches between previous and current trial features (Altmann, 2011; Marí-Beffa et al., 2012). Unfortunately, the individual effects of these processes can hardly be separated. According to the response-inhibition account, however, together they usually outweigh the negative effects of response inhibition, resulting in the observed benefits on task-repetition trials.

An important question is whether responses are inhibited by bottom-up or by top-down processes (see Arbuthnott, 1995, for a related discussion). The fact that response inhibition affects performance on task-switch and task-repetition trials (e.g., Cooper & Marí-Beffa, 2008; Hübner & Druey, 2006) suggests that the strategic implementation of inhibition is rather rigid and that inhibition is not adjusted on a trial-by-trial basis by top-down control. Consequently, it can be assumed that local adjustments are controlled by bottom-up mechanisms. One candidate in this respect is *self-inhibition* (MacKay, 1986), a type of inhibition that is triggered automatically to overcome perseverative tendencies of activated units in the system (e.g., Arbuthnott, 1995; Baddeley, Emslie, Kolodny, & Duncan, 1998) and that seems to be important for performing action sequences (e.g., Houghton & Tipper, 1996; Juvina & Taatgen, 2009; Li, Lindenberger, Rünger, & Frensch, 2000). Accordingly, self-inhibition has also been suggested as a mechanism involved in sequential action control at the level of task sets (Mayr, 2009).

Evidence for bottom-up controlled response inhibition is provided by studies showing that RR costs are larger after congruent than after incongruent stimuli (Altmann, 2011; Druey & Hübner, 2008b; Grzyb & Hübner, 2012b; Hübner & Druey, 2006). This *previous-trial congruency effect* can be explained by the assumption that congruent stimuli activate the correct response stronger

than do incongruent stimuli. Given a constant response threshold, the stronger activation is reflected in faster response selection for congruent stimuli (Grzyb & Hübner, 2012b). Because a stronger activation would result in higher residual activation and, thus, increase the perseverative bias of the system, it is counteracted by an automatic increase of response inhibition.

However, it has also been suggested that top-down processes are involved in adjusting the size of response inhibition (Hübner & Druey, 2006; Marí-Beffa et al., 2012). Hübner and Druey (2006), for instance, hypothesized that top-down control adjusts the strength of inhibition according to the global risk of perseveration. Their reasoning was mainly based on results showing that RR costs are larger for bivalent than for univalent stimuli (Hübner & Druey, 2006; Lien, Schweickert, & Proctor, 2003; see also Kleinsorge, 1999, Experiment 1 vs. 2 and 3; Schuch & Koch, 2004, Experiment 1 vs. replication of Experiment 1, p. 577 ff.). If one assumes that the residual activation of the last response produces a bias toward its repetition, then especially bivalent stimuli that activate the wrong response via the irrelevant task would increase this bias (i.e., the risk of perseveration). We call those bivalent stimuli *bivalent-incongruent* (cf. Table 1). Consequently, on task-switch trials a response shift would be rather difficult with bivalent-incongruent stimuli, because the residual activation of the last but now wrong response would be further increased by the irrelevant stimulus category (which was relevant on the previous trial). Thus, it seems that in bivalent-stimulus conditions the global risk of perseveration is increased, relative to univalent-stimulus conditions. Hübner and Druey (2006) therefore assumed that this increase is counterbalanced by a strategic increase of response inhibition.

Objective of the Study and the General Procedure

The objective of this study was to investigate the extent to which top-down and bottom-up processes modulate RR costs. After assessing the basic RR costs for bivalent and univalent stimuli in our first experiment, we examined in Experiment 2 the idea that top-down processes control the strength of response inhibition in dependence of the global risk of perseveration, where the risk was manipulated by the ratio of bivalent-incongruent (bivalent) to neutral (univalent) stimuli. The results clearly showed that RR

Table 1
Definition of Stimulus Types According to Their Item Congruency and Valency

	Item congruency		
Valency	Neutral	Congruent	Incongruent
Univalent	Neutral (e.g., *G* or 6*)	Univalent-congruent (e.g., KGK or 868)	Univalent-incongruent (e.g., AGA or 363)
Bivalent		Bivalent-congruent (e.g., 8G8 or K6K)	Bivalent-incongruent (e.g., 3G3 or A6A)

Note. The item-congruency feature specifies if a category and its corresponding response are associated with the task-irrelevant stimulus item, and if so, how this response is related to the correct response (none = neutral; same as correct response = congruent; different from correct response = incongruent). The valency feature specifies how many tasks can be performed with a stimulus (one = univalent; two = bivalent). According to this definition, neutral stimuli are always univalent. The tasks in the experiments were consonant/vowel judgments of letters and even/odd judgments of numbers indicated by left/right button presses. Examples of the stimulus types assume that the target item (G or 6) is located in the middle of the three-item stimulus. In Experiments 1 to 3, however, target items were presented randomly either in the middle or the outer locations of the array.

costs were substantially larger for bivalent-incongruent than for univalent stimuli. However, they did not depend on the proportion of the stimulus types, which suggests that the increase in RR costs for bivalent-incongruent stimuli was caused by a bottom-up mechanism. As a possible mechanism we propose the *amplification of response conflict* (ARC) account. It assumes that the basic mechanism that induced an RS bias (e.g., response inhibition) amplifies the response conflict on the current trial, which, in turn, increases RR cost. This account was tested in Experiments 3 and 4.

In all of our experiments we employed a sequential two-task procedure as in Druey and Hübner (2008b). This procedure has the advantage that it minimizes expectancy effects and allows one to control for higher order repetition effects (e.g., Soetens, 1998). On each trial participants first had to perform Task 1 and then Task 2, with respective stimuli S1 and S2. Participants signaled their decisions in the two tasks by responses R1 and R2, respectively. Because we needed stimuli that differed in both valency and congruency, we arranged numerals, letters, and neutral symbols in a similar way (see Figure 1) as in the flanker task (Eriksen & Eriksen, 1974). Parity and consonant/vowel judgments served as tasks. With these three-item stimuli we constructed five stimulus types. Table 1 shows how we denote these types and their feature combinations.

Furthermore, to obtain large effects of incongruency and bivalency, the relative position (center or outer) of target and nontarget

Figure 1. A: Associations between stimulus categories and responses. B: Examples of trials of different conditions. A cue indicates the relevant judgment for Task 1. Task 2 is always the alternative judgment. Note that only trials with univalent-congruent S1 are depicted. Experiment 1 also includes bivalent-congruent S1, and Experiment 3 also includes univalent-incongruent S1. For details see text.

items in S2 varied randomly from trial to trial. Accordingly, position could not be used for target selection, and item category (letter vs. numeral) had to be used instead.[1]

Experiment 1

In this experiment we wanted to assess the basic RR costs for bivalent versus univalent stimuli. To observe performance that was not influenced by experience with other stimulus conditions, we manipulated the valency of stimuli in the two-task sequence between participants. First, we examined effects of S2 valency. To this end, for half of the participants the irrelevant items of S2 were neutral (i.e., not related to any task). For the other half, S2 was bivalent-incongruent. That is, the irrelevant items of S2 were chosen from the other item category (letters or numerals, respectively) and were always associated with the wrong response. We expected that bivalent-incongruent S2 would increase the risk of perseveration, which should result in larger response inhibition.

Second, we further wanted to examine effects of S1 valency. It has been suggested that bivalent-congruent stimuli produce *lateral inhibition* between the activated category-response (C-R) rules (e.g., Schuch & Koch, 2004). Because for bivalent-congruent S1 the irrelevant category-response rule on Task 1 becomes relevant on Task 2, RR costs might be larger after bivalent than after univalent S1. To test this hypothesis, each group of participants was further divided into two subgroups. Members of one subgroup (univalent) had univalent-congruent S1, whereas members of the other subgroup (bivalent) responded to bivalent-congruent S1.

Altogether we had four different experimental groups of participants: the univalent/neutral group, the univalent/bivalent-incongruent group, the bivalent/neutral group, and the bivalent/bivalent-incongruent group. The participants in the univalent/neutral group had to switch between two tasks with univalent stimuli. Accordingly, there was neither the potential of lateral inhibition between category-response rules nor a substantial risk of perseveration. Yet, if responses are generally inhibited after their execution, RR costs should also occur under these conditions. The performance of the univalent/neutral group was contrasted with that of the univalent/bivalent-incongruent group. The other two groups were analogous to the first two, except that their members responded to bivalent (bivalent-congruent) S1. When bivalent S1 contributes to response inhibition by lingering lateral inhibition between C-R rules, then the RR costs should be larger for these groups than for the two groups with univalent S1. Because the paradigm was relatively complex and performance on task-repetition trials would have been largely uninformative for the present objective, we had only task-switch trials.

Method

Participants. Forty-eight (16 male; mean age = 23 years) persons with normal or corrected-to-normal vision were recruited at the Universität Konstanz and either were paid 5 € per hour or fulfilled a course requirement. Participants were equally assigned
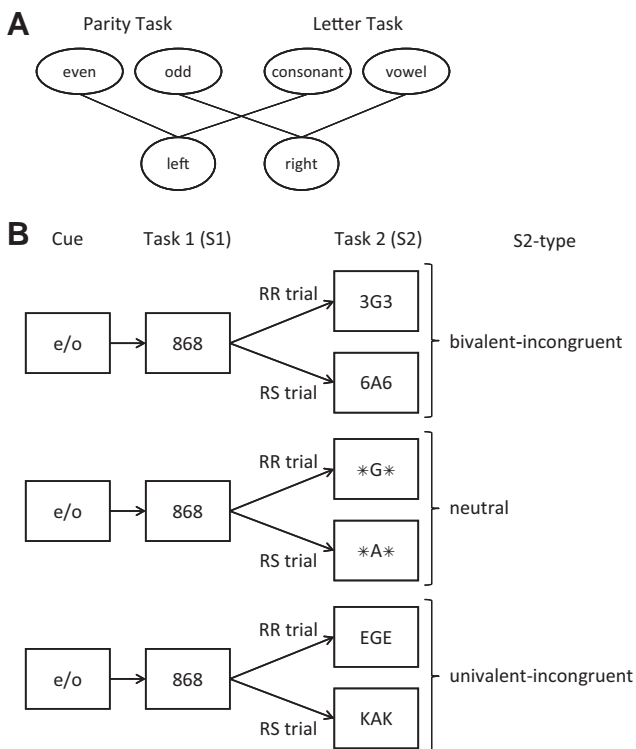
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[1] Because the relative position of the target in S2 did not significantly interact with the critical effects reported in this study—neither with the increase in RR costs for bivalent-incongruent S2 nor with RR costs in general—it was not included in the analyses of the experiments.

to one of four experimental groups: univalent/neutral, univalent/bivalent-incongruent, bivalent/neutral, and bivalent/bivalent-incongruent. The labels indicate the corresponding property of S1/S2.

Apparatus. Stimuli were presented on a 19-in. color monitor with a resolution of 1.280×768 pixels and a refresh rate of 60 Hz. A PC controlled stimulus presentation and response registration.

Stimuli. Relevant stimulus items comprised letters (G, K, R, A, E, U) and numerals (4, 6, 8, 3, 5, 7). Furthermore, there was a neutral symbol (∗) that was unrelated to any task. The stimulus arrays S1 and S2 for Task 1 and Task 2, respectively, consisted of three items. One item was displayed at the center of the screen, and the other two, identical items were presented to the left and right of the center item, respectively (cf. Figure 1B). For S1 the center item was always the target. For S2 it was determined randomly on each trial whether the center item or the flanker items were the target. This spatial uncertainty should increase difficulty of target selection and, consequently, also the relevant effects. S1 was either univalent-congruent or bivalent-congruent. S2 could be neutral or bivalent-incongruent. Neutral stimuli were constructed by using the neutral symbol as nontarget. A stimulus pattern subtended a visual angle of approximately 5.5° width and of 2.1° height. The stimuli were displayed in white on a black background.

Procedure. A trial started with the presentation of a cue for 800 ms that indicated the relevant judgment for Task 1. The cue *g/u* (abbreviation for the German words *gerade* ["even"] and *ungerade* ["odd"]), indicated the parity judgment, and the cue *k/v* (abbreviation for German words *Konsonant* ["consonant"] and *Vokal* ["vowel"]), symbolized the consonant/vowel judgment. After a blank screen lasting 200 ms, the first stimulus (S1) was presented. Stimuli remained visible until response. The stimulus S2 for Task 2 was displayed 1,500 ms after S1 or, if the response time for S1 was longer than 1,500 ms, immediately after R1. The result of a judgment had to be indicated by pressing the left ("even" and "consonant") or the right ("odd" and "vowel") button on a mouse (cf. Figure 1A). After an incorrect response a short feedback tone (500 Hz, 100 ms) was presented. The next trial started 1,000 ms after the second response. Participants were instructed to prepare for Task 1 and then to switch to the other task. They were asked to respond as fast as possible while keeping accuracy high. There were 12 blocks, each consisting of 72 trials, and the first two blocks served as training blocks and were not analyzed.

Design. As in all other experiments, response latencies to S1 (RT1) and to S2 (RT2) and corresponding error rates (ER1 and ER2, respectively) served as dependent variables. The experiment was a between-groups design with response transition (repetition, shift), S1 type (univalent, bivalent), and S2 type (neutral, bivalent-incongruent) as independent variables. There were only task-switch trials. However, due to the two-task sequence procedure, intertrial sequences were random and included both repetitions and shifts from Task 2 to Task 1. The intertrial transitions were not analyzed.

Results

RT1. On average, RT for the first stimulus (S1) was 643 ms. Mean latencies were entered into a two-way, between-groups analysis of variance (ANOVA) with the independent variables S1 type (univalent, bivalent) and S2 type (neutral, bivalent-incongruent). The difference between the two S1 types (bivalent 659 ms; univalent 627 ms) was not significant, $F(1, 44) = 0.771$, $p = .385$, as were all other effects, $Fs(1, 44) < 2$, $ps > .20$.

ER1. The mean error rate (ER) for responses to S1 was 5.14%. The difference between the two S1 types (bivalent 6.07%; univalent 4.21%) was not significant, $F(1, 44) = 2.39$, $p = .129$, as were all other effects, $Fs(1, 44) < 1$.

RT2. Trials with erroneous R1, with RT1 > 1,500 ms, or with RT larger than four standard deviations of the mean in the corresponding condition (<1.5% of all trials) were excluded from the analysis. Mean RTs were then subjected to a 2 (response transition: repetition, shift) × 2 (S1 type: univalent, bivalent) × 2 (S2 type: neutral, bivalent-incongruent) mixed ANOVA, with response transition realized within groups and S1 type and S2 type between groups.

The analysis revealed significant main effects of S2 type, $F(1, 44) = 14.1$, $p < .001$, $\eta_p^2 = .242$, and response transition, $F(1, 44) = 32.0$, $p < .001$, $\eta_p^2 = .421$. Responses were slower to bivalent-incongruent than to neutral S2 (730 ms vs. 586 ms, respectively), and RRs were slower than RSs (677 ms vs. 637 ms, respectively). Further, there was a significant two-way interaction between both variables, $F(1, 44) = 12.0$, $p < .01$, $\eta_p^2 = .215$, which indicated that RR costs were larger for bivalent-incongruent S2 (RR = 763 ms, RS = 696 ms) than for neutral S2 (RR = 594 ms, RS = 578 ms; see also Figure 2). A further test revealed that the RR costs were also reliable for neutral S2 alone, $F(1, 22) = 6.46$, $p < .05$, $\eta_p^2 = .227$. The main effect of S1 type did not reach a level of significance, $F(1, 44) = 2.79$, $p > .10$, nor did the interaction between S1 type and S2 type, $F(1, 44) < 1$. Critical to
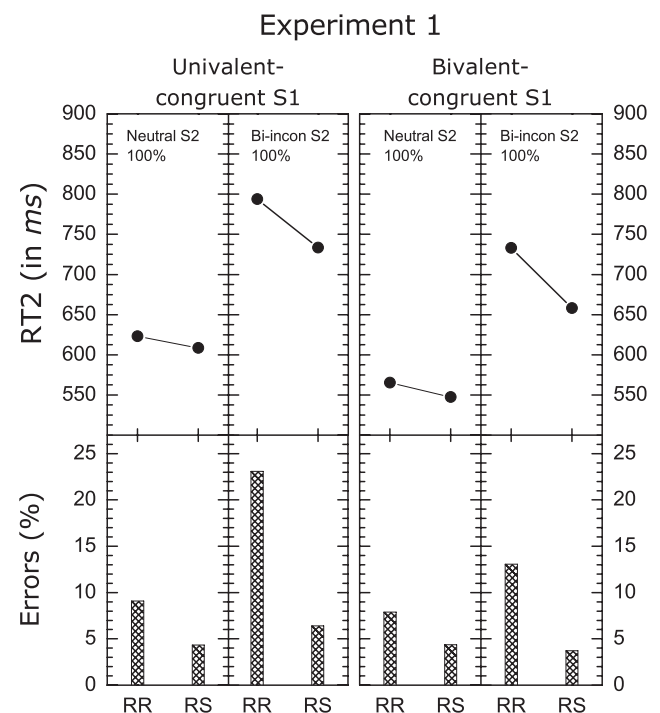

Experiment 1

Figure 2. Mean response times and errors rates in the different conditions of Experiment 1. Bi-incon S2 = bivalent-incongruent S2; RR = response repetition; RS = response shift.

the lateral inhibition hypothesis, S1 type did neither interact with response transition, nor did it modulate the interaction between response transition and S2 type, $Fs(1, 44) < 1$.

ER2. Mean ERs for responses to S2 were subjected to an ANOVA of the same type as for latencies. The analysis revealed a significant main effect of S1 type, $F(1, 44) = 5.62$, $p < .05$, $\eta_p^2 = .113$. More errors occurred after responses to univalent S1 than after responses to bivalent S1 (10.7% vs. 7.26%, respectively). The main effects of response transition, $F(1, 44) = 67.6$, $p < .001$, $\eta_p^2 = .606$, and S2 type, $F(1, 44) = 12.4$, $p < .001$, $\eta_p^2 = .219$, were significant as well. However, there was also a significant two-way interaction between both variables, $F(1, 44) = 18.2$, $p < .001$, $\eta_p^2 = .293$, indicating that the RR costs were larger for bivalent-incongruent S2 (RR = 18.1%, RS = 5.05%) than for neutral S2 (RR = 8.48%, RS = 4.36%; see Figure 2). A further test revealed that the RR costs were significant for neutral S2 alone, $F(1, 22) = 29.6$, $p < .001$, $\eta_p^2 = .573$. Critical to the lateral inhibition hypothesis, the main effect of S1 type was qualified by a significant interaction with response transition, $F(1, 44) = 4.20$, $p < .05$, $\eta_p^2 = .0872$. RR costs were larger after univalent S1 (RR = 16.1%, RS = 5.37%) than after bivalent S1 (RR = 10.5%, RS = 4.04%). Furthermore, the two-way interaction between S1 type and S2 type was marginally significant, $F(1, 44) = 3.88$, $p = .055$, $\eta_p^2 = .081$. Follow-up tests showed that more errors were made for bivalent-incongruent S2 if S1 was univalent (14.7%) than if it was bivalent (8.39%), $F(1, 44) = 5.77$, $p < .05$, $\eta_p^2 = .207$, whereas error rates did not differ for neutral S2 (univalent S1: 6.71%, bivalent S1: 6.12%), $F(1, 44) < 1$. Finally, the modulation of the two-way interaction between response transition and S2 type by S1 type failed to reach significance, $F(1, 44) = 2.15$, $p = .150$.

Discussion

The results show that RR costs occurred in all conditions. Even in the easiest condition with univalent S1 and neutral (univalent) S2 there were RR costs in RT and ER. This is in line with the idea that responses are generally inhibited after their execution. In addition, it is also obvious that the RR costs varied with both S1 and S2 type.

First, RR costs in ER were larger for univalent than for bivalent S1. This outcome is opposite to what would be expected from lateral inhibition of category-response rules. However, the result is compatible with the idea that the size of response inhibition depends on the activation strength of the previous response (e.g., Druey & Hübner, 2008b). One could make the reasonable assumption that univalent S1 activated the correct response stronger than did bivalent ones, because the irrelevant items in the latter stimuli could be filtered out by their category (number or letter). Then, response inhibition should have been stronger after univalent S1 than after bivalent S1, which explains the difference in RR costs.[2]

Second, RR costs were considerably larger for bivalent-incongruent S2 than for neutral ones. This result could be explained by top-down processes. Because bivalent-incongruent S2 increased the global risk of perseveration, it is conceivable that participants in the groups with bivalent-incongruent S2 (univalent/bivalent-incongruent group and bivalent/bivalent-incongruent group) deliberately increased the inhibition of the last response (Hübner & Druey, 2006). However, it is also conceivable that

bottom-up processes were responsible for the difference in RR costs. Which account is valid was tested in the next experiment.

Experiment 2

If bivalent-incongruent S2 produced large RR costs in the previous experiment, because they increased the global risk of perseveration, which, in turn, was counterbalanced by a top-down controlled increase in response inhibition, then one should expect reduced RR costs in blocks with a smaller proportion of bivalent-incongruent stimuli. Whether this prediction holds was tested in the present experiment by randomly mixing neutral S2 and bivalent-incongruent S2 within each block of trials, so that their proportion was 50%. If response inhibition is indeed adapted according to the global risk of perseveration, then this mixing should produce distinct results. Relative to the previous experiment, RR costs should be smaller for bivalent-incongruent S2 but larger for neutral S2. That is, the difference in RR costs between the two stimulus types should be considerably reduced. Alternatively, if bottom-up mechanisms are responsible for RR costs, then the results should be similar to those in the previous experiment.

Method

Participants. Twenty-nine students (nine male; mean age = 22 years) of the Universität Konstanz participated in the experiment. All had normal or corrected-to-normal vision and either were paid 5 € per hour or fulfilled a course requirement.

Stimuli and procedure. The stimuli and procedure were similar to those of Experiment 1 with the exception that there were three neutral symbols (∗, %, &).

Design. Unlike in Experiment 1, this time S1 was always univalent-congruent. Moreover, S2 type was randomized across trials, resulting in a 2 (S2 type: neutral, bivalent-incongruent) × 2 (response transition: repetition, shift) within-subject design.

Results

RT1. The mean RT for the first stimulus was 578 ms.
ER1. The mean ER for responses to S1 was 2.86%.
RT2. Trials with erroneous R1, with RT1 > 1,500 ms, or with RT larger than four standard deviations of the mean in the corresponding condition (<1.5% of all trials) were excluded from the analysis. Mean latencies of correct R2 were analyzed with a 2 (response transition: repetition, shift) × (S2 type: neutral, bivalent-incongruent) repeated-measures ANOVA.

The analysis revealed significant main effects of S2 type, $F(1, 28) = 90.6$, $p < .001$, $\eta_p^2 = .764$, and response transition, $F(1,$

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[2] Another possible interpretation of this result is that compared with the bivalent/bivalent-incongruent group, the univalent/bivalent-incongruent group had difficulties controlling the response conflict induced by bivalent-incongruent S2. This is indicated by the marginal interaction between S1 type and S2 type in the error rates. If response conflict in the univalent/bivalent-incongruent group was indeed larger than in the bivalent/bivalent-incongruent group, then we would also expect larger RR costs in the former group due to an amplification of response conflict (ARC) as will be explained in more detail in the discussion of Experiment 2. In fact, in ER2 of the univalent/bivalent-incongruent group there was a trend toward such an interaction, $F(1, 44) = 3.56$, $p = .072$, $\eta_p^2 = .14$.

28) = 39.4, $p < .001$, $\eta_p^2 = .584$. However, there was also a significant two-way interaction between the two variables, $F(1, 28) = 15.0$, $p < .001$, $\eta_p^2 = .348$, indicating that the RR costs were larger for bivalent-incongruent S2 (RR = 783 ms, RS = 709 ms) than for neutral S2 (RR = 641 ms, RS = 608 ms; see also Figure 2). The costs were also significant for neutral S2 alone, $F(1, 28) = 28.6$, $p < .001$, $\eta_p^2 = .505$.

ER2. Mean ERs were subjected to an ANOVA of the same type as for the latencies. The analysis revealed a significant main effect of response transition, $F(1, 28) = 75.8$, $p < .001$, $\eta_p^2 = .729$, and S2 type, $F(1, 28) = 75.4$, $p < .001$, $\eta_p^2 = .730$. These effects were qualified by a significant two-way interaction between both variables, $F(1, 28) = 50.1$, $p < .001$, $\eta_p^2 = .642$, indicating that the RR costs were larger for bivalent-incongruent S2 (RR = 16.5%, RS = 4.96%) than for neutral S2 (RR = 4.59%, RS = 1.97%; see also Figure 2). The costs were also significant for the neutral S2 alone, $F(1, 28) = 15.2$, $p < .001$, $\eta_p^2 = .352$.

Discussion

Although neutral and bivalent-incongruent S2 were randomly mixed in this experiment, RR costs for the two S2 types differed almost as much (41 ms; 8.88%) as in the previous experiment (51 ms; 8.98%), where S2 type was blocked.[3] For simplification we call the effect of larger RR costs for bivalent-incongruent S2 than for neutral S2 *increase in RR costs*. The result that the increase in RR costs was independent of the proportion of the two S2 types contradicts the hypothesis that response inhibition was strategically adapted by top-down mechanisms to the global risk of perseveration. Rather, it suggests that a large part of the increase in RR costs stemmed from bottom-up mechanisms. But how can bottom-up processes affect the size of RR costs within a trial? A possible mechanism is that a general RS bias amplifies response conflict on RR trials compared with RS trials. Accordingly, we call this explanation of the increase in RR costs the amplification of response conflict (ARC).

Applying the ARC idea to the inhibition account would mean that the self-inhibition of the last response modulates the interference between the responses. If, for example (see also Figure 1), a consonant (with odd numerals as nontarget items; e.g., "3G3") is presented as a target item in Task 2 requiring a *left* response, then, on an RR trial, an even numeral has been displayed as a target item in Task 1, which also required a *left* response. Therefore, response selection is difficult on Task 2, because the correct *left* response is inhibited. The nontarget item, however, activates the competing uninhibited *right* response. Thus, compared with a situation with uninhibited responses, the self-inhibition of the last response would increase the response conflict. In contrast, if an odd numeral was presented as S1, then responding to the consonant in Task 2 implies an RS. Because the *right* response is inhibited in this case, the target item of S2 activates the uninhibited *left* response, while the nontarget item activates the inhibited *right* response. Thus, for an RS self-inhibition would reduce the response conflict, relative to a situation with uninhibited responses. Together, the increased congruency effect on RR trials and the reduced congruency effect on RS trials result in an increase in RR costs for bivalent-incongruent S2 compared with neutral S2. This ARC account was tested in the next experiment.

Experiment 3

If the observed increase in RR costs was the result of an interaction between response conflict and the basic mechanism producing an RS bias, then the increase should be more pronounced in conditions where the bias is larger. We tested this prediction in the present experiment by means of the previous-trial congruency effect (i.e., by the fact that RR costs are larger after a congruent than after an incongruent stimulus on the previous trial; Altmann, 2011; Druey & Hübner, 2008b; Grzyb & Hübner, 2012b; Hübner & Druey, 2006). The inhibition account explains this effect by assuming that the size of response inhibition depends on the activation of the previous response (Grzyb & Hübner, 2012b). Because congruent stimuli produce stronger activation than do incongruent ones, response inhibition and, consequently, the RS bias should be larger after a congruent than after an incongruent S1. Moreover, the amplification of an S2-induced response conflict and the corresponding RR costs should vary accordingly.

The error rates in Experiment 1 already showed a weak tendency toward such a modulation. However, because the potential of activating responses differs only slightly between univalent-congruent and bivalent-congruent S1, the difference in RS bias was relatively small. Moreover, because of the between-subjects design, statistical power was low to detect such a high-order interaction. Therefore, to test our prediction more strictly, we used a stronger modulation of the RS bias than in Experiment 1 by presenting univalent-congruent and univalent-incongruent S1. Using only univalent S1 had also the advantage that it controls for sequential influences of so-called competitor-rule suppression (e.g., Meiran, Hsieh, & Dimov, 2010).

First of all, we expected to again observe an increase in RR costs for bivalent-incongruent S2. Moreover, there should be a reliable previous-trial congruency effect (i.e., RR costs should be larger after univalent-congruent S1 than after univalent-incongruent S1). Given these two basic effects, then according to the ARC account, both effects should interact, resulting in a three-way interaction between S1 congruency, response transition, and S2 type. This modulation of the increase in RR costs by previous-trial congruency would allow us to assess whether the increase is mainly due to ARC on RR trials or also due to reduced response conflict on RS trials.

Method

Participants. Forty-four persons with normal or corrected-to-normal vision completed the experiment. All participants were students of the Universität Konstanz and were paid 8 € per hour.

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[3] A direct statistical comparison of the magnitude of the interaction is not possible, because S2 type was manipulated between participants in Experiment 1 and within participant in Experiment 2. Separate ANOVAs computed for the individual S2 types to compare Experiment 2 with the univalent groups of Experiment 1 revealed only trends. In RT2 the RR costs for neutral S2 in Experiment 2 were marginally larger than in the univalent/neutral group, $F(1, 39) = 2.89$, $p = .097$. However, in ER2 the RR costs were marginally smaller in Experiment 2, $F(1, 39) = 2.86$, $p = .099$. For bivalent-incongruent S2, the RR costs did not differ between experiments in RT2, $F(1, 39) = 0.33$, $p = .57$, and they were only marginally smaller in Experiment 2 than in the univalent/bivalent-incongruent group, $F(1, 39) = 3.86$, $p = .057$.

Data of three participants had to be excluded from the analysis because of exceptionally high mean response times or error rates.[4] The final sample included 41 persons (12 male; mean age = 23.1 years).

Stimuli, procedure, and design. Apparatus, stimuli, and procedure were similar to those in Experiment 2. However, in addition to univalent-congruent S1, univalent-incongruent S1 stimuli were presented as well. Thus, S1 always consisted of three items of the same item category (either letters or numerals) that were related to only one task. In this experiment, participants completed 14 blocks, each consisting of 64 trials. The first three blocks were declared as practice blocks and not analyzed. S1 congruency and S2 type were randomized across trials, resulting in a 2 (S1 congruency: univalent-congruent, univalent-incongruent) × 2 (S2 type: neutral, bivalent-incongruent) × 2 (response transition: repetition, shift) within-subject design.

Results

As before, trials with RT1 > 1,500 ms were excluded from the analysis. Also, for every condition trials with response times larger than four standard deviations of the mean were excluded (<1.5% of all trials).

RT1. The mean RTs of correct responses were entered into a repeated-measures ANOVA with the independent variable S1 congruency (univalent-congruent, univalent-incongruent).

The effect of S1 congruency was significant, $F(1, 40) = 92.1$, $p < .001$, $\eta_p^2 = .697$. Responses to univalent-incongruent S1 (635 ms) were slower than those to univalent-congruent S1 (593 ms).

ER1. The means of ERs were subjected to an ANOVA of the same type as for the latencies. The effect in the ERs mirrored the RT data, $F(1, 40) = 106$, $p < .001$, $\eta_p^2 = .725$. Responses to univalent-incongruent S1 (7.82%) led to more errors than did responses to univalent-congruent S1 (4.38%).

RT2. Trials with erroneous responses to S1 were excluded from the analysis. The mean latencies of correct R2 were entered into a repeated-measures 2 (S1 congruency: univalent-congruent, univalent-incongruent) × 2 (S2 type: neutral, bivalent-incongruent) × 2 (response transition: repetition, shift) ANOVA. The analysis revealed significant effects of S1 congruency, $F(1, 40) = 11.7$, $p < .01$, $\eta_p^2 = .227$, S2 type, $F(1, 40) = 131$, $p < .001$, $\eta_p^2 = .766$, and response transition, $F(1, 40) = 23.4$, $p < .001$, $\eta_p^2 = .369$. These main effects were qualified by two two-way interactions with response transition. First, the interaction of S1 congruency and response transition, $F(1, 40) = 5.02$, $p < .05$, $\eta_p^2 = .111$, showed that RR costs were larger after univalent-congruent S1 (49 ms) than after univalent-incongruent S1 (28 ms). Second, the Response Transition × S2 Type interaction, $F(1, 40) = 8.74$, $p < .01$, $\eta_p^2 = .179$, disclosed an increase in RR costs when S2 was bivalent-incongruent (53 ms) compared with when it was neutral (26 ms). The interaction between S1 congruency and S2 type was not significant, $F(1, 40) = 1.95$, $p = .17$. Finally, the critical three-way interaction was also significant, $F(1, 40) = 4.60$, $p < .05$, $\eta_p^2 = .103$. We analyzed this interaction further in separate ANOVAs for each S1 type. These calculations revealed that the increase in RR costs was not reliable after univalent-incongruent S1 (see the left panel in Figure 3: neutral S2: 23 ms, bivalent-incongruent S2: 34 ms), $F(1, 40) = 1.76$, $p = .192$, $\eta_p^2 = .042$, whereas the increase in RR costs was significant after
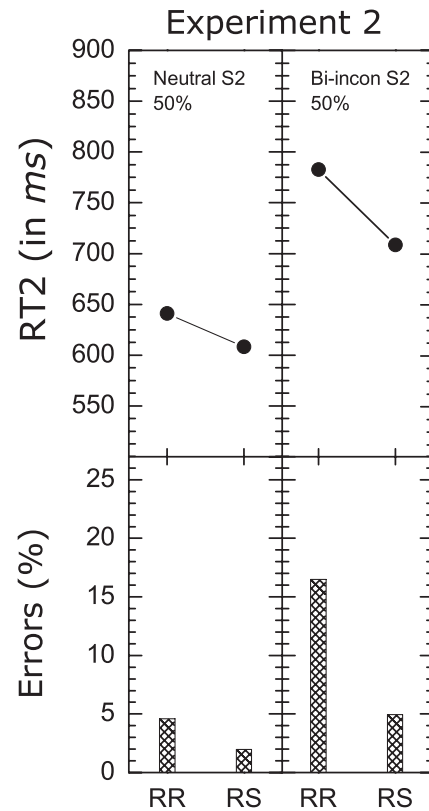
univalent-congruent S1 (see the right panel in Figure 3, neutral S2: 29 ms, bivalent-incongruent S2: 71 ms), $F(1, 40) = 9.76$, $p < .01$, $\eta_p^2 = .196$.

Additionally, we calculated *t* tests for the difference between mean response times after univalent-congruent S1 versus after univalent-incongruent S1 to bivalent-incongruent S2 on RR trials and the corresponding difference on RS trials. The difference was significant on RR trials (univalent-congruent S1: 771 ms, univalent-incongruent S1: 734 ms), $t(40) = 3.14$, $p < .01$. The corresponding difference on RS trials was zero (univalent-congruent and univalent-incongruent S1: 700 ms). Parallel *t* tests for neutral S2 on the effect of S1 congruency were not significant ($ps > .33$).

ER2. Again, trials with erroneous responses to S1 were excluded from the analysis. The means of ERs for responses to S2 were entered into an ANOVA of the same type as for the latencies of R2. The analysis revealed significant effects of S1 congruency, $F(1, 40) = 14.1$, $p < .001$, $\eta_p^2 = .261$; S2 type, $F(1, 40) = 146$, $p < .001$, $\eta_p^2 = .785$; and response transition, $F(1, 40) = 106$, $p < .001$, $\eta_p^2 = .726$. These main effects were qualified by three two-way interactions. First, S1 congruency and S2 type interacted significantly, $F(1, 40) = 9.70$, $p < .01$, $\eta_p^2 = .195$. Second, the

Figure 3. Mean response times and errors rates in the different conditions of Experiment 2. Bi-incon S2 = bivalent-incongruent S2; RR = response repetition; RS = response shift.

[4] Outliers were identified with box plots. The criterion for bad performance was two standard deviations above the group mean (RT1 > 1,292 ms, ER1 > 10.3%, RT2 > 1,185 ms, ER2 > 11.9%).

interaction between S1 congruency and response transition was significant, $F(1, 40) = 29.2$, $p < .001$, $\eta_p^2 = .423$. Third, the interaction between S2 type and response transition was also significant, $F(1, 40) = 65.4$, $p < .001$, $\eta_p^2 = .620$. Most important, however, was the significant three-way interaction of all factors, $F(1, 40) = 6.15$, $p < .05$, $\eta_p^2 = .133$. The three-way interaction indicated that the increase in RR costs was larger after univalent-congruent S1 (see the right panel in Figure 4: neutral S2: 4.06%, bivalent-incongruent S2: 14.0%), $F(1, 40) = 53.0$, $p < .001$, $\eta_p^2 = .570$, than after univalent-incongruent S1 (see the left panel in Figure 4: neutral S2: 2.11%, bivalent-incongruent S2: 9.00%), $F(1, 40) = 44.7$, $p < .001$, $\eta_p^2 = .528$.

Again, we calculated t tests for the difference between mean ERs after univalent-congruent S1 versus after univalent-incongruent S1 for bivalent-incongruent S2 on RR trials and the corresponding difference on RS trials. The difference was significant on RR trials (univalent-congruent S1: 20.4%, univalent-incongruent S1: 15.7%), $t(40) = 5.14$, $p < .001$, but not on RS trials even though the direction of the difference was as predicted (univalent-congruent S1: 6.34%, univalent-incongruent S1: 6.65%; $p = .62$). Parallel t tests for neutral S2 on the effect of S1 congruency showed that on RR trials error rates were significantly larger after univalent-congruent S1 than after univalent-incongruent S1 (univalent-congruent S1: 6.49%, univalent-incongruent S1: 5.44%), $t(40) = 2.51$, $p < .05$, whereas on RS trials there was a trend showing a decrease in error rates after univalent-congruent S1 (univalent-congruent S1: 2.43%, univalent-incongruent S1: 3.33%), $t(40) = 1.89$, $p = .065$.

Figure 4. Mean response times and errors rates in the different conditions of Experiment 3. Bi-incon S2 = bivalent-incongruent S2; RR = response repetition; RS = response shift.

Discussion

Our data clearly show that the increase in RR costs for bivalent-incongruent S2 was modulated by the previous-trial congruency effect. It was larger after univalent-congruent S1 than after univalent-incongruent S1. This supports the ARC hypothesis (i.e., the idea that the basic mechanism that produces an RS bias in task switching also affects the response conflict on S2). More specifically, we found a distinct pattern of S1 congruency for RR and RS trials. Whereas the previous-trial congruency effect was reliable on RR trials, it was reversed or absent on RS trials. Similar results have also been reported elsewhere (Altmann, 2011), a fact to which we come back in the General Discussion. This asymmetry of the effect on RR and RS trials indicates that the increase in RR costs is largely a consequence of impaired performance on RR trials and to a lesser extent of improved performance on RS trials.

Importantly, our findings also suggest that the large RR costs typically found for bivalent stimuli are a consequence of the interaction between several bottom-up processes and not—as initially proposed—the result of a strategic adaptation of response inhibition to the global risk of perseveration.

Another important result of the present experiment was that a previous-trial congruency effect on RR costs was also found in ER2 for neutral S2. To our knowledge, this is the first time this has been observed. In previous studies the previous-trial congruency effect was assessed either by averaging across bivalent-congruent and bivalent-incongruent trials (Altmann, 2011; Druey & Hübner, 2008b; Koch et al., 2011), or by merely considering bivalent-incongruent trials (Altmann, 2011; Grzyb & Hübner, 2012b). Therefore, one might have argued that the origin of this effect is not the modulation of response inhibition but rather conflict adaptation (Brown, Reynolds, & Braver, 2007). The conflict adaptation account assumes that the control settings of the system are dynamically adjusted. After the detection of a conflict, control is increased (e.g., by focusing attention) in order to reduce subsequent conflicts (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Applied to our data, RR costs for bivalent-incongruent S2 could have been smaller after univalent-incongruent S1, because response conflict was weaker after conflict adaptation. However, it is hard to see how conflict adaptation could have modulated the processing of neutral S2 in such a way that a constant degree of response inhibition would lead to varying RR effects. Moreover, on RS trials ERs for neutral S2 tended to be smaller after univalent-congruent S1 than after univalent-incongruent S1. This reversed effect of S1 congruency on RS trials cannot easily be explained by conflict adaptation.

So far, we have found an increase in RR costs for between-subjects as well as within-subject manipulations. The effect was further modulated by S1 congruency. This phenomenon can be explained by our ARC account. The results show that the interference between responses induced by bivalent-incongruent S2 is increased, if the previous response has to be repeated. If the previous response has to be shifted, the response conflict is unchanged or even slightly reduced. However, according to the ARC account the bivalency of S2 is not necessary to produce an increase in RR costs. Rather, incongruency alone should suffice. This assumption was tested in the next experiment.

Experiment 4

To test whether the increase in RR costs in the previous experiments was mainly the result of an interaction between response
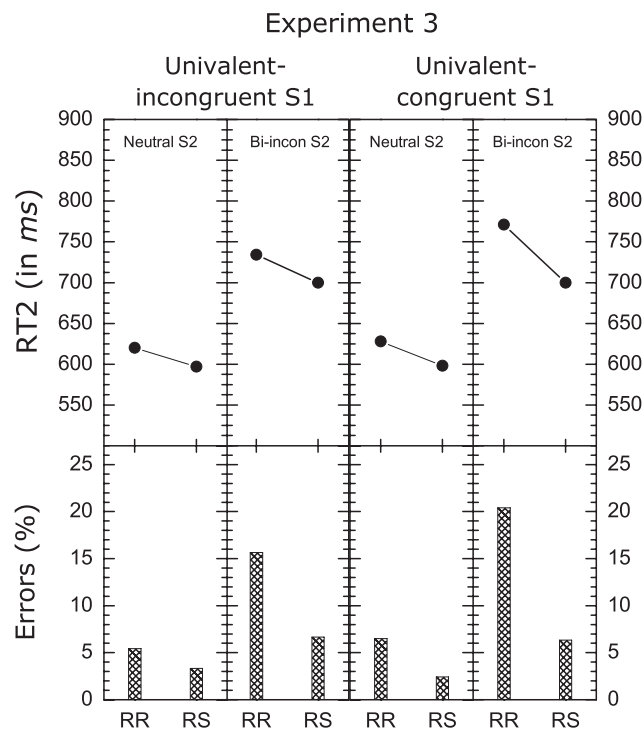
inhibition and response conflict and not due to bivalency, we replicated Experiment 2. However, we replaced the bivalent-incongruent S2 by univalent-incongruent ones. These stimuli activate the correct and the wrong response via the same task. Because it was no longer possible with these univalent stimuli to select the target item on the basis of its category (numerals or letters), we always presented the target item of S2 in the center of the stimulus array. Consequently, spatial attention could now be used to select the target, which, unfortunately, should reduce the congruency effect compared with the previous experiments. This should also result in a smaller increase in RR costs, because, according to the ARC account, its magnitude also depends on the size of the response conflict induced by S2. In any case, we expected to find a reliable, even if small, increase in RR costs.

Method

Participants. Fifteen students (five male; mean age = 23.2 years) of the Universität Konstanz participated in the experiment. All participants had normal or corrected-to-normal vision and either were paid 5 € per hour or fulfilled a course requirement.

Stimuli, procedure, and design. The experimental design was as in Experiment 2. Also, the stimuli and procedure were kept as close as possible to those in Experiment 2. However, univalent-incongruent S2 were used, and the target item was always presented in the center of the array. Univalent-incongruent S2 were constructed using flankers of the same item category as the target item (i.e., letters or numerals, respectively). Participants were instructed to respond always to the center item of S2.

Results

Again, trials with RT1 > 1,500 ms or with RT larger than four standard deviations of the mean in the corresponding condition (<1.5% of all trials) were excluded from the analysis.

RT1. The mean RT for the first stimulus was 561 ms.

ER1. The mean ER for responses to S1 was 4.30%.

RT2. Trials with erroneous R1 were excluded. A 2 (response transition: repetition, shift) × 2 (S2 congruency: neutral, univalent-incongruent) repeated-measures ANOVA was calculated on the mean latencies of correct R2.

The analysis revealed significant main effects of S2 congruency, $F(1, 14) = 29.4$, $p < .001$, $\eta_p^2 = .677$, and response transition, $F(1, 14) = 10.4$, $p < .01$, $\eta_p^2 = .427$. The interaction between both variables was null, $F(1, 14) < .001$. RR costs were virtually the same after neutral S2 (RR = 589 ms, RS = 569 ms) and after univalent-incongruent S2 (RR = 613 ms, RS = 592 ms; see also Figure 5).

ER2. Mean ERs were subjected to an ANOVA of the same type as for the latencies. The analysis revealed a significant main effect of response transition, $F(1, 14) = 20.7$, $p < .001$, $\eta_p^2 = .597$, and S2 congruency, $F(1, 14) = 17.0$, $p < .01$, $\eta_p^2 = .548$. These effects were qualified by a significant two-way interaction, $F(1, 14) = 9.24$, $p < .01$, $\eta_p^2 = .397$, indicating that RR costs were larger for univalent-incongruent S2 (RR = 11.5%, RS = 5.67%) than for neutral S2 (RR = 8.03%, RS = 4.05%; see also Figure 5). The effect of S2 congruency was also significant on RS trials alone, $F(1, 14) = 8.15$, $p < .05$, $\eta_p^2 = .413$.
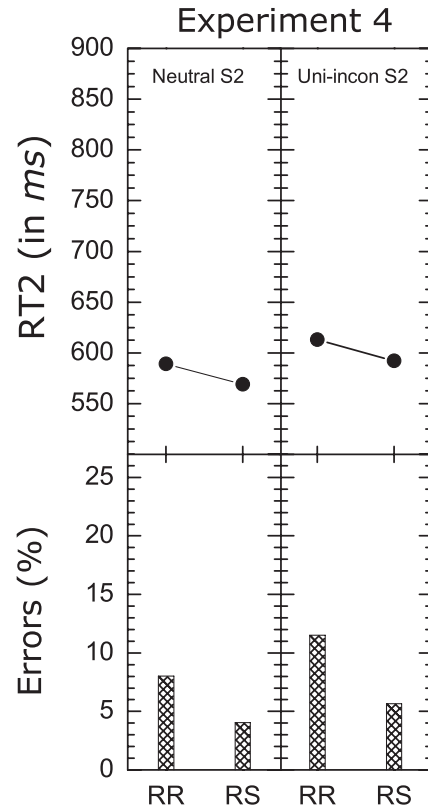

Figure 5. Mean response times and errors rates in the different conditions of Experiment 4. Uni-incon S2 = univalent-incongruent S2; RR = response repetition; RS = response shift.

Discussion

In this experiment the congruency of S2 was not confounded with bivalency. Nonetheless, we found a reliable increase in RR costs in ER. This indicates that incongruency alone is sufficient to produce this effect. Thus, the result is in line with our assumption that a large part of RR costs is produced by bottom-up mechanisms, namely, self-inhibition of the previous response and stimulus-triggered response conflict. The pure impact of response inhibition can be estimated by comparing RR costs for neutral S2.[5] In Experiment 2 these costs were similar to those in the present experiment (difference in RT and ER: Fs < 1.55, ps > .22). Yet, RR costs for the univalent-incongruent S2 in the present experiment were smaller than those for the bivalent-incongruent S2 in Experiment 2 in RT (21 ms vs. 74 ms, respectively), $F(1, 42) = 8.12$, $p < .01$, $\eta_p^2 = .162$, and in ER (5.83% vs. 11.54%, respectively), $F(1, 42) = 8.20$, $p < .01$, $\eta_p^2 = .163$. This difference is also reflected in the smaller increase in RR costs in the present experiment, RT: $F(1, 42) = 6.79$, $p < .05$, $\eta_p^2 = .139$; ER: $F(1, 42) = 15.2$, $p < .001$, $\eta_p^2 = .266$.

As expected, the congruency effect was also small, because spatial attention could be used to select the target item in S2. In

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[5] As Experiment 3 indicated that response inhibition not only hinders RR but also slightly facilitates RS, RR costs for neutral S2 overestimate the size of response inhibition.

fact, the congruency effect (RT: 23 ms; ER: 2.55%) was only about a fifth to a third of that in Experiment 2 (RT: 122 ms; ER: 7.45%).[6] Thus, according to ARC, the increase in RR costs was smaller in Experiment 4 mainly because the response conflict was smaller. However, part of the congruency effect might also have been due to priming of the currently irrelevant task set by the nontarget item of S2 (e.g., Steinhauser & Hübner, 2007) in Experiment 2. Therefore, we cannot fully exclude that some interference caused by bivalency also increased the magnitude of RR costs.

General Discussion

The aim of the present study was to investigate whether top-down or bottom-up mechanisms, or even both, can account for observed modulations of RR costs in task switching (e.g., Kleinsorge & Heuer, 1999; Rogers & Monsell, 1995; Schuch & Koch, 2004). Of special interest was the phenomenon that RR costs are larger for bivalent than for univalent stimuli. Initially we hypothesized that bivalent stimuli increase the global risk of perseveration and that, therefore, top-down processes increase response inhibition (Druey & Hübner, 2008b; Hübner & Druey, 2006). In our first two experiments, we tested this hypothesis by varying the proportion of neutral and bivalent-incongruent stimuli. As expected, RR costs were substantially larger for bivalent-incongruent stimuli than for neutral ones (see Table 2). However, this effect did not depend on the proportion of the stimulus types, which suggested that it was mainly produced by bottom-up processes.

As a possible mechanism for explaining the increase in RR costs, we proposed the amplification of response conflict (ARC). According to this account, response conflict resulting from the processing of an incongruent stimulus is amplified by the same mechanism that produces the basic RR costs. If one assumes, for instance, that self-inhibition of the last response is responsible for the basic RR costs, then the response conflict induced by an incongruent stimulus would be amplified by that inhibition on RR trials but not on RS trials.

The results of Experiments 3 and 4 provide further evidence in favor of the ARC account. The increase in RR costs was modulated by the congruency of the stimulus on the previous trial (S1 congruency, Experiment 3), which is known to affect the basic RR costs (Druey & Hübner, 2008b; Grzyb & Hübner, 2012b; Hübner & Druey, 2006). Thus, a larger basic effect also produced a larger increase in RR costs, as expected. These results suggest that the interaction of several bottom-up processes produces the large RR costs typically observed with bivalent stimuli.

According to the ARC idea, incongruency rather than bivalency is the crucial stimulus property of S2. The results of Experiment 4 show that incongruency alone is indeed sufficient for an increase in RR costs, which indicates that a large part of the increase in RR costs for bivalent-incongruent stimuli in the other experiments was due to incongruency and the corresponding response conflict. Interestingly, the response conflict induced by bivalent-incongruent stimuli usually affects ER much stronger than RT (e.g., Rogers & Monsell, 1995). Thus, the finding that RR costs are more stable in ER (Altmann, 2011) might be explained by a more stable ARC in ER.

Because the present study was motivated by the response-inhibition idea, we have interpreted our results mainly in terms of

this account. However, the results are also relevant for alternatives accounts of the origin of RR costs in task switching. In the next section, we briefly describe these alternative ideas and discuss to what extent they can also explain the present results.

Implications for Theories on RR Costs in Task Switching

Of the various alternative accounts of RR costs in task switching (e.g., Rogers & Monsell, 1995), we discuss only the most important ones, the *hierarchical switching*, the *strengthening*, and the *episodic retrieval* account. We evaluate how far they can explain the increase in RR costs and the previous-trial congruency effect. The results of these evaluations are summarized in Table 3.

Hierarchical switching. The hierarchical switching account assumes that task structures are mentally represented in a hierarchical form. A switch to a new task at a high level of representation (e.g., the intended judgment) also leads to a switch signal that propagates downstream to subordinate levels including the response level (Kleinsorge & Heuer, 1999). Thus, a switch at any higher level leads to an RS bias at the motor level (Kleinsorge, 1999). Similar to the response inhibition idea, the RS bias is thought to be adaptive because it protects the system against perseveration. If the same response is required again, however, a reswitch is necessary at the response level, which produces RR costs. On task-repetition trials, though, RR requires fewer switch operations, resulting in RR benefits.

With respect to the increase in RR costs, hierarchical switching makes the same predictions as does response inhibition, because it generally assumes an RS bias on task-switch trials. However, this account cannot explain the previous-trial congruency effect, because the proposed switch mechanisms are independent of the previous trial.

Strengthening. The strengthening account is based on learning category-response (C-R) rules (see e.g., Meiran, 2000a, 2000b). After the selection of a response with a C-R rule, this rule is strengthened, while the alternative rule is weakened. Thus, on task-repetition trials, RR produces a benefit because of the strengthened C-R rule. In case of a task switch, however, an RR implies that the response has to be selected with the weakened C-R rule, which explains the RR costs (compare Figure 1A). Similarly, Schuch and Koch (2004) assumed that the meaning of a response changes with the task. For instance, the response (e.g., pushing a *left* button) that means "even" for the parity task could mean "consonant" for the letter judgment. Such a change of meaning is thought to increase the difficulty of response selection, which could explain RR costs under task switching.

The strengthening account predicts that the strengthening and weakening of C-R rules amplifies the response conflict triggered by bivalent-incongruent stimuli on both RR and RS trials and, therefore, cannot account for the increase in RR costs. Response conflict is increased on RR trials because the C-R rule that is

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[6] The congruency effect was smaller in Experiment 4 than in Experiment 2 for both levels of response transition; that is, on RR trials, RT: $F(1, 42) = 29.9, p < .001, \eta_p^2 = .416$; ER: $F(1, 42) = 16.5, p < .001, \eta_p^2 = .282$, and on RS trials, RT: $F(1, 42) = 20.0, p < .001, \eta_p^2 = .322$; ER: $F(1, 42) = 3.20, p = .08, \eta_p^2 = .071$. This was reflected in the ordinal three-way interaction Experiment × S2 Congruency × Response Transition.

Table 2
Overview of Experiments

Experimental group	Stimulus type		RR costs		Increase in RR costs	
	S1	S2	RT (ms)	ER (%)	RT (ms)	ER (%)
Experiment 1						
Uni/neutral	Uni-con	Neutral	14	4.73**	47[†]	12.0***
Uni/bi-incon	Uni-con	Bi-incon	61*	16.7***		
Bi/neutral	Bi-con	Neutral	18[†]	3.51**	57**	5.86[†]
Bi/bi-incon	Bi-con	Bi-incon	75***	9.37**		
Experiment 2	Uni-con	Neutral	33***	2.62***	41***	8.88***
		Bi-incon	74***	11.5***		
Experiment 3	Uni-con	Neutral	29**	4.06***	42**	9.94***
		Bi-incon	71***	14.0***		
	Uni-incon	Neutral	23**	2.11**	11	6.89***
		Bi-incon	34**	9.00***		
Experiment 4	Uni-con	Neutral	20**	3.98***	1	1.85**
		Uni-incon	21**	5.83***		

Note. Stimulus types were manipulated within-participant. Response repetition (RR) costs are calculated as response repetition minus response shift, and the increase in RR costs as the RR costs for incongruent S2 minus RR costs for neutral S2. S1 = stimulus of the first task in the two-task sequence; S2 = stimulus of the second task; RT = reaction time; ER = error rate; Uni = univalent; Uni-con = univalent congruent; Uni-incon = univalent-incongruent; Bi = bivalent; Bi-incon = bivalent-incongruent; Bi-con = bivalent-congruent.
[†] $p < .10$.   * $p < .05$.   ** $p < .01$.   *** $p < .001$.

target-related was weakened, and on RS trials, because the C-R rule that is nontarget-related was strengthened. However, with the additional assumption that a weakening of the target-related C-R rule has a larger impact on response conflict than a strengthening of the C-R rule that is related to the nontarget, the disadvantage for the correct response would be larger on RR trials, which would account for the increase in RR costs at least for bivalent-incongruent S2. Yet, the previous-trial congruency effect cannot be explained by this account, because the strengthening and weakening of C-R rules is independent of the previous trial.

Episodic retrieval.   An idea closely related to strengthening is episodic retrieval (Altmann, 2011). This account assumes that not only a repeating stimulus but any repeating feature, including a

response, serves as a cue for the episodic trace of the previous task performance. Benefits or costs arise because the retrieved episode matches or mismatches the present episode (see also Hommel, Müsseler, Aschersleben, & Prinz, 2001). Costs are assumed to be particularly large when there is a partial mismatch. Thus, if on task-switch trials the response switches as well, then no feature of the previous task does interfere. However, if the response repeats, then the features of the old task are retrieved and partially interfere with the features of the new task, which impairs performance.

The prediction of the episodic retrieval account for our paradigm is less clear, because it is open which features of the tasks are relevant for episodic (mis-)match (e.g., Marí-Beffa et al., 2012). From a conservative perspective, one could reason that at least on RR trials the only feature that repeats from Task 1 to Task 2 is the response.

Table 3
Predictions of Different Accounts Related to Response Conflict, RR Costs, and Previous-Trial Congruency Effect

Account	Response transition	Prediction		
		Response conflict (bivalent-incongruent S2 vs. neutral S2)	Increase in RR costs	Previous-trial congruency effect
Response inhibition	RR	Increase	✓	✓
	RS	Decrease		✓
Hierarchical switching	RR	Increase	✓	—
	RS	Decrease		—
Strengthening	RR	Increase	— / ✓[a]	—
	RS	Increase[a]		—
Episodic retrieval	RR	No change	—	✓
	RS	Increase		—

Note. S2 = stimulus of the second task; RR = response repetition; RS = response shift; ✓ = prediction confirmed by present results; — = account does not predict the observed effect.
[a] Might also predict a reduced effect on RS trials. For details see text.

Therefore, the mismatch would be the same for trials with neutral S2 and for trials with bivalent-incongruent S2. As a consequence, there should be no effect of S2 type on RR trials due to retrieval processes. On RS trials, however, the situation is different if the nontarget item is conceptualized as a feature of the integrated episode. Because, on average, in one third of the RS trials the target item of univalent-congruent S1 repeats as nontarget item of S2, the mean retrieval interference on RS trials would be, if anything, slightly larger for bivalent-incongruent S2 than for neutral S2. In sum, the predictions for RS and RR trials would result in similar or reduced RR costs for bivalent-incongruent S2 compared with neutral S2. Thus, episodic retrieval cannot account for the increase in RR costs. However, it can account for the previous-trial congruency effect with the additional assumption that an extra association for congruent stimuli increases the interference between episodes on an RR trial when the task switches (see Altman, 2011). However, on RS trials the account predicts that "there should be no effect of previous-trial congruency" (Altmann, 2011, p. 948).

Taken together, the reconfiguration account, the strengthening account, and the inhibition account can explain the increase in RR costs. The episodic retrieval account predicts either a null interaction or the reversed pattern. A further discrimination between these accounts is possible by considering the previous-trial congruency effect and its interaction with the increase in RR costs (Experiment 3). As we explain in the next section, the response-inhibition account explains not only the effect of previous-trial congruency on RR trials but also its reversal on RS trials. The episodic-retrieval account can explain the previous-trial effect, but only on RR trials. Moreover, because it cannot explain the increase in RR costs, it also cannot account for its modulation by previous-trial congruency (in our case S1 congruency, Experiment 3).

Obviously, the considered accounts differ in their ability to explain the present results. The response-inhibition idea was the most successful one at explaining the current data. Nevertheless, it has to include additional mechanisms such as priming (Hübner & Druey, 2006), episodic retrieval (Altmann, 2011), or the strengthening of C-R rules (Schuch & Koch, 2004) to explain RR benefits on task-repetition trials (which were not investigated here).

Response-Shift Trials

As predicted by the response-inhibition account, the previous-trial congruency effect on the performance in Experiment 3 was opposite for RR and RS trials. Whereas performance after univalent-congruent S1 was impaired on RR trials, it was improved on RS trials. However, this effect of S1 congruency was small on RS trials compared with RR trials, and it was only observable in ER for neutral S2. This suggests that such small sequential effects are easier to detect in neutral and simple conditions, because in complex situations the effect might be obscured by other phenomena that are either sequential in nature or that are related to the processing of the current stimulus (e.g., priming of task sets, response conflict).

Recently, Altmann (2011) reported the same reversal of the previous-trial congruency effect between RR and RS trials. It occurred in two experiments with bivalent stimuli and with larger sample sizes than in the present experiments. Because his episodic-retrieval model could not account for the facilitation on RS trials, he concluded that another mechanism might be needed to explain the

data pattern. In addition, he claimed that the response-inhibition account would have similar difficulties in explaining the results. Yet, contrary to this assertion, response inhibition affects RSs as well. Clearly, with binary responses the disadvantage of one response is the advantage of the other. This implies that, if self-inhibition of the last response is increased, the benefit of an RS should increase. The fact that we found such an effect for neutral S2 suggests that this is a general phenomenon. Therefore, no additional mechanism is needed to explain beneficial effect on RS trials. The finding that the previous-trial congruency effect was much larger on RR trials than on RS trials indicates that response inhibition will affect response selection on the next trial more if the inhibited response is required again, as on an RR trial. This is presumably due to the fact that the effect of inhibition on RS trials is only indirect.

Can the strengthening and the hierarchical-switching accounts also explain RS benefits? Whereas an RS bias is central to the hierarchical-switching account, the strengthening account does not predict a benefit for an RS on task-switch trials. Also, both accounts cannot explain the beneficial effect of previous-trial congruency on RS trials (with neutral S2 in this study, and with bivalent stimuli in Altmann, 2011).

Bottom-Up and Top-Down Control of Response Inhibition

Our results suggest that RR costs in task switching are largely determined by bottom-up processes. One such mechanism presumably is response inhibition, whose size depends on the response activation on the previous trial (e.g., Druey & Hübner, 2008b). Another mechanism is the amplification of response conflict (ARC) by the basic response inhibition. Because these two mechanisms are related multiplicatively, their combined effects result in rather large RR costs.

In contrast, but similar to Hübner and Druey (2006), Marí-Beffa and her colleagues (Cooper & Marí-Beffa, 2008; Marí-Beffa et al., 2012) suggested that response inhibition is implemented strategically. In their studies they used different tasks with nonoverlapping response mappings and analyzed the contribution of RR to mixing cost (i.e., to the performance difference between task-repetition trials in pure vs. mixed-tasks blocks; e.g., Rubin & Meiran, 2005). Comparing RR trials with RS trials, they found RR costs also on task-repetition trials in the mixed blocks (Cooper & Marí-Beffa, 2008; see also Steinhauser & Hübner, 2006). Moreover, the mixing costs were largest on RR trials (Marí-Beffa et al., 2012). Accordingly, the researchers concluded that RR costs "reflect the inhibition of highly active responses that may conflict with the new goals of the task. This top-down process appears to be applied over the entire block of trials rather than on a trial-by-trial basis" (Cooper & Marí-Beffa, 2008, p. 1209).

Some aspects of the present data might also hint to some top-down influences. Whereas the increase in RR costs was reliable in ER in all experiments, it was less stable in RT. Notably, the effect in RT covaried with differences in RT between neutral and bivalent-incongruent S2. A large part of this difference can probably be explained by priming of irrelevant task set (e.g., Steinhauser & Hübner, 2007) and the fact that target identification was easier for neutral S2 than for bivalent-incongruent S2. However, there is still room for other mechanisms. One possibility is that strategic response slowing for bivalent-incongruent S2 increased

the effect of response inhibition on response selection. In fact, data from our laboratory indicate that RR costs in RT increase with RT, whereas this is not the case for RR costs in ER. These results suggest that strategic slowing of responses for bivalent-incongruent S2 might also contribute to the increase in RR costs in RT (Grzyb & Hübner, 2012a). This view is supported by the observation that in our study this increase was generally more stable in ER than in RT (cf. Altmann, 2011).

Is there any way to integrate the divergent evidence? One possibility is to assume that response inhibition is strategically implemented in overall as well as trial-specific mechanisms. Similar accounts have been put forward for attentional adjustments to local interference and global frequency of interference (Botvinick et al., 2001; Brown et al., 2007). However, we think that it is rather unlikely that, on the one hand, top-down control of response inhibition is so rigid that it is not turned off on task-repetition trials and, on the other hand, so flexible that it adjusts the inhibition from trial to trial. Therefore, another possibility is to assume that in contexts where great flexibility is required (e.g., mixed-tasks blocks) an *antirepetition bias* (Marí-Beffa et al., 2012) is strategically implemented as self-inhibition of responses that is locally controlled by bottom-up mechanisms. The observed RR costs might be additionally modulated by further bottom-up mechanisms like response conflict or top-down strategies like speed–accuracy trade-offs.

Inhibition and Action Control

Inhibitory mechanisms are generally assumed to be important for action control (cf. Koch, Gade, Schuch, & Philipp, 2010). In task switching, inhibition has been suggested to enable the system to detach from past goals and to reduce interference. Prominent is the concept of so-called backward inhibition (BI; Mayr & Keele, 2000)—the inhibition of activated task sets that are no longer relevant. Although the exact circumstances of its implementation are still under debate (e.g., Houghton, Pritchard, & Grange, 2009; Koch et al., 2010), BI, similar to response inhibition, is thought to represent an antiperseverative mechanisms that aids the switch to a new task. Because these two concepts are so closely related, one might speculate that they reflect the same mechanism. It is conceivable, for instance, that the inhibition of the last task set includes the inhibition of the associated response set. Under the assumption that the binding of the last response within its task set has been strengthened, BI would affect the last response disproportionally strongly. However, BI is thought to proceed only on task-switch trials, whereas response inhibition is also present on task-repetition trials (Cooper & Marí-Beffa, 2008). Moreover, the amount of response inhibition is adjusted independently of whether the task switches or repeats (Druey & Hübner, 2008b). Thus, it is unlikely that BI and response inhibition are based on the same mechanism, although they may be closely related to each other (Marí-Beffa et al., 2012).

In our view, several inhibitory mechanisms work together to maintain flexibility in goal-directed behavior. BI, for instance, is usually conceptualized as a reactive mechanism that serves to reduce interference from the last task during the preparation and execution of a new task. Accordingly, the strength of BI depends on the level of conflict between tasks (e.g., Gade & Koch, 2005). Recently, Meiran and colleagues (Meiran, Hsieh, & Chang, 2011; Meiran et al., 2010) provided evidence for another task-inhibiting mechanism that specif-

ically reduces interference from bivalent-incongruent stimuli. Interestingly, this *competitor-rule suppression* (CRS) was additive to BI, even though both mechanisms affect the representation of task sets. However, because CRS is applied more specifically than is BI, Meiran et al. (2010) suggested that CRS works on a less general level of representation than does BI. Finally, it has been suggested that there is self-inhibition of task sets, which serves to execute tasks in sequence (Mayr, 2009). Given these various mechanisms, self-inhibition of response is just another member of mechanisms that serve a common goal: the flexible selection of an appropriate response in situations where perseverative tendencies of the system would produce high degrees of interference.

Conclusion

In four experiments we found a reliable modulation of RR costs by the congruency of stimuli. RR costs were larger if the current stimulus was incongruent than if it was neutral. This increase in RR costs can be explained by assuming that response inhibition amplifies the response conflict only on RR trials, which results in larger RR costs. The inhibition of executed responses seems to be implemented strategically to produce an RS bias. The magnitude of response inhibition, however, is determined by stimulus-driven processes (i.e., the response activation on the previous trial). In its pure form this mechanism produces only small RR costs. Yet, RR costs can drastically increase when response inhibition accidentally amplifies response conflict, as observed in our study. Further research should examine if this amplification between response inhibition and conflict applies also on task-repetition trials, which were not investigated here.

In sum, our results are in line with a broader view that in task-switching situations inhibitory mechanisms play a significant role in enhancing behavioral flexibility and reducing interference.

References

Altmann, E. M. (2011). Testing probability matching and episodic retrieval accounts of response repetition effects in task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 935–951. doi:10.1037/a0022931

Arbuthnott, K. D. (1995). Inhibitory mechanisms in cognition: Phenomena and models. *Cahiers de Psychologie Cognitive/Current Psychology of Cognition, 14*(1), 3–45.

Baddeley, A., Emslie, H., Kolodny, J., & Duncan, J. (1998). Random generation and the executive control of working memory. *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 51,* 819–852. doi:10.1080/027249898391413

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624–652. doi:10.1037/0033-295X.108.3.624

Brown, J. W., Reynolds, J. R., & Braver, T. S. (2007). A computational model of fractionated conflict-control mechanisms in task-switching. *Cognitive Psychology, 55,* 37–85. doi:10.1016/j.cogpsych.2006.09.005

Cooper, S., & Marí-Beffa, P. (2008). The role of response repetition in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 1198–1211. doi:10.1037/0096-1523.34.5.1198

Druey, M. D., & Hübner, R. (2008a). Effects of stimulus features and instruction on response coding, selection, and inhibition: Evidence from repetition effects under task switching. *Quarterly Journal of Experimental Psychology, 61,* 1573–1600. doi:10.1080/17470210701643397

Druey, M. D., & Hübner, R. (2008b). Response inhibition under task

switching: Its strength depends on the amount of task-irrelevant response activation. *Psychological Research/Psychologische Forschung, 72,* 515–527. doi:10.1007/s00426-007-0127-1

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149. doi:10.3758/BF03203267

Gade, M., & Koch, I. (2005). Linking inhibition to activation in the control of task sequences. *Psychonomic Bulletin & Review, 12,* 530–534. doi:10.3758/BF03193800

Grzyb, K. R., & Hübner, R. (2012a). *Control of rule-incongruency in task-switching goes at the expense of increased response-repetition costs.* Manuscript in preparation.

Grzyb, K. R., & Hübner, R. (2012b). Response-repetition costs in task switching: How they are modulated by previous-trial response-category activation. *Acta Psychologica, 139,* 97–103. doi:10.1016/j.actpsy.2011.10.006

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24,* 849–878; discussion 878–937. doi:10.1017/S0140525X01000103

Houghton, G., Pritchard, R., & Grange, J. (2009). The role of cue-target translation in backward inhibition of attentional set. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 466–476. doi:10.1037/a0014648

Houghton, G., & Tipper, S. P. (1996). Inhibitory mechanisms of neural and cognitive control: Applications to selective attention and sequential action. *Brain and Cognition, 30,* 20–43. doi:10.1006/brcg.1996.0003

Hübner, R., & Druey, M. D. (2006). Response execution, selection, or activation: What is sufficient for response-related repetition effects under task shifting? *Psychological Research/Psychologische Forschung, 70,* 245–261. doi:10.1007/s00426-005-0219-8

Hübner, R., & Druey, M. D. (2008). Multiple response codes play specific roles in response selection and inhibition under task switching. *Psychological Research/Psychologische Forschung, 72,* 415–424. doi:10.1007/s00426-007-0118-2

Juvina, I., & Taatgen, N. A. (2009). A repetition-suppression account of between-trial effects in a modified Stroop paradigm. *Acta Psychologica, 131,* 72–84. doi:10.1016/j.actpsy.2009.03.002

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching: A review. *Psychological Bulletin, 136,* 849–874. doi:10.1037/a0019842

Kleinsorge, T. (1999). Response repetition benefits and costs. *Acta Psychologica, 103,* 295–310. doi:10.1016/S0001-6918(99)00047-5

Kleinsorge, T., & Heuer, H. (1999). Hierarchical switching in a multidimensional task space. *Psychological Research/Psychologische Forschung, 62,* 300–312. doi:10.1007/s004260050060

Koch, I., Gade, M., Schuch, S., & Philipp, A. M. (2010). The role of inhibition in task switching: A review. *Psychonomic Bulletin & Review, 17,* 1–14. doi:10.3758/PBR.17.1.1

Koch, I., Schuch, S., Vu, K. P., & Proctor, R. W. (2011). Response-repetition effects in task switching: Dissociating effects of anatomical and spatial response discriminability. *Acta Psychologica, 136,* 399–404. doi:10.1016/j.actpsy.2011.01.006

Li, K. Z. H., Lindenberger, U., Rünger, D., & Frensch, P. A. (2000). The role of inhibition in the regulation of sequential action. *Psychological Science, 11,* 343–347. doi:10.1111/1467-9280.00268

Lien, M. C., Schweickert, R., & Proctor, R. W. (2003). Task switching and response correspondence in the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 692–712. doi:10.1037/0096-1523.29.3.692

MacKay, D. G. (1986). Self-inhibition and the disruptive effects of internal and external feedback in skilled behavior. In H. Heuer & C. Fromm (Eds.), *Generation and modulation of action patterns* (pp. 174–186). London, England: Springer.

Marí-Beffa, P., Cooper, S., & Houghton, G. (2012). Unmixing the mixing cost: Contributions from dimensional relevance and stimulus-response suppression. *Journal of Experimental Psychology: Human, Perception and Performance, 38,* 478–488. doi:10.1037/a0025979

Mayr, U. (2009). Sticky plans: Inhibition and binding during serial-task control. *Cognitive Psychology, 59,* 123–153. doi:10.1016/j.cogpsych.2009.02.004

Mayr, U., & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129,* 4–26. doi:10.1037/0096-3445.129.1.4

Meiran, N. (2000a). Modeling cognitive control in task-switching. *Psychological Research/Psychologische Forschung, 63,* 234–249. doi:10.1007/s004269900004

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

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41,* 211–253. doi:10.1006/cogp.2000.0736

Meiran, N., Hsieh, S., & Chang, C. C. (2011). "Smart inhibition": Electrophysiological evidence for the suppression of conflict-generating task rules during task switching. *Cognitive, Affective & Behavioral Neuroscience, 11,* 292–308. doi:10.3758/s13415-011-0037-y

Meiran, N., Hsieh, S., & Dimov, E. (2010). Resolving task rule incongruence during task switching by competitor rule suppression. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36,* 992–1002. doi:10.1037/a0019761

Pashler, H., & Baylis, G. (1991). Procedural learning: 2. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 33–48.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207–231. doi:10.1037/0096-3445.124.2.207

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cuing task-switching paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 1477–1491. doi:10.1037/0278-7393.31.6.1477

Schuch, S., & Koch, I. (2004). The costs of changing the representation of action: Response repetition and response-response compatibility in dual tasks. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 566–582. doi:10.1037/0096-1523.30.3.566

Schuch, S., & Koch, I. (2010). Response-repetition effects in task switching with and without response execution. *Acta Psychologica, 135,* 302–309. doi:10.1016/j.actpsy.2010.07.016

Soetens, E. (1998). Localizing sequential effects in serial choice reaction time with the information reduction procedure. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 547–568. doi:10.1037/0096-1523.24.2.547

Steinhauser, M., & Hübner, R. (2006). Response-based strengthening in task shifting: Evidence from shift effects produced by errors. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 517–534. doi:10.1037/0096-1523.32.3.517

Steinhauser, M., & Hübner, R. (2007). Automatic activation of task-related representations in task shifting. *Memory & Cognition, 35,* 138–155. doi:10.3758/BF03195950

Steinhauser, M., Hübner, R., & Druey, M. D. (2009). Adaptive control of response preparedness in task switching. *Neuropsychologia, 47,* 1826–1835. doi:10.1016/j.neuropsychologia.2009.02.022

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136,* 601–626. doi:10.1037/a0019791