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Evidence for task-specific resolution of response conflict

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When a target requires different responses to a relevant and to an irrelevant task in a task-switching paradigm, there is response conflict. This target-induced response conflict was combined with conflict caused by a subliminally presented prime presented prior to the target. We found that target-related conflict reduced prime-induced conflict effects within the same trial. However, target-related conflict modified prime-related conflict effects according to the irrelevant stimulus–response (S–R) rule, but not according to the relevant S–R rule. Moreover, trial-to-trial modulations of the target congruency effect were observed in task repetition trials, but not in task switch trials. These results indicate that conflict resolution mechanisms, at least under the present circumstances, operate in a strictly task-specific manner.

Humans are confronted with complex situations in which different stimuli require different responses. Just imagine a typical situation in which you are preparing dinner: Boiling water tells you that it is time to put the rice in the pot. At the same time, a sound of the timer might urge you to remove the turkey from the oven. And while you are removing the turkey, you hear the telephone ring and a knock on the door. The best strategy in such a situation would be to just concentrate on the most important task and to ignore other, distracting stimuli.

However, numerous experimental studies have shown that stimulus processing is not restricted to task-relevant information but that task-irrelevant information influences performance as well. In so-called *conflict* tasks, it has been shown that location (Simon, 1969), word meaning (Stroop, 1935), or distractor (Eriksen & Eriksen, 1974) information is processed despite being task irrelevant. In task-switching situations, performing the currently relevant task is hindered when stimuli are presented that belong to another, currently irrelevant task (Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). And finally, in priming studies, it has been shown that task-irrelevant information influences performance even when it is presented not simultaneously with, but in close succession to, the target and when the irrelevant prime stimuli are presented subliminally—that is, too quickly to be recognized consciously (see Dehaene et al., 1998; Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003).

Conflict and Conflict Resolution

In all these settings, conflict is determined by comparing incongruent and congruent stimulus conditions: When the irrelevant stimulus requires a response different from that required by the relevant stimulus, response times (RTs; and quite often, also error rates) are increased. However, processing of irrelevant information is not as automatic as is suggested at first glance. Several studies have shown that congruency effects (measured as the difference between congruent and incongruent trials) depend on congruency sequence. After an incongruent trial, the congruency effect in the current trial is reduced and, sometimes, even eliminated (see Gratton, Coles, & Donchin, 1992; Kunde, 2003; Kunde & Wühr, 2006; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002).

These sequential modulations of congruency effects have been taken as evidence for a *conflict adjustment mechanism* (such as that proposed by Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Presumably, the anterior cingulate cortex (ACC) registers the occurrence of conflict and triggers "compensatory adjustments in cognitive control" (Botvinick et al., 2004, p. 539). Thus, top-down processes are assumed to compensate for conflict. There are several conflict resolution models that differ regarding the nature of these top-down processes; for example, it has been proposed that conflict induces a more cautious mode of

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information processing by stressing accuracy over speed (Gratton et al., 1992), increasing attention toward the target (Botvinick et al., 2001), or blocking automatic stimulus processing (Stürmer et al., 2002).

Currently, it is under debate whether these conflict adjustment mechanisms operate in a manner that is specific or nonspecific to type of conflict. That is, a single conflict control mechanism might exist that is activated by and has an impact on every type of conflict, or various control modules triggered by and impacting on specific types of conflict might exist.

In recent research, an attempt has been made to decide between both accounts by combining different conflict settings. If conflict resolution is type specific, conflict of one type should not affect conflict of another type. Consequently, the types of conflict should combine additively. If conflict resolution is not type specific, incongruency of one type should reduce the congruency effect of the other type. Hence, an (underadditive) interaction of congruency effects should ensue. Unfortunately, existing evidence for this proposal is mixed. Combining Simon and Eriksen tasks did, indeed, reveal an underadditive interaction (at least for some quintiles of the RT distribution; Hommel, 1997), whereas combinations of Simon and Stroop interference (Hommel, 1997) and combinations of spatial and temporal Simon interference (Kunde & Stöcker, 2002) did not.

Given this inconclusive evidence, we think that it is a reasonable strategy to further explore conflict and conflict resolution in different settings. Perhaps broadening the kind of conflict investigated will lead to more insights into the underlying processes. In the present study, we investigated conflict in a task-switching setting and added conflict caused by subliminal primes. The favorable aspect of such subliminal primes was that they were unlikely to induce conflict resolution themselves (Kunde, 2003; Mayr, 2004). Therefore, we could investigate how these subliminal priming effects would be shaped by target conflict, without taking the risk that they themselves might affect the target conflict.

Exploring Conflict in a Task-Switching Setting

In task-switching experiments (e.g., Allport et al., 1994; Meiran, 1996; Rogers & Monsell, 1995), participants are asked to switch between different task requirements. Conflict by means of target congruency effects arises when targets and responses are bivalent—that is, when the same targets and responses are used for both tasks. For example, participants might switch between categorizing a digit as being smaller or larger than 5 or as being odd or even by pressing left and right response keys. The mapping for the tasks might be smaller–left/larger–right and even–left/odd–right. With this mapping, the target "7" would require a right response in both tasks, and it is thus called *congruent*. By contrast, the target "6" would require a right response in the magnitude task but a left response in the parity task. The number "6" would thus be an *incongruent* target. Usually, RTs and error rates are increased for incongruent targets, in comparison with congruent ones (e.g., Goschke, 2000; Kiesel, Wendt, & Peters, in press; Meiran, 1996; Rogers & Monsell, 1995), reflecting target conflict.

Within such a setting, we additionally introduced subliminal primes that were presented prior to the target. In conventional prime–target paradigms, participants respond according to a (task-relevant) target. Prior to the target, an irrelevant stimulus, the so-called *prime*, is presented. Performance is impaired if the prime requires a different, rather than the same, response as the target—that is, if the prime is inconsistent, rather than consistent.[1] In order to ensure that the prime is presented subliminally, it is masked and presented for less than 50 msec (see Dehaene et al., 1998).

Introducing subliminal primes into our task-switching setting allows us to assess two priming effects. As an illustration of the possible priming effects, imagine that in the previous example, the magnitude task is currently relevant. As the target, the number "7" is presented, and it requires participants to press the right response key (see Figure 1). Prior to the target, a prime (also a digit) is presented subliminally that may activate responses according to the relevant, as well as the irrelevant, task set.

In this setting, first, the prime can be either consistent (as is the digit "8" in the example) or inconsistent (as is the "3") according to the currently *relevant* task set. Second, the prime can be either consistent (as is the "3") or inconsistent (as is the "8") according to the currently *irrelevant* task set. In addition, a third effect is expected, since the target itself is either congruent (as is the "7") or incongruent (as is the "6").

Table 1 shows the distribution of the 64 possible prime–target combinations for the $2 \times 2 \times 2 = 8$ different combinations of the two prime consistency relations and the target congruency relation, provided that the participants currently perform the magnitude task with the mapping smaller–left and larger–right and the (currently irrelevant) parity mapping even–left and odd–right. Identical prime–target pairs (1–1 to 9–9, given in bold), which can be assumed to be especially effective (Bodner & Dypvik, 2005), occur only in two of the eight conditions: If the target is congruent, they occur when the prime is consistent with respect to both the currently relevant and the irrelevant task. In contrast, if the target is incongruent, they occur under the condition in which the prime is consistent with respect to the relevant task but inconsistent with respect to the irrelevant task. This unequal distribution might distort the interesting impact of target congruency on the task-specific prime consistency effects. Thus, data from identical prime–target pairs were excluded from further analyses.

The aim of the experiment was to explore whether conflict resolution in such a task-switching setting operates in a task-unspecific or a task-specific way. Therefore, we considered whether target congruency affects one or both of the possible prime consistency effects. Our expectations were as follows: If target-induced response conflict is resolved separately for each task, an incongruent target that caused conflict according to the irrelevant task would trigger a task-specific conflict resolution process. Thus, the prime consistency effect according to the same (currently irrelevant) task would be decreased (or absent). Therefore, target congruency and prime consistency for the currently irrelevant task would be supposed to interact underaddi-

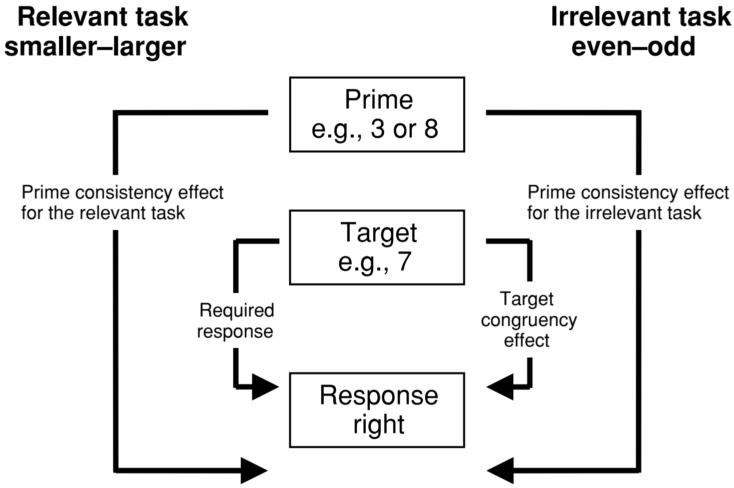

Figure 1. Potential congruency and consistency effects in Experiment 1. The target determines the required response according to the currently relevant task set. The prime may cause a prime consistency effect for the relevant task and a prime consistency effect for the irrelevant task, and the target is expected to cause a target congruency effect.

tively, whereas the prime consistency effect for the relevant task would be independent of and, thus, unaffected by target congruency. If, however, conflict resolution operates on a general level, the prime consistency effects according to the relevant *and* the irrelevant task would be expected to be smaller in trials with incongruent targets than in those with congruent targets, since nonspecific conflict resolution would decrease both of them. Thus, an underadditive interaction between the target congruency and both prime consistency effects should emerge.

METHOD

Participants

Twenty-four volunteers (19–32 years of age) took part in an individual session of approximately 60 min either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

Apparatus and Stimuli

Stimulus presentation and collection of responses were performed by an IBM-compatible computer with a 17-in. VGA display controlled by E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Stimulus presentation was synchronized with the vertical retraces of a 70-Hz monitor, resulting in a vertical refresh rate of approximately 14.5 msec. Responses were executed with the index fingers of both hands and were collected with the outer buttons of the PST response box (Psychology Software Tools).

The digits 1–9, except for 5, were used as primes and targets. The primes were presented for two refresh cycles of the display (i.e., 29 msec). They were preceded and followed by a mask consisting of five randomly chosen symbols (out of §, $,%, &, ?, and #) with a duration of 72 msec. The target was presented for 200 msec imme-

Table 1
Distribution of the 64 Different Prime–Target Combinations for the Two Different Prime Consistency Relations and the Target Congruency Relation Exemplarily for the Case in Which Participants Currently Perform the Magnitude Task With the Mapping Smaller–Left and Larger–Right and the (Currently Irrelevant) Parity Mapping Even–Left and Odd–Right

	Irrelevant Task (e.g., Even–Odd)			
	Target Congruent		Target Incongruent	
Relevant Task (e.g., Smaller–Larger)	Prime Consistent	Prime Inconsistent	Prime Consistent	Prime Inconsistent
Prime consistent	**2–2**, 4–2	1–2, 3–2	2–1, 4–1	**1–1**, 3–1
	2–4, **4–4**	1–4, 3–4	2–3, 4–3	1–3, **3–3**
	7–7, 9–7	6–7, 8–7	7–6, 9–6	**6–6**, 8–6
	7–9, **9–9**	6–9, 8–9	7–8, 9–8	6–8, **8–8**
Prime inconsistent	6–2, 8–2	7–2, 9–2	6–1, 8–1	7–1, 9–1
	6–4, 8–4	7–4, 9–4	6–3, 8–3	7–3, 9–3
	1–7, 3–7	2–7, 4–7	1–6, 3–6	2–6, 4–6
	1–9, 3–9	2–9, 4–9	1–8, 3–8	2–8, 4–8

Note—Identical prime–target pairs are shown in boldface.

diately after the postmask. All the characters were presented in white on a black background. The prime and the target were presented in Arial 44 point type; the symbols for the mask were presented in Arial 48 point.

Design and Procedure

Each trial started with an auditory cue (200 or 800 Hz) that indicated the currently relevant task. The stimulus, consisting of premask, prime, postmask, and target, was presented 1,000 msec later. RTs were recorded from the onset of the target up until the onset of the response. The next trial started after 150 msec had passed. Errors were indicated by a beep.

The participants first performed two training blocks with 32 trials each. The experiment consisted of eight experimental blocks with 128 trials. In each block, the combination of prime (8) × target (8) × task (2) was presented once. The response mappings for both the magnitude and the parity tasks and the tones used to signal each task were counterbalanced over participants.

After the experiment, the participants performed a detection task to test whether they were able to consciously perceive the primes. The participants were fully informed about the precise structure of the prime stimuli and were then presented with 128 trials identical to the experimental trials. In order to asses whether the participants were able to detect the prime, in half of the trials the neutral sign "0," instead of a prime, was presented. The participants were to indicate whether the neutral sign was presented or which prime number was presented in each trial by pressing the corresponding key on the number keyboard.

RESULTS

Prime Visibility

To assess prime visibility, the discrimination performance between neutral signs and primes was computed. To compute the signal detection value d', hit and false alarm proportions of 0 or 1 were corrected according to the log-linear rule (Goodman, 1970; Hautus, 1995). That is, in the two-by-two contingency table that defines the performance of observers, .5 is added to each cell. The participants' discrimination performance for primes versus neutral signs was $d' = .06$ (the mean hit rate was 76.4%, false alarm rate 73.8%) and did not deviate from zero [$t(23) = 1.29, p > .2$]. Thus, the primes were indeed unidentifiable, the usual result under the experimental conditions that we adopted (e.g., Dehaene et al., 1998).

Within-Trial Analyses

The first trial of each block, trials after an error (8.5%), and trials with RTs deviating more than 2.5 standard deviations from the mean RT of each experimental condition per participant (2.6%) were considered to be outliers and were excluded from the analysis. Furthermore, data from prime–target repetitions were excluded, for the reasons described above. For the remaining trials, mean RTs for correct trials and mean percentages of error (PEs) were computed for each participant and separately for each combination of the factors of target congruency, prime consistency for the relevant task, and prime consistency for the irrelevant task (see Table 2).

An ANOVA with the within-subjects factors of target congruency, prime consistency for the relevant task, and prime consistency for the irrelevant task over mean RTs revealed that the participants responded more slowly for incongruent targets (611 msec) than for congruent targets (572 msec) [$F(1,23) = 14.9, p < .001$]. In addition, RTs were increased if the prime was inconsistent (597 msec), rather than consistent (586 msec), according to the currently relevant task [$F(1,23) = 6.6, p < .01$].

Moreover, there was a significant interaction between target congruency and prime consistency for the irrelevant task, which is depicted in Figure 2 [$F(1,23) = 16.0, p < .001$]. If the target was congruent, there was a prime consistency effect for the irrelevant task (inconsistent prime, 579 msec; consistent prime, 565 msec). In contrast, if the target was incongruent, the prime consistency effect for the irrelevant task was reversed (inconsistent prime, 604 msec; consistent prime, 618 msec). All other effects were not significant ($ps > .22$).

The same ANOVA for the error rates showed significant main effects for the factors of target congruency [$F(1,23) = 64.7, p < .001$] and prime consistency for the relevant task [$F(1,23) = 9.5, p < .01$]. The participants made more errors in trials with incongruent targets (13.1%) than in those with congruent targets (4.4%) and in trials in which the prime was inconsistent (9.2%) than in those in which the prime was consistent (8.2%) for the relevant task set.

There was a marginally significant interaction for the factors of target congruency and prime consistency for the relevant task [$F(1,23) = 3.8, p = .064$]. The prime consistency effect for the relevant task decreased somewhat for incongruent targets (13.3% vs. 12.8%), as opposed to congruent targets (5.2% vs. 3.6%). No other effects reached significance ($ps > .33$).

Altogether, our results thus indicate that conflict is resolved task specifically: An incongruent target that affords an inadequate response according to the currently irrelevant task set modifies priming effects according to the irrelevant task, but not according to the relevant task.

Trial-to-Trial Analyses

To further corroborate the existence of task-specific conflict control, we also looked at trial-to-trial modulations of the target congruency effect. Conflict control is assumed to reduce congruency effects following an in-

Table 2
Response Times (RTs, in Milliseconds) and Error Rates (Percentages of Error [PEs]) Depending on Target Congruency and Prime Consistency for the Relevant Task and Prime Consistency for the Irrelevant Task

	Target Incongruent		Target Congruent	
	RT	PE	RT	PE
Relevant prime inconsistent				
Irrelevant prime inconsistent	609	13.3	580	4.8
Irrelevant prime consistent	629	13.4	570	5.5
Relevant prime consistent				
Irrelevant prime inconsistent	600	13.3	578	3.5
Irrelevant prime consistent	607	12.4	561	3.6

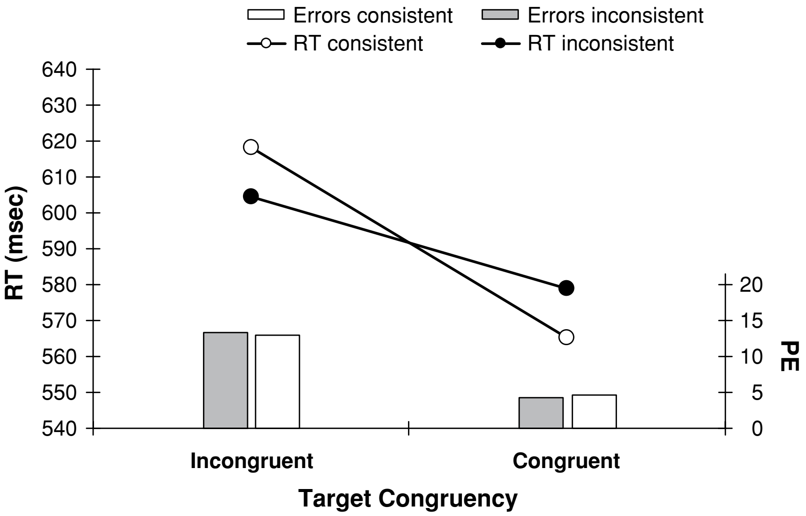

Figure 2. Response times (RTs; lines) and error proportions (percentages of error [PEs]; bars) to incongruent and congruent targets, according to irrelevant-task consistency of the prime.

congruent event in the preceding trial (Botvinick et al., 2001). If conflict is, indeed, registered and solved task specifically, sequential modulations of congruency effects should be task specific as well. In our setting, we would expect that target congruency in trial $n-1$ influences target congruency in trial n only in task repetition trials. In contrast, in task switch trials, no sequential modulation of target congruency effect should be observed, since the conflict results from two different tasks in this case. To asses this issue, we computed an ANOVA with the within-subjects factors of task repetition versus switch, target congruency in trial $n-1$, and target congruency in trial n, which revealed significant three-way interactions between all factors [$F(1,23) = 10.1, p < .01$, for RTs; $F(1,23) = 13.8, p < .001$, for PEs].

Figure 3 illustrates this interaction. The left panel shows that in task repetition trials, the target congruency effect is modulated by target congruency in trial $n-1$. If the target in trial $n-1$ was congruent, the participants responded more slowly and more erroneously for incongruent than for congruent targets in trial n. However, this congruency effect was largely reduced when the target in trial $n-1$ was incongruent [post hoc tests revealed that $F(1,23) = 27.9, p < .001$, and $F(1,23) = 55.0, p < .001$, for RTs and error rates, respectively, for the interaction between target congruency in $n-1$ and n in task repetition trials]. In contrast, in task switch trials, the target congruency effect was not modulated by target congruency in trial $n-1$ [RTs, $F(1,23) < 1$; error rates, $F(1,23) = 2.0, p = .17$, for the interaction between target congruency in $n-1$ and n in task switch trials; see the right side of Figure 3]. Thus, this data pattern is exactly what would be predicted from a task-specific conflict resolution model. Finally, in task switch trials, RTs generally increased when the target in trial $n-1$ was incongruent, as opposed to congruent [$F(1,23) = 8.0, p < .01$].

DISCUSSION

As was expected, a strong effect of target congruency emerged. The participants responded more slowly and less accurately to incongruent targets than to congruent targets. Thus, a target that requires different responses for two randomly varying tasks generates sizeable conflict. Next, there was a general priming effect for the relevant task: The participants responded more quickly and more accurately when the subliminally presented prime was consistent than when it was inconsistent according to the currently relevant task set. This effect did not interact with target congruency when the RT data were considered, and only a marginally significant interaction was observed for error rates. Thus, it seems that the priming effect according to the currently relevant task is not affected by target congruency.

However, we observed an interaction between target congruency and prime consistency for the irrelevant task (see Figure 2). When the target was congruent, there was a priming effect for the irrelevant task. When the target was incongruent, the priming effect due to the irrelevant task set was reversed; that is, the participants responded more slowly and were more error prone for consistent than for inconsistent primes according to the currently irrelevant task set.

We assume that incongruent targets cause a response conflict because the target activates different responses according to the relevant versus irrelevant task rules. To overcome this conflict and to perform the currently relevant task correctly, response activation according to the rules of the irrelevant task must be inhibited. This inhibition of response activation due to irrelevant stimulus–response (S–R) rules spreads to prime-induced response activation as well. Therefore, with incongruent targets, the already ongoing response activation from subliminal primes is inhibited. Presumably, with a sufficiently strong

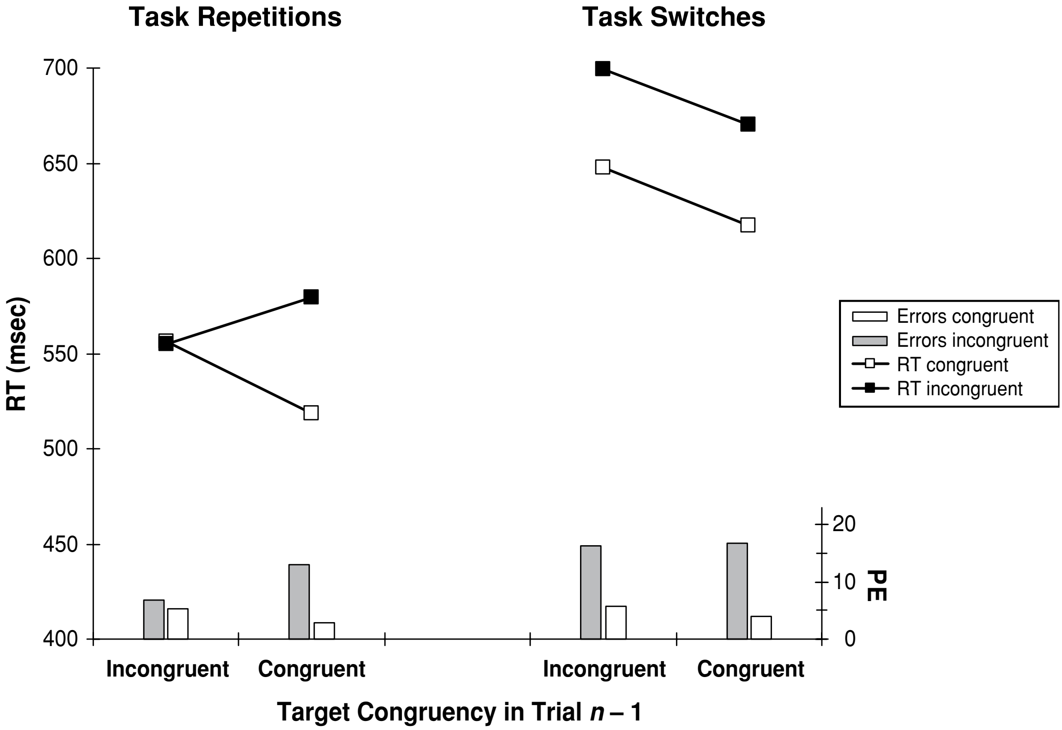

Figure 3. Response times (RTs; lines) and error rates (percentages of error [PEs]; bars) for incongruent (filled) and congruent (unfilled) targets depending on target congruency in trial $n-1$ for task repetitions (left side) and task switches (right side).

target-related response conflict, the inhibition of the much weaker prime-related response activation produces an overshot, thereby resulting in reversed priming effects.

Sequential trial-to-trial analyses corroborated the assumption of task-specific control devices. An incongruent target reduced target congruency in the next trial, but only when the task repeated, and not when the task changed. It should be noted that an incongruent trial increased RTs overall even when the task switched. This should not, however, be interpreted as an effect of task-nonspecific conflict resolution. In fact, this result is a well-known observation that has been ascribed to a persisting inhibition of a task set (Goschke, 2000). It is assumed that in task-switching settings, task conflict is stronger in incongruent than in congruent trials and, therefore, the irrelevant task set has to become more inhibited in incongruent than in congruent trials (indeed, it is questioned whether there is any inhibition at all in congruent trials). For the present setting, this means that in trial $n-1$, the incongruent task set is inhibited. When trial n is a task switch trial, participants have to switch to the task that they inhibited in $n-1$. Due to sustained inhibition of the specific task set, switching to it takes more time than does switching after congruent trials. Thus, this observation also points to a task-specific conflict resolution working on the broader level of task sets.

To conclude, our results contradict the assumption of general conflict adjustment. Since conflict is solved task specifically, a possible conflict adjustment mechanism must also recognize the source of conflict. Not simply the occurrence of conflict, but also the source of conflict is considered when conflict is resolved. This assumption is in line with the results of a recent study by Fan and colleagues (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). They measured brain activity by means of fMRI while participants performed a Simon, a Stroop, and an Erikson task. Despite conflict causing common activation (in the ACC and prefrontal areas), the peak activation and spatial extent across the three tasks were not identical. Therefore, the authors concluded that “either distinct networks for each conflict task or a single network that monitors conflict with different sites” (p. 42) is used to resolve conflict.

Unfortunately, the matter becomes a bit more complicated when one takes into account existing instances of task-nonspecific effects (Kunde & Wühr, 2006). In that study, participants responded with a left or right response to left- and right-pointing arrows that were presented in a left or right location. In addition, a prime arrow preceded each target. Two types of congruency effects were found: a Simon effect (faster responding when target and response location matched than when they did not), and a prime–target congruency effect (faster responding when prime and target direction matched than when they did not). Interestingly, an incongruent Simon-type event reduced the prime–target congruency effect in the next trial. It thus appears that under certain circumstances, sequential modulations of congruency effects cross the border between different types of task. One aspect that might be relevant here is the involvement of a common S–R feature that was present in the study by Kunde and Wühr (2006; both tasks included the stimulus feature left and right), but not in the present experiment, in which the tasks referred to different features of otherwise identical stimuli and responses (parity vs. magnitude). Further experiments are certainly warranted to determine when (and when not) mutual interactions of congruency within and between trials can be observed.

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NOTE

1. In the present study, we refer to the prime–response relation as consistency, in order to avoid confusing prime– and target–response relations. However, several terms, such as *consistency*, *congruency*, and *compatibility*, have been used to describe the prime relation in subliminal priming experiments.

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