Journal of Experimental Psychology:
Learning, Memory, and Cognition
2010, Vol. 36, No. 4, 992–1002

0278-7393/10/$12.00 DOI: 10.1037/a0019761

Resolving Task Rule Incongruence During Task Switching by Competitor Rule Suppression

Nachshon Meiran
Ben-Gurion University of the Negev

Shulan Hsieh
National Cheng Kung University

Eduard Dimov
Ben-Gurion University of the Negev

Task switching requires maintaining readiness to execute any task of a given set of tasks. However, when tasks switch, the readiness to execute the now-irrelevant task generates interference, as seen in the task rule incongruence effect. Overcoming such interference requires fine-tuned inhibition that impairs task readiness only minimally. In an experiment involving 2 object classification tasks and 2 location classification tasks, the authors show that irrelevant task rules that generate response conflicts are inhibited. This competitor rule suppression (CRS) is seen in response slowing in subsequent trials, when the competing rules become relevant. CRS is shown to operate on specific rules without affecting similar rules. CRS and backward inhibition, which is another inhibitory phenomenon, produced additive effects on reaction time, suggesting their mutual independence. Implications for current formal theories of task switching as well as for conflict monitoring theories are discussed.

Keywords: task-switching, inhibition, response repetition, congruency, conflict monitoring

It is widely assumed that behavioral inhibition is a major form of self-control (e.g., Ach, 2006/1910; Anderson & Spellman, 1995; Friedman & Miyake, 2004; Logan, 1994; Muraven & Baumeister, 2000; Nigg, 2000; Trope & Fishbach, 2000). Inhibition is usually studied by requiring participants to act, feel, or think in a manner discordant with a strong momentary tendency. In order to succeed in executing the required task (which we label *relevant*), one must somehow overcome the competition brought by the strong (but inappropriate) momentary tendency. The processes involved in overcoming competition are jointly termed *inhibition* or *suppression*, and we therefore use these terms interchangeably.

The present article introduces a new form of inhibition found in task switching. Before introducing it, we first lay out the required background.

Nachshon Meiran and Eduard Dimov, Department of Psychology, Ben-Gurion University of the Negev, Beer-Sheva, Israel; Shulan Hsieh, Department of Psychology and Institute of Cognitive Science, National Cheng Kung University, Tainan, Taiwan.

The research was supported by a Bi-National Taiwan–Israel research grant to Shulan Hsieh and Nachshon Meiran. We thank Ronald Hübner for his very helpful comments. We also thank Ami Braverman for help in programming and American Journal Experts for English proofreading.

Correspondence concerning this article should be addressed to Nachshon Meiran, Ben Gurion University of the Negev, P.O. Box 653, Beer-Sheva, Israel; or to Shulan Hsieh, Department of Psychology, National Cheng Kung University, No. 1, University Road, Tainan 701, Taiwan. E-mail: nmeiran@bgu.ac.il or psyhsl@mail.ncku.edu.tw

Inhibition and Task Switching

In some contexts, the best strategy is to apply inhibition without restraint. For example, in the Stroop (1935) task, participants are asked to name the ink color in which color words are printed while ignoring the words themselves. Optimal performance in this task seems to benefit from a strong and consistent inhibition of word reading. Evidence supporting this idea comes from studies showing that performance on a Stroop-related task (naming the ink colors in which color-unrelated words are printed) impairs subsequent word reading (e.g., Masson, Bub, Woodward, & Chan, 2003; see also Allport & Wylie, 2000, Experiment 5).

However, task contexts rarely remain unchanged for long periods of time. Instead, these contexts often change frequently and unpredictably, so that the very same task that was inhibited in one context may be attended in another context a few seconds afterwards. In such scenarios, consistent inhibition may be costly. Therefore, the inhibitory mechanisms ideally should be highly flexible and finely tuned to operate with minimal costs. For the reasons specified above, task switching is an especially attractive context for studying the fine-tuning of inhibitory processes (see Koch, Gade, Schuch, & Philipp, 2010, for a review of inhibition in task switching) in the face of these seemingly conflicting demands (see Goschke, 2000).

Formal Notation

To facilitate the following discussion, we introduce a formal notation to represent the various experimental conditions and explain the differences between the various inhibitory phenomena. In our notation, each stimulus is represented by a series of letter–number pairs. Because most of the effects we discuss are sequential effects, they are represented by series of stimuli, representing a series of trials ending with Trial *n*.

The letters (e.g., *A, B*) represent stimulus dimensions (e.g., gender, hair color) and the letter–number pairs represent the dimension values (such as male and female for the dimension gender) that go with a specific response key (such as Key 1, Key 2) according to the instructions. The numbers are replaced by an asterisk to denote that the key's identity is unimportant. The relevant dimension is emphasized by boldface and italics. Thus, ***a1***b1 represents a two-dimensional stimulus such as a blond male, in which both dimensions are associated with Key 1 (namely, the correct response to blond is Key 1, and the same is true for male) and Dimension A is the relevant dimension.

The critical comparison that defines a given phenomenon is always indicated by a double-headed arrow, ↔. For simplicity's sake, the condition (predicted to be) associated with poorer performance is presented on the left side of this arrow, whereas the quicker condition is represented on its right side. Some dimensions are not critical for defining a given effect and could be omitted. However, we present them to make the table more readily interpretable. We begin using this notation in the next section.

The Task Rule Congruency Effect

An important behavioral marker for the costs associated with maintaining readiness for any task (among the given set of tasks) is the task rule congruency effect (TRCE; see Sudevan & Taylor, 1987, for the first demonstration and Meiran & Kessler, 2008, for review). In typical task-switching experiments, participants apply two or more task rules to the same set of stimuli. These rules typically map a set of categorizations, usually dimension values (such as red and green), to response keys (such as *right* and *left*). In task-switching experiments, each trial involves a relevant rule that dictates how the correct response should be chosen, but there are also irrelevant task rules. These rules are related to tasks that have been required previously or will be required soon. These currently irrelevant task rules may activate the correct response (creating a congruent condition) but may also activate responses that conflict with the correct response (creating an incongruent condition). The contrast defining the TRCE is presented in Table 1. On the left side of the double arrow, we see the incongruent condition, in which Dimensions A and B are associated with conflicting responses (1 and 2). On the right side, we see the congruent condition, in which these dimensions are associated with the same response (1). This congruency effect is called TRCE because the responses that generate the conflict become activated due to the instructed task rules and would not have been activated otherwise. The TRCE thus reflects a conflict between responses generated by competing rules.

Table 1
Formal Representation of the Various Effects Studied and Discussed in the Article

Trial	Slow		Quick
	Task rule congruency		
Trial *n*	***a1***b2	↔	***a1***b1
	Competitor rule suppression		
Trial *n* − 1	***a1***b2c*d*		***a1***b1c*d*
Trial *n*	a****b****c*d*	↔	a****b****c*d*
	Similar (or other)		
Trial *n* − 1	***a1***b*c2d*		***a1***b*c1d*
Trial *n*	a****b****c*d*	↔	a****b****c*d*
	Backward inhibition (BI)		
Trial *n* − 2	***a****b*c*		a*b****c****
Trial *n* − 1	a****b****c*		a****b****c*
Trial *n*	***a****b*c*	↔	***a****b*c*
	Response repetition slowing		
Trial *n* − 1	***a1***b*		***a1***b*
Trial *n*	a****b1***	↔	a****b2***
	M. Hübner et al. (2003)		
Trial *n* − 1	***a****		***a****
Trial *n*	c****b****	↔	a****b****
	Masson et al. (2003)		
Trial *n* − 1	***a***b		***a***
Trial *n*	***b***	↔	***b***

Note. The letters (e.g., *A*, *B*) represent stimulus dimensions (e.g., gender, hair color) and the letter–number pairs represent the dimension values (such as male and female for the dimension gender) that go with a specific response key (such as Key 1, Key 2) according to the instructions. The numbers are replaced by an asterisk to denote that the key's identity is unimportant. The relevant dimension is emphasized by boldface and italics. Thus ***a1***b1 represents a two-dimensional stimulus such as a blond male, in which both dimensions are associated with Key 1 (namely, the correct response to blond is Key 1, and the same is true for male) and Dimension A is the relevant dimension. The critical comparison that defines a given phenomenon is always indicated by a double-headed arrow, ↔. The condition associated with poorer performance is presented on the left side of this arrow, whereas the quicker condition is represented on its right side.

The New Inhibitory Phenomenon: Competitor Rule Suppression

The issue we address in the current work is how the response (or rule) conflicts evident in the TRCE are being resolved. An intriguing possibility is that they are resolved by some form of inhibition (e.g., Schneider & Verbruggen, 2008; Schuch & Koch, 2003; see Koch et al., 2010, for review). These authors' approach was to relate response conflict to a frequently studied inhibitory phenomenon, backward inhibition (BI; Mayr & Keele, 2000), which will be described later on.

In the present work, instead of asking whether a given known inhibitory phenomenon reflects a mechanism that helps to combat incongruence, we searched for relatively direct evidence that task rules that generate incongruence are inhibited to begin with. Our rationale was that if such "troublemaking" irrelevant task rules are inhibited, their subsequent execution (when relevant) would be hampered. We call the related phenomenon *competitor rule suppression* (CRS).

CRS is a sequential effect, because it refers to the relationship between the incongruence that took place in Trial *n* − 1 (the preceding trial) to performance in the subsequent Trial *n* (the current trial). Because CRS is a sequential effect, it is represented in Table 1 by a trial sequence ending with Trial *n*. Without loss of generality, Trial $n - 1$ always involves Dimension A as the relevant dimension and Dimension B as the irrelevant dimension. Trial n always involves Dimension B as the relevant dimension. The critical comparison is between two conditions. The first condition is one in which Dimension B generated incongruence in Trial $n - 1$. This condition appears on the left side in Table 1 and was hypothesized to be associated with slow responses in Trial n. We call it CRS+. The comparison condition (CRS−) was one in which Dimension B did not generate incongruence in Trial $n - 1$. The defining feature of CRS+ is that the competitor (or troublemaking) rule in Trial $n - 1$ becomes the relevant rule in Trial n. The reasoning is that if the competitor rule was inhibited in Trial $n - 1$, there should be a performance cost in Trial n once this rule becomes relevant.

One cannot, however, simply compare CRS+ trials to CRS− trials, because their difference could be explained in terms of conflict monitoring (Botvinick, Braver, Carter, Barch, & Cohen, 2001), as CRS+ trials are characterized by greater conflict in Trial $n - 1$. According to the conflict monitoring theory, conditions characterized by a high degree of conflict result in subsequent increase in control, reflected for example in the boosting of the relevant goal, as discussed in detail in the General Discussion.

To show evidence that CRS targets the troublemaking task rule, we used a paradigm with more than two tasks (rules). Such a paradigm provides the relevant comparison condition in which there was incongruence versus congruence in Trial $n - 1$ but there was no CRS. Two such conditions are realized in our paradigm (see "Similar and other" in Table 1). These are explained below.

Overview of the Experiment

Here we report the results of a single experiment. In this experiment, there were four tasks, which were cued in each trial by meaningful icons. Two tasks involved spatial location (vertical and horizontal), and two tasks involved object identification (gender vs. hair color; see Figure 1).

We decided to use more than two tasks to show evidence that CRS targets the troublemaking rule rather than merely reflecting increased control in general. Our strategy was to compare the CRS effect to two other effects that are also characterized by incongruence versus congruence. The two other effects have the same formal structure. We thus present their common features first. Table 1 depicts these effects, labeled "Similar and other." In both cases, Dimension C generated (or did not generate) incongruence in Trial $n - 1$, but the relevant dimension in Trial n was B, not the troublemaking dimension/rule (C).

The difference between similar and other refers to the fact that we used a paradigm with two task categories because there were two spatial tasks and two object-based tasks. *Similar* refers to cases in which Dimension B and Dimension C belong to the same task category—for example, when Dimension B is gender and Dimension C is hair color. *Other* refers to cases in which Dimension B and Dimension C do not belong to the same task category, such as when Dimension B is gender and Dimension C is the vertical location.

The distinction between Similar and Other enabled us to explore the degree of fine-tuning of the inhibitory effort. Specifically, the design of our paradigm enabled us to specify three levels of fine-tuning. The most finely tuned form of inhibition involves just the troublemaking rule, without negatively influencing any other

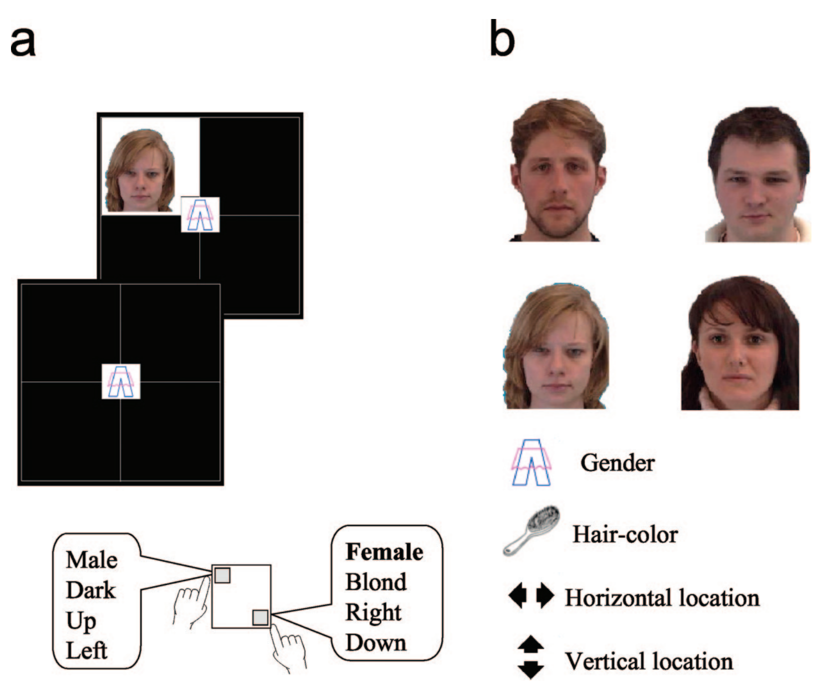

Figure 1. a: Examples of cue–target pairs and response key arrangements in the experiment. b: Objects and task cues. Photographs are taken from the Facial Expressions and Emotion Database (Wallhoff, 2006).

rule. Such a high level of fine-tuning seems optimal, as inhibition is likely to affect performance in the following trials because of either memory retrieval or persistence (see General Discussion). Such negative influence should therefore be minimized. This form of inhibition is predicted to be associated with a significant effect of CRS (so that reaction time [RT] in CRS+ > CRS−). The least finely tuned form of inhibition is one that affects all of the rules without discrimination. This form of inhibition is associated with maximal costs because performance in the trial that follows the conflict will always suffer if there is a task switch. This form of inhibition is predicted to be associated with significant main effects of CRS (as above), Similar (Similar+ > Similar−) and Other (Other+ > Other−). Between these two levels, there is the inhibition of the processing pathway that is associated with the troublemaking rule. It represents an in-between level because the detrimental effects of inhibition on the next trial generalize only minimally (but still generalize, unlike in the case of the most finely tuned inhibition). Such inhibition is predicted to manifest in significant main effects of CRS (as above) and Similar (as above), but not of Other.

There were several more pragmatic considerations that led us to design the paradigm as we did. Specifically, to maximize the need for inhibition, we used a relatively short cue–target interval (Druey & Hübner, 2007; but see Grange & Houghton, 2009) and avoided any task repetitions, even during the practice phase (Philipp & Koch, 2006). In this regard, it is worth mentioning that CRS can only be seen in switch trials, because if the task in Trial n is repeated from Trial $n - 1$, the conflict-generating rule in Trial $n - 1$ cannot become the relevant rule in Trial n. Accordingly, we used only switch trials to maximize the number of trials that we could use in our analyses.

Method

Participants

Twenty-four undergraduate students from Ben-Gurion University took part in the present experiment in return for partial course credit or for 35 Israeli New Shekels (approximately $9). The participants reported having normal or corrected-to-normal vision. The response key arrangement was counterbalanced between the participants. Half of the participants used the upper left (*7*) and lower right (*3*) keys on the keypad to indicate up/left or down/right, whereas the other half used the upper right (*9*) and lower left (*1*) keys to indicate up/right or down/left. The assignment of object values (such as female, blonde, etc.) to response keys was also counterbalanced. Thus, there were eight counterbalancing conditions, and we assigned the participants to these conditions according to the order in which they entered the experiment.

Stimuli and Procedure

The experiments were run on Pentium 4 computers with 17-in. (43.18-cm) monitors. The procedure was programmed in E-Prime (Version 1.0; W. Schneider, Eschman, & Zuccolotto, 2002). The stimulus consisted of an object presented inside a 2 × 2 grid subtending a visual angle of approximately 13.10 (width) × 13.10 (height) degrees. The object was a face subtending a visual angle of 4.74 × 6.62 degrees. The faces were photographs of young adult Europeans, two men and two women, two blonde and two dark-haired, forming all of the possible combinations of gender and hair color. The task cues were task-related icons that were presented in the center of the grid while the target object was presented in the grid's quadrants.

The experiment began with an explanation of the tasks, accompanied by illustration of the tasks' stimuli. The keypad that was used to collect RTs was aligned with the center of the screen, and the participants were instructed to respond with their two index fingers. Afterward, the participants were required to execute one practice block and 18 experimental blocks. Each block consisted of 64 trials; excluding the practice, there were 1,152 trials for each participant. We gave the participants 2-min rests between the blocks in an effort to keep them alert. The total session took approximately 1 hr 10 min. The participants were asked to be as accurate and quick as possible in their responses.

A trial started with a response-cue interval of 500 ms during which a black screen was presented. This was followed by the task-cue presentation in the center of the empty grid/boxes array for 500 ms. The cue-target interval was followed by adding the object to the display, which was kept on the screen until the response was given. A 400-Hz beep was heard for 100 ms after the response if an error was made.

Design

The design of the core analysis employed four independent variables: task type (object vs. space), CRS (CRS+ vs. CRS−), Similar (Similar+ vs. Similar−) and Other (Other+ vs. Other −). Due to the complex nature of this design, we will give an example of a trial pair belonging to the condition characterized as CRS+, Similar+, and Other−. For this trial, the rule in Trial $n - 1$ was gender and interference came from vertical and horizontal. In Trial n, the rule was vertical. This trial is classified as CRS+ because vertical interfered in Trial $n - 1$ and was the required rule in Trial n. It is classified as Similar+ because horizontal interfered in Trial $n - 1$ and (the similar rule) vertical was relevant in Trial n. It is classified as Other− because Hair (an object rule) did not cause interference in Trial $n - 1$ and the rule in Trial n was spatial in nature. As the reader may notice, all possible combinations of the independent variables CRS, Similar, and Other are possible.

Results

In preparing the results for the analyses, we excluded trials that followed an error either immediately or after two trials. This precaution was required to assess BI, which is defined by the repetition of the task from Trial $n - 2$ (see more below), and because errors in task switching are often associated with the execution of the wrong task (Meiran & Daichman, 2005). This precaution enabled us to ensure the switch status of the analyzed trials. We analyzed RT only for correct trials (thus excluding 2.21% of the trials) and excluded from the analysis RTs less than 100 ms (anticipatory errors) or longer than 3,000 ms (outliers), thus excluding an additional 1.92% of the remaining trials. For each analysis, we computed the cell means separately for each participant.

Incongruence in Trial *n*

Before examining CRS, we had to first show the existence of TRCE in this paradigm. Namely, if there were no evidence for competition between relevant and irrelevant rules, there would not be a need for inhibition to begin with. Because there were four rules, one relevant and three irrelevant, incongruence had four levels: congruent and one to three incongruent rules. A one-way analysis of variance (ANOVA) with this independent variable indicated a significant main effect, $F(3, 69) = 42.83$, MSE = 828.78, $\eta_p^2 = .65$, $p < .0001$. Mean RTs were 670, 703, 737, and 757 for congruent and one to three competitor rules, respectively. The pairwise comparisons between adjacent levels of incongruence were all significant ($p < .05$). A parallel ANOVA on the proportion of errors (PE) indicated a significant effect, $F(3, 69) = 17.39$, MSE = 0.0004, $\eta_p^2 = .43$, $p < .0001$, indicating a similar trend (.006, .01, .03, .05, respectively). These results clearly show a robust TRCE, a fact that sets the stage for the core analyses.

Incongruence in Trial $n - 1$

The core ANOVA included CRS, Similar, Other, and Task Type (Object vs. Space). We use the suffixes + and − to denote the conditions in which inhibition was presumably present (the left side of the double-headed arrow in Table 1) or absent (the right side of the arrow). It is important to note that a given trial could represent any combination of the levels of CRS, Similar, and Other. For example, the fully congruent condition was characterized by CRS−, Similar− and Other−, whereas the mostly incongruent condition was characterized by CRS+, Similar + and Other+. As the reader may notice, there was only one similar rule and two dissimilar rules. For example, if Dimension B was gender, hair color was the only similar rule, and both vertical and horizontal were dissimilar rules. To simplify the analytic design, we did not distinguish between conditions involving incongruence from one vs. two dissimilar rules. Thus, Other+ could mean either one or two competing rules.

In this four-way ANOVA, there were only two significant main effects: CRS, $F(1, 23) = 11.18$, MSE = 3,578.91, $\eta_p^2 = .33$, $p < .005$; and Task Type, $F(1, 23) = 39.87$, MSE = 161,597.14, $\eta_p^2 = .63$, $p < .0001$. Mean RTs were 713 and 734 for CRS− and CRS+, respectively, indicating a CRS effect of 21 ms. RT was considerably longer with the object tasks (853 ms) than with the spatial tasks (594 ms). The effects of Other and Similar were both 5 ms and clearly nonsignificant. Moreover, none of the interactions reached significance; all $\eta_p^2 < .12$.

A parallel ANOVA on PE indicated that all of the main effects were significant, $F(1, 23) = 10.70$, 11.25, 9.76, and 5.25, MSE = 0.0092, 0.0005, 0.0004, 0.0005, $\eta_p^2 = .13$, .14, .12, .07, $p < .05$, for Task Type, CRS, Similar and Other, respectively. However, none of the interactions was significant, all $\eta_p^2 < .10$. Mean PEs were .04 and .02 in the object and spatial tasks, respectively; .030 and .035 in CRS− and CRS+, respectively; .034 and .030 in Similar− and Similar+, respectively; and .034 and .030 for Other− and Other+, respectively. These results indicate a reversed effect for Similar and Other.

The results indicate a robust effect of CRS seen in both RT and PE. In contrast, the effects of Similar and Other were negligible in RT and reversed in PE, suggesting a speed–accuracy tradeoff for the latter effects. These results support in full the presence of a finely tuned form of inhibition targeted only the troublemaking rule and not spreading to other rules, including neighboring rules. This result also indicates that it is not the congruence in Trial $n - 1$ that facilitated performance in Trial n. Specifically, one could argue that the CRS effect does not reflect inhibition, but rather facilitation due to the congruence in Trial $n - 1$. However, the CRS− condition was associated with the same degree of congruence in Trial $n - 1$ as were the conditions Similar− and Other−. If the CRS effect reflected facilitation rather than inhibition, one would expect the effects of Similar and Other to be significant too. Thus, the present results show that the CRS effect reflects incongruence-related inhibition rather than congruence-related facilitation. We wish to note that we do not deny the possible role of activation due to previous congruence. We only claim that this is not the reason why CRS is observed. In the next section, we relate CRS to other inhibitory phenomena to see if these are involved in the resolution of incongruence.

CRS and Its Relation to Other Inhibitory Phenomena

In the next section, we deal with the relationships between CRS and two other inhibitory phenomena in task switching. We provide a brief review of each phenomenon, describe its potential relevance to CRS and report a joint analysis of CRS and the related inhibitory phenomenon. In this report, we focus on results that have not yet been reported; namely, we do not report the main effect of CRS, which was already reported.

BI. The BI phenomenon was first documented by Mayr and Keele (2000). It is based on comparing two types of task-switch trials: those involving a repetition of a just-abandoned task rule and those in which the relevant rule has not just been abandoned. Mayr and Keele, for example, required participants to detect an odd item out of four items. The odd item was to be determined on the basis of instructions indicating which stimulus dimension defines oddity. The dimensions included movement, orientation and color. BI has been indexed by comparing A-B-A task sequences (with A, B, and C indicating different relevant dimensions or tasks) in which the current task has just been abandoned (BI+) to C-B-A sequences (BI−), where A, B, and C denote different rules, such as color, orientation and movement.

Importantly, the BI phenomenon has also been identified in choice tasks like the ones used here (see Koch et al., 2010, for review). Table 1 depicts the formal representation of BI in our paradigm. Of greatest interest are the following features. First, all of the trials in the triplet are switch trials. This feature is critical, because the assumption is that when Dimension B becomes relevant in Trial $n - 1$, Dimension A, which was relevant in Trial $n - 2$, was inhibited. Second, the critical comparison involves what took place in Trial $n - 2$. In the BI+ condition, participants were asked to execute Task A. In the BI− condition, they were asked to execute Task C. As a result, Trial n, which provides the data for analysis, compares performance on Rule A when Dimension A has just been inhibited in Trial $n - 1$ (BI+) to when it was inhibited a longer time ago or has not yet been inhibited (BI−).

The BI phenomenon is explained by assuming that task switching requires inhibition of the abandoned task set to prevent it from interfering with the new task. When it becomes necessary to return to the just-abandoned task, performance suffers because the respective task set is still partly inhibited. The BI phenomenon has been subjected to intense research efforts, and reviewing them is beyond the scope of the current article (but see Koch et al., 2010; Mayr, 2007). We only mention that subsequent research has shown that the BI phenomenon is found in conditions requiring top-down control (Mayr & Keele, 2000, Experiment 3), including response conflict (Gade & Koch, 2007) and short preparation interval (Druey & Hübner, 2007, but see Grange & Houghton, 2009). BI also depends on response selection (Schuch & Koch, 2003) and execution (Philipp, Jolicœur, Falkenstein, & Koch, 2007).

Of greatest relevance here is Schneider and Verbruggen's (2008) suggestion that BI is the mechanism that is involved in resolving response conflicts. Specifically, these authors followed on earlier works by Koch and colleagues (Gade & Koch, 2007; Schuch & Koch, 2003; Philipp et al., 2007) showing that BI is dependent on response selection and inhibition in Trial $n - 1$. Schneider and Verbruggen compared conditions in which all of the tasks were associated with the same categorizations. This was accomplished by judging if a number is above/below a reference point, with the tasks being associated with different reference points. The authors compared a condition in which the tasks also had the same response or had different responses (and thus different categorization-to-response mappings). The results showed BI to be present when the different tasks were associated with different categorization-to-response mappings rules, but absent (in fact, slightly reversed) when the tasks involved the same mapping. These results suggest that what is being inhibited in BI is the mapping of the categorizations to their responses. Still, this evidence is not completely clear-cut because some studies show BI despite the fact that they employ a constant mapping rule in all of their tasks (e.g., Arbuthnott & Frank, 2000; Mayr & Keele, 2000).

The purpose of the following analysis was to examine if CRS and BI operate jointly or independently of one another. We reasoned that because both CRS and BI presumably reflect inhibition that took place in Trial $n - 1$, it is conceivable that they influence the same process (and processing stage), in which case they should interact. However, if they influence different processing stages, each involving a different aspect of the task set, then they should produce additive effects on RT.

In addition to specifying the potential locus of influence for CRS, the present analysis also informs the debate concerning unitary versus distributed task representations. That is, if we show that CRS and BI produce additive effects on RT, this would support the notion regarding complex and multielement representation of tasks as suggested by some theories (especially Arrington, Altmann, & Carr, 2003; R. Hübner, Futterer, & Steinhauser, 2001; Logan & Gordon, 2001; Meiran, Kessler, & Adi-Japha, 2008). Such a result is less easily explained by theories that treat task sets as unitary entities (e.g., Allport, Styles, & Hsieh, 1994; Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2003).

We analyzed performance in Trial n as a function of two independent variables: CRS (whether the relevant rule in Trial n was the interfering rule in Trial $n - 1$) and BI (whether the relevant rule in Trial n was the same as the relevant rule in Trial $n - 2$; see Figure 2). An ANOVA indicated a significant effect for BI, $F(1, 23) = 13.72$, MSE = 1,250.79, $\eta_p^2 = .37$, $p < .005$, and a clearly nonsignificant interaction between CRS and BI, $F = 0.06$, $\eta_p^2 = .003$. The BI effect was 29 ms in CRS− and 25 ms in CRS+.

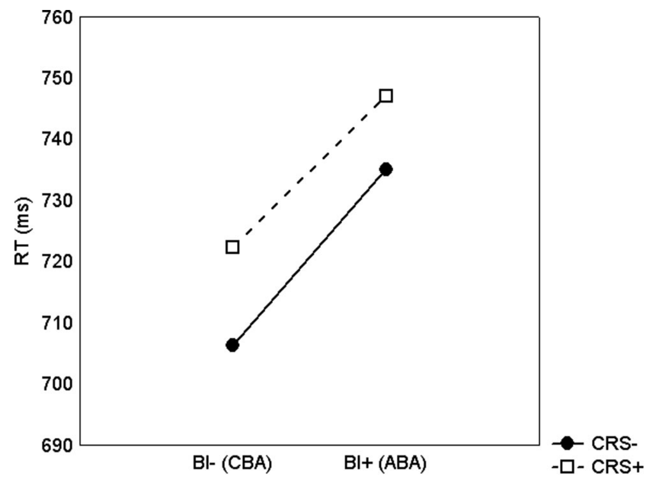

Figure 2. Mean reaction times (RTs) according to backward inhibition (BI) and competitor rule suppression (CRS).

A parallel analysis on PE revealed a significant main effect of CRS, $F(1, 23) = 9.39$, MSE = 0.0001, $\eta_p^2 = .29$, $p < .01$, in the same direction as the RT effect.

On the basis of Sternberg (1969), the present results suggest that BI and CRS influence different processing stages. Note that both BI and CRS represent the inhibition of the task set in Trial n due to processes that presumably took place in Trial $n - 1$. Specifically, BI reflects the inhibition of the set used in Trial $n - 2$ when switching away from this set in Trial $n - 1$. CRS reflects the inhibition of the interfering rule in Trial $n - 1$. If these two processes were operating on the retrieval and/or implementation of the same representation, they should have interacted. Their additive influence on RT provides further evidence that task sets comprise multiple and even independent representations and processes.

Response–repetition slowing. Another effect putatively involving inhibition concerns response repetition slowing. Response repetition in single-task settings is associated with improved performance (e.g., Campbell & Proctor, 1993; Pashler & Baylis, 1991; Soetens, Boer, & Heuting, 1985). However, in task switching, response repetition results in slowing. The reasons for this slowing are still debated, but it is noteworthy that two accounts are related to inhibition. According to Kleinsorge and Heuer (1999), the task space is organized as a hierarchy in working memory. At the top level of the hierarchy is the relevant dimension, whereas responses occupy lower levels in the hierarchy. According to this theory, the switch signal, which pertains to the level of the dimension, spreads uncontrollably to subordinate levels in the hierarchy, including the response, thus generating a tendency to switch responses when a task switch is required and to repeat responses when a task repetition is required. This account is supported mainly by mathematical modeling. According to the second theory (Druey & Hübner, 2008, but see also Brown, Reynolds, & Braver, 2007; Rogers & Monsell, 1995), participants inhibit just-executed responses in an effort to overcome their perseverative tendencies, which are especially counterproductive in task switching. None of these two theories links response-repetition slowing to the specific rule that has generated the response.

In this analysis, we included two independent variables, CRS and response repetition (see Figure 3). There was a significant main effect of response repetition, $F(1, 23) = 15.94$, MSE = 826.47, $\eta_p^2 = .41$, $p < .001$, as well as a significant interaction with CRS, $F(1, 23) = 6.05$, MSE = 526.47, $\eta_p^2 = .21$, $p < .05$. Follow-up planned contrasts indicated that the CRS simple main effect was significant in the response switch condition (720 vs. 694 ms, respectively; $p < .005$), but not with response repetitions (732 vs. 729 ms; $p = .72$). Another perspective on this interaction is that there was response-repetition slowing only in CRS− trials (729 vs. 694 ms; $p < .0005$) and not on CRS + trials (732 vs. 720 ms; $p = .11$).

Because of the interaction, we decided to explore the issue a bit further by examining whether an analogous interaction would be found with Similar and Other. Specifically, the interaction could be interpreted as reflecting the inhibition of the competing response in Trial $n - 1$ (rather than the competing rule in that trial). In such a case, the competing response is inhibited (because it was competing) and the executed response is also inhibited (to prevent perseveration). As a result, the difference between the two conditions (which is the response−repetition effect) is eliminated. We therefore ran an additional four-way ANOVA on RT in which the independent variables were CRS, Similar, Other, and Response Repetition. If the competing response was inhibited following incongruent trials (and regardless of the rule that generated it), then there should be interactions between Similar and Other on one hand and Response Repetition on the other hand. The two interactions were clearly nonsignificant, Fs < 0.30, $\eta_p^2 < .01$. These results suggest that the competing response was not inhibited in Trial $n - 1$.

A parallel analysis on PE revealed a significant main effect of CRS, $F(1, 23) = 5.06$, MSE = 0.0003, $\eta_p^2 = .18$, $p < .05$, a significant main effect of Response–Repetition, $F(1, 23) = 10.57$, MSE = 0.0007, $\eta_p^2 = .31$, and a significant interaction between the two variables, $F(1, 23) = 4.52$, MSE = 0.0003, $\eta_p^2 = .16$, $p < .05$. None of the other effects including those involving Similar and Other approached significance.

An examination of the interaction shows a non significant CRS effect for switched responses ($F = 0.01$; mean PE = .026 for both CRS+ and CRS−), and a significant CRS effect for repeated responses ($p < .005$; mean PE = .022 and .014 for CRS+ and CRS−, respectively). This interaction is opposite in direction to that seen for RT in that a CRS effect was observed among repeated responses. Note also that the effect of Response–Repetition is also opposite to that seen for RT, indicating better performance after response repetition. Importantly, although the RT interaction and the PE interaction were opposite in trend, the simple effects of CRS were never reversed. Thus, when the effect was significant for one (PE or RT), it was eliminated but not reversed in the other (RT or PE).

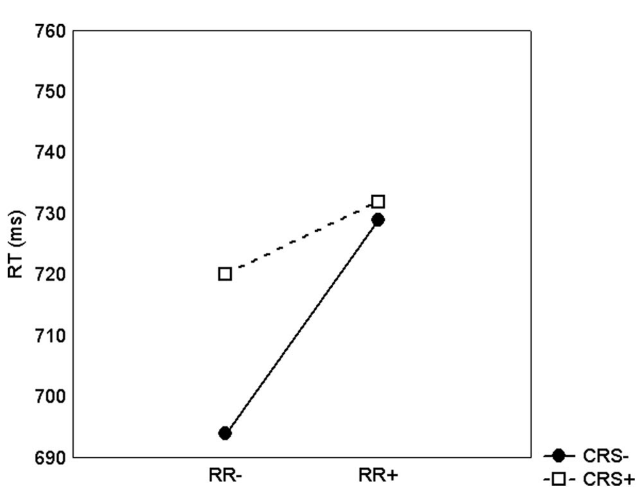

Figure 3. Mean reaction times (RTs) according to response repetition (RR) and competitor rule suppression (CRS).

To summarize, we found a CRS effect among both the repeated and the switched responses. For reasons which we do not fully understand, the effect for repeated responses was seen in RT whereas the effect of switched responses was seen in PE. These results show at least some degree of independence of CRS and response–repetition slowing.

General Discussion

In the present work, we focused on CRS, which is a form of inhibition that has not yet been reported in the literature. CRS reflects the inhibition of a rule that generated incongruence in a preceding trial. Inhibition is reflected in slowing in Trial n if that trial involves the same rule that generated conflict in Trial $n - 1$. Moreover, inhibition is not merely a reaction to incongruence in Trial $n - 1$ because Similar and Other did not produce significant effects. In other experiments, not reported here, we have successfully and fully replicated the CRS effect using paradigms with different tasks than those used here, such as shape and color as object tasks and in vs. out as a spatial task. We were also able to replicate CRS with completely arbitrary category–response mappings (as opposed to the nonarbitrary mapping used in the spatial tasks here).

Once we had a relatively direct index for CRS, we were able to examine how this effect is related to other inhibitory phenomena reported in the literature. Our results show that the BI effect is nearly perfectly additive with CRS. This result suggests that BI and CRS influence different processing stages, possibly by operating on different task representations. The fact that BI is found under conditions that do not involve incongruence (Arbuthnott & Frank, 2000; Mayr & Keele, 2000; Sdoia & Ferlazzo, 2008) may suggest that, relative to CRS, BI operates on a more abstract representation of the task than the specific rule, which is presumably the target of CRS. Theories that make a distinction between abstract task representations on the one hand and task implementation on the other hand (e.g., Brown et al., 2007; Meiran et al., 2008; Rubinstein, Meyer, & Evans, 2001; Sohn & Anderson, 2001) are potentially equipped to handle this dissociation. However, this remains an open issue for future research, surely beyond the scope of the present article.

CRS interacted significantly with response repetition in the RT analysis, yet the PE results were in an opposite direction. When RT and PE are considered jointly, we can quite safely conclude that there was a CRS effect for both repeated and switched responses.

In a yet unpublished study in which we recorded event-related potentials, we found a significant CRS effect during the cue–target interval of Trial n. During this interval, the target stimulus and the response of Trial n are not yet determined. The only thing that is determined is task identity. This result further supports the notion that the CRS represents rule inhibition, at least for ERPs.

In showing significant effects of CRS and no effects of Similar and Other, we were able to rule out (at least to a significant extent) the possibility that CRS represents facilitation (following congruent trials). Rather, the pattern of results indicates that CRS reflects inhibition (following incongruent trials). This is because a facilitation-based account wrongly predicts equivalent effects for CRS, Similar and Other, which share a control condition that involves trials following (relatively more) congruent trials.

Maintaining the Delicate Balance Between Activation and Inhibition in Task-Switching

We opened this article by noting that, unlike single task settings, in which inhibition may be exercised without restraint, task switching calls for subtle and fine-tuned forms of inhibition. The reason is that, in task switching, one needs to maintain readiness to engage in all of the potential tasks, possibly by activating the related representations in long-term memory. However, a special characteristic of activated long-term memory representations is that they are relatively insensitive to context changes, and thus might produce automatic (and unwanted) processing (Oberauer, 2001), seen, for example, in the TRCE (Meiran & Kessler, 2008). One cannot simply inhibit all the irrelevant rules because this would reduce the readiness to execute them. Similarly, any choice task requires maintaining the motor readiness to execute the key presses. Inhibiting the motor actions runs the risk of generating slow responses when the now-inhibited response needs to be executed.

The present paradigm allowed us to begin specifying the degree of fine-tuning that characterizes CRS. We were able to show that participants did not increase overall control following incongruent trials. Such an indiscriminate strategy is predicted to produce general slowing following incongruent trials, a prediction that was not borne out by the results. We were also able to show that participants did not inhibit the entire object or spatial processing pathway because inhibition did not affect tasks that shared the pathway with the troublemaking task rule.

The present results indicate that CRS represents inhibition that is as finely tuned as our paradigm could distinguish. This high degree of fine tuning is to be expected from an optimally functioning system given the conflicting demands associated with task switching. What remains to be shown, of course, is that such a highly fine-tuned form of inhibition is indeed associated with improved overall performance.

Relationship to Similar Phenomena

The CRS effect is reminiscent of several other phenomena reported in the literature. Below we discuss the relationships between these phenomena and CRS.

Mayr and Keele (2000, Experiment 2) asked participants to detect a deviant item in a four-item display. Deviance was defined in each trial according to a specified rule, such as color, orientation, or movement. Each display contained a relevant deviant, such as a deviant in color when color was the instructed rule. There were also irrelevant deviants, such as deviants according to orientation in color trials. Mayr and Keele reported slowing in trials in which the relevant dimension was a dimension that created an irrelevant deviant in Trial $n-1$. This slowing could be explained in terms of item inhibition (ignoring a moving object because this particular object was an irrelevant deviant beforehand), but it may also hint at the possibility that an entire dimension or task rule (movement, in this example) had been inhibited.

Goschke (2000) and Brown et al. (2007) found larger task switching costs following rule-incongruent trials. Note that both of these works used paradigms in which switching between two tasks occurred. Therefore, if Trial $n-1$ was incongruent and Trial n involved a task switch, the rule that generated the conflict in Trial $n-1$ became the relevant rule in Trial n, just like in the CRS. The limitation of this paradigm is the inability to separate effects that are due to the general level of conflict in Trial $n-1$ from CRS because when the previous trial was incongruent, both take place.

M. Hübner, Dreisbach, Haider, and Kluwe (2003) asked participants to switch between symbol classification, letter classification and digit classification. They were interested in pairs of trials in which the first trial involved a single target character and the second trial involved a target character that was flanked by two identical characters belonging to another task. The flankers were never the same as the target in Trial $n-1$. Of interest was the slowing in trials in which the flankers belonged to the task in Trial $n-1$ compared to trials in which the flankers belonged to the third task (see Table 1 for a formal presentation). This slowing was observed only when there was an opportunity to prepare for the task switch. M. Hübner et al. interpreted this result as showing that task preparation involves the inhibition of the just-abandoned task set, as in BI. Note that the aforementioned effect is quite different from CRS in that there was no response competition in Trial $n-1$, whereas CRS is defined by the congruency condition in that trial.

Finally, following Allport and Wylie (2000, Experiment 5), Masson et al. (2003; see also Masson, Bub, & Ishigami, 2007) identified a mechanism that helps to overcome a strong tendency to execute a dominant task (word reading) when a nondominant task is required (color naming). These authors showed that word reading performance was impaired following color naming of the ink color in which color-unrelated words were printed. These results suggest that the entire word reading processing pathway is blocked to overcome the strong tendency to read the word. Note that this form of pathway blocking operated in conditions in which the task identity generated a strong conflict (assuming that there is a strong tendency to read words rather than to name their ink colors). This effect differs formally from CRS (see Table 1) in that the comparison is being made between two conditions in Trial $n-1$, bivalent stimuli, affording two potentially relevant tasks (colored words, affording color naming and reading) and univalent stimuli (colored asterisks) affording only color naming. CRS, in contrast, is based on comparing two kinds of bivalent stimuli. Moreover, in Masson et al.'s studies, the response set in Trial $n-1$ (color names) was different from that in Trial n, whereas in the CRS the response set is the same, allowing us to examine the joint influence of CRS and response repetition. Finally, in Masson et al.'s design, the role of incongruence in Trial $n-1$ (rather than specific competition from word reading) cannot be completely ruled out, although such an account seems extremely unlikely.

Relevance to Current Theories of Task Switching

Only three formal theories of task switching account for incongruency and as such are potentially equipped to handle the present findings. According to Schneider and Logan (2005), participants choose an abstract response category such as male, up, and so forth, based on the combined information in the task cue and the target. Incongruency effects arise because some of the response categories are associated with the currently irrelevant task. Yet, these categories might be retrieved. In such cases, the retrieved categories activate their response, which might be a competing response.

Schneider and Logan's (2005) theory could potentially be extended to account for the present results by assuming that when there is a response conflict, the related response category (such as female) and not the actual response (such as Key 1) is inhibited. Inhibition in this model might be accomplished by reducing the weight given to the response category (see Logan & Gordon, 2001). Yet Schneider and Logan's model does not specify the conflict detection mechanism that would trigger inhibition.

Our model (Meiran et al., 2008) assumes that task control is achieved by first activating an abstract task representation, which, in turn, activates two types of task sets. Input sets are responsible for biasing incoming information in favor of the relevant task. For example, if gender is relevant, then gender information is emphasized at the expense of other pieces of information (such as hair color and location). Action sets are responsible for biasing the link between abstract response categorizations (such as male, up, etc.; see also Schuch & Koch, 2004) and movements such as key presses. The models assume that there is a separate action set for each key press. Biasing in the action sets is similar to that in the input sets in that emphasizing the representations associated with one task comes at the expense of the other task(s). The model could be modified to explain CRS by assuming that action sets become strongly biased if they have been responsible for response conflicts.

Schneider and Logan's (2005) model and our model (Meiran et al., 2008) suffer from similar shortcomings regarding CRS in that they do not incorporate a mechanism to detect response conflict. They also have the same advantage in that they assume the existence of an abstract response category level, which could be the target of inhibition if these models were extended to account for CRS.

The third model proposes a mechanism to detect conflict. In Brown et al.'s (2007) model, incongruence results from the activation of competing action plans by the target stimulus. Importantly, the model specifies how the brain reacts to such conflict. On the basis of physiological evidence, the model assumes that the conflict is detected by one mechanism (residing in the dorsal anterior cingulate cortex), which sends signals to another mechanism (residing in systems like the dorso-lateral prefrontal cortex) to strengthen the bias in favor of the correct task by augmenting the correct task set's representations. When there is incongruence between Task A (relevant) and Task B (irrelevant) in Trial $n - 1$, Task A's representations are augmented. When the subsequent Trial n involves a task switch, Task B becomes relevant and Task A becomes irrelevant. However, Task A, which is now a competitor, is associated with augmented representations. As a result, the switch cost in Trial n increases (relative to congruent Trial $n - 1$). Thus, whereas Brown et al.'s model has an incongruence detector that could potentially generate CRS, this detector signals the activation of the relevant task rather than signaling the inhibition of the irrelevant task. This feature does not seem accidental because Brown et al.'s theory extends Botvinick et al.'s (2001) conflict monitoring theory. The latter theory does not seem to have a mechanism to detect the exact source of conflict. It only specifies a mechanism to detect conflict in general. A potential modification of Brown et al.'s model is to make the activation of representations of a given task come at the expense of the alternative task(s), as in Meiran et al.'s (2008) model. Yet, it is not entirely clear what would happen if there is more than one alternative task as in the present experiment. Thus, even this modification would need to incorporate a process that somehow detects the incongruence generating rule. We wish to add a cautionary note here. Although our results indicate consistent CRS effects and do not show consistent postconflict effects, we cannot (and do not wish to) rule out the possibility that both of these mechanisms coexist.

Limitations and Cautionary Remarks

We wish to add an important cautionary note in this section. The literature discusses two forms of inhibition (e.g., see Tipper, 2001). One form is online inhibition of representations. This inhibition presumably lingers and is therefore evident in subsequent trials (e.g., Tipper, 1985). We call this account *online*. The second form of inhibition consists of forming episodic traces, including a "do not process" or "do not respond" tag (e.g., Neill, Terry, & Valdes, 1994). This tag, when subsequently retrieved, impairs processing. We call this process *episodic tagging*. We view both of these processes as representing cognitive control, and we do not attempt to distinguish between them. In this regard, the crucial difference between them is that the online process helps to overcome interference immediately, whereas episodic tagging helps to overcome similar interference in subsequent encounters. We wish to make a clear statement that our results do not permit us at present to distinguish between online inhibition and episodic tagging.

Regarding limitations, although the present results clearly support the existence of CRS and characterize it to some degree, we do not know at present how general the phenomenon may be. Specifically, our paradigm involved 100% switch trials and did not include task repetitions. We chose this design because CRS can only be observed in switch trials; thus, including more switch trials resulted in a larger number of analyzable observations and greater statistical reliability. Another reason was that we wished to obtain reliable BI in order to examine the relationship of BI and CRS, and BI is more reliably observed without task repetitions (Philipp & Koch, 2006). Thus, future research should determine whether CRS, like BI, depends on this design feature.

There are additional limitations. Specifically, our stimuli were integral in that the information related to all of the tasks was present in the same target object. This feature most likely increases the competition from the irrelevant dimensions and thus possibly encourages inhibition. Thus, we cannot rule out the possibility that CRS would be reduced or even eliminated when using nonintegral stimuli, such as those used by Rogers and Monsell (1995), M. Hübner et al. (2003), and others. Finally, although we replicated the CRS with different tasks, all of these replications involved four tasks, two spatial and two object-based. Furthermore, none of our tasks were semantic in nature. Thus, we cannot rule out the unlikely possibility that something about this design feature encourages CRS.

References

Ach, N. (2006). *On volition* (T. Herz, Trans.). (Original work published 1910) Retrieved from http://www.psychologie.uni-konstanz.de/abteilungen/kognitive-psychologie/various/narziss-ach/

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and Performance XV: Conscious and unconscious processing* (pp. 421–452). Cambridge, MA: MIT Press.

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

Anderson, M. C., & Spellman, B. A. (1995). On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review, 102, 68*–100.

Arbuthnott, K. D., & Frank, J. (2000). Executive control in set switching: Residual switch cost and task–set inhibition. *Canadian Journal of Experimental Psychology, 54,* 33–41.

Arrington, C. M., Altmann, E. M., & Carr, T. H. (2003). Tasks of a feather flock together: Similarity effects in task switching. *Memory & Cognition, 31,* 781–789.

Botvinick, M. M., Braver, T. S., Carter, C. S., Barch, D. M., & Cohen, J. D. (2001). Evaluating the demand for control: Anterior cingulate cortex and crosstalk monitoring. *Psychological Review, 108,* 624–652.

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.

Campbell, K. C., & Proctor, R. W. (1993). Repetition effects with categorizable stimulus and response sets. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 1345–1362.

Druey, M., & Hübner, R. (2007). The role of temporal cue–target overlap in backward inhibition under task switching. *Psychonomic Bulletin & Review, 14,* 749–754.

Druey, M., & Hübner, R. (2008). Response inhibition under task switching: Its strength depends on the amount of task-irrelevant response activation. *Psychological Research, 72, 515*–527.

Friedman, N., & Miyake, A. (2004). The relations among inhibition and interference control functions. *Journal of Experimental Psychology: General, 133,* 101–135.

Gade, M., & Koch, I. (2007). The influence of overlapping response sets on task inhibition. *Memory & Cognition, 35,* 603–609.

Goschke, T. (2000). Intentional reconfiguration and involuntary persistence in task-set switching. In S. Monsell & J. Driver (Eds.), *Attention and Performance XVIII: Control of cognitive processes* (pp. 331–355). Cambridge, MA: MIT Press.

Grange, J. A., & Houghton, G. (2009). Temporal cue–target overlap is not essential for backward inhibition in task switching. *Quarterly Journal of Experimental Psychology, 62,* 2068–2079.

Hübner, M., Dreisbach, G., Haider, H., & Kluwe, R. H. (2003). Backward inhibition as a means of sequential task-set control: Evidence for reduction of task competition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 289–297.

Hübner, R., Futterer, T., & Steinhauser, M. (2001). On attentional control as a source of residual shift costs: Evidence from two-component task shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 640–653.

Kleinsorge, T., & Heuer, H. (1999). Hierarchical switching in a multi-dimensional task space. *Psychological Research, 62,* 300–312.

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.

Logan, G. D. (1994). On the ability to inhibit thought and action: A users guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189–239). San Diego, CA: Academic Press.

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

Masson, M. E. J., Bub, D. N., & Ishigami, Y. (2007). Task set persistence modulates word reading following resolution of picture–word interference. *Memory & Cognition, 35, 2012*–2018.

Masson, M. E. J., Bub, D. N., Woodward, T. S., & Chan, J. C. K. (2003). Modulation of word-reading processes in task switching. *Journal of Experimental Psychology: General, 132,* 400–418.

Mayr, U. (2007). Inhibition of task sets. In D. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 27–44). Washington, DC: American Psychological Association.

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

Meiran, N., & Daichman, A. (2005). Advance task preparation reduces task error rate in the cueing task-switching paradigm. *Memory & Cognition, 33,* 1272–1288.

Meiran, N., & Kessler, Y. (2008). The task rule congruency effect in task switching reflects activated long term memory. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 137–157.

Meiran, N., Kessler, Y., & Adi-Japha, E. (2008). Control by Action Representation and Input Selection (CARIS): A theoretical framework for task switching. *Psychological Research, 72,* 473–500.

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin, 126,* 247–259.

Neill, W. T., Terry, K. M., & Valdes, L. A. (1994). Negative priming without probe selection. *Psychonomic Bulletin & Review, 1,* 119–121.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126, 200*–246.

Oberauer, K. (2001). Removing irrelevant information from working memory: A cognitive aging study with the modified Sternberg task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 948–957.

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

Philipp, A. M., Jolicœur, P., Falkenstein, M., & Koch, I. (2007). Response selection and response execution in task switching: Evidence from a go-signal paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 1062–1075.

Philipp, A. M., & Koch, I. (2006). Task inhibition and task repetition in task switching. *European Journal of Cognitive Psychology, 18,* 624–639.

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

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 763–797.

Schneider, D. W., & Logan, G. D. (2005). Modeling task switching without switching tasks: A short-term priming account of explicitly cued performance. *Journal of Experimental Psychology: General, 134,* 343–367.

Schneider, D. W., & Verbruggen, F. (2008). Inhibition of irrelevant category–response mappings. *Quarterly Journal of Experimental Psychology, 61,* 1629–1640.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). E-Prime (Version 1.0) [Computer software]. Pittsburgh, PA: Psychology Software Tools.

Schuch, S., & Koch, I. (2003). The role of response selection for inhibition of task sets in task shifting. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 92–105.

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

Sdoia, S., & Ferlazzo, F. (2008). Stimulus related inhibition of task set during task switching. *Experimental Psychology, 55,* 322–327.

Soetens, E. L. L., Boer, L. C., & Heuting, J. E. (1985). Expectancy or automatic facilitation? Separating sequential effects in two-choice reaction time. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 598–616.

Sohn, M. H., & Anderson, J. R. (2001). Task preparation and task repetition: Two-component model of task switching. *Journal of Experimental Psychology: General, 130,* 764–778.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica, 30,* 276–315.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

Sudevan, P., & Taylor, D. A. (1987). The cuing and priming of cognitive operations. *Journal of Experimental Psychology: Human, Perception and Performance, 13,* 89–103.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 37(A),* 571–590.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 54(A),* 321–343.

Trope, Y., & Fishbach, A. (2000). Counteractive self-control in overcoming temptation. *Journal of Personality and Social Psychology, 79,* 493–506.

Wallhoff, F. (2006). *Facial expressions and emotion database* [Database]. Munich, Germany: Technische Universität München. Retrieved from http://www.mmk.ei.tum.de/~waf/fgnet/feedtum.html

Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: Role of episodic stimulus–task bindings in task-shift costs. *Cognitive Psychology, 46,* 361–413.

Received June 29, 2009
Revision received February 23, 2010
Accepted March 1, 2010 ■