

# Irrelevant Stimulus Processing When Switching Between Tasks

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**Abstract.** Frequent switching between two tasks afforded by the same stimuli is associated with between-task congruency effects, that is, relatively impaired performance when a stimulus affords different responses as compared to the same responses in both tasks. These congruency effects indicate some form of application of the stimulus-response (S-R) rules of the currently irrelevant task. Between-task congruency effects are usually enhanced on task switch trials compared with task repetition trials. Here we investigate whether this interaction reflects stronger proactive interference from the irrelevant task on switch trials or whether performance on switch trials is characterized by generally enhanced susceptibility to task-irrelevant information processing. To this end, we contrasted between-task congruency effects with interference exerted from flanker stimuli taken from the current task (Experiment 1) and from spatial-numerical association of response codes (SNARC; Experiment 2). In both experiments, between-task congruency effects were larger on switch trials than on repetition trials, whereas interference from the other source remained constant, thus demonstrating that switch trials are not characterized by generally increased distractibility.

**Keywords:** stimulus processing, task switching, irrelevant stimuli, congruency effects, interference

The cognitive literature comprises overwhelming evidence for stimulus processing which is irrelevant regarding a currently performed task. Reaction time (RT) and accuracy are contingent on both irrelevant perceptual stimulus features (e.g., flanker or Stroop interference; Eriksen & Eriksen, 1974; Stroop, 1935) and non-perceptual stimulus information (e.g., interference because of spatial-numerical association of response codes [SNARC]; Dehaene, Bossini, & Giraux, 1993).

A particular case of such interference effects can be observed in task switching situations. Here, performance is usually impaired when a stimulus includes a feature which affords the currently irrelevant task compared to “single-affordant” stimuli (*exogenous task cuing*; e.g., Fagot, 1994; Rogers & Monsell, 1995). Provided the same set of responses is used, stimuli which afford both tasks can be associated with the same or with different responses in the two tasks. For example, when participants switch between a digit classification task that requires a left-sided keypress if the current digit is even and a right-sided keypress if the digit is odd, and a letter task that requires the left-sided keypress for vowel classifications and the right-sided keypress for consonant classifications, presenting the digit 2 alongside with the letter *A* would call for the same response under both tasks’ instructions, whereas presenting the digit 2 alongside with the letter *B* would call for different responses depending on the currently relevant

task. These two conditions are usually referred to as (response) *congruent* and *incongruent*, respectively, and responding is usually impaired for incongruent rather than congruent targets (e.g., Fagot, 1994; Kiesel, Wendt, & Peters, 2007; Meiran, 2000; Rogers & Monsell, 1995; Wendt & Kiesel, 2008; for reviews see Kiesel et al., 2010; Vandierendonck, Liefoghe, & Verbruggen, 2010). In the current study, we denote the performance difference between incongruent and congruent targets as the *between-task congruency effect*.

Both the exogenous task cuing effect and the between-task congruency effect tend to be more pronounced on task switch trials than on task repetition trials (e.g., Fagot, 1994; Kiesel et al., 2007; Meiran & Kessler, 2008; Rogers & Monsell, 1995). Such switch-specific enhancement of interference related to representations of the currently irrelevant task is not surprising given that these task representations (i.e., the irrelevant task set) are assumed to have higher activation after recent application (Allport, Styles, & Hsieh, 1994; Gilbert & Shallice, 2002; Koch, 2001; Koch & Allport, 2006).

A theoretical alternative to this proactive interference account, however, is to assume that task switch trials and task repetition trials differ more generally regarding susceptibility to irrelevant stimulus information. Two lines of research are in line with the assumption that irrelevant stimulus information per se induces more interference in task switch compared

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to task repetition trials. First, more pronounced distractibility on task switch trials seems a plausible possibility in light of findings of enhanced interference effects under increased working memory load (for review see Lavie, 2005). Specifically, flanker interference was increased under conditions of concurrent working memory load (Lavie, Hirst, de Fockert, & Viding, 2004). Converging evidence was obtained in a visual search task (Lavie & de Fockert, 2005), a Stroop-like task (de Fockert, Rees, Frith, & Lavie, 2001), and in a neuro-imaging study which involved irrelevant motion (Rees, Frith, & Lavie, 1997). Lavie's load theory (Lavie et al., 2004) accounts for these findings by assuming that the degree of processing selectivity depends on maintaining processing priorities in working memory and that drawing on working memory's capacity disrupts such maintenance, thereby resulting in relatively enhanced processing of irrelevant stimulus aspects. Assuming that executive demands of task switching (i.e., task-set reconfiguration) draw on the same resources as working memory load (e.g., Baddeley, Chincotta, & Adlam, 2001), similar consequences would be expected on a task switch trial as under conditions of additional working memory load.

Second, task switch compared to task repetition trials might differ because in task switch trials the shielding function of task set is not active to the same extent as in task repetition trials (Dreisbach & Wenke, 2011). According to Dreisbach and Haider (2008, 2009) the formation of separate task sets reduces interference effects due to irrelevant information because task sets support shielding current task performance from irrelevant stimulus processing. In task switch trials this shielding function of task sets has to be relaxed to enable switching to the alternative task (Dreisbach & Wenke, 2011). Inasmuch as shielding does not selectively affect the competitor task set, switch trials should be generally more susceptible to interference. Indeed, Dreisbach and Wenke (2011) found that the sequence of a stimulus feature (i.e., stimulus color or font), that was unrelated to both tasks between which participants switched, interacted with response sequence on task switch trials but not on task repetition trials, suggesting that stronger shielding on task repetition trials prevented processing of this feature from affecting performance.

To conclude, the proactive interference account predicts more interference by stimulus material related to the currently irrelevant task while interference from other sources should not vary for task switch and task repetition trials. In contrast, both versions of the notion of generally increased susceptibility to irrelevant stimulus processing on task switch trials would predict more pronounced interference effects not only by stimulus material related to the currently irrelevant task but also from unrelated sources. To test these possibilities, we examined interference from irrelevant stimuli of the currently relevant task (Experiment 1) and semantic information of a target stimulus (Experiment 2) on switch and repetition trials.

It is worth noting that a number of previous studies investigated the impact of congruency depending on the congruency level of the previous trial by presenting different types of irrelevant stimuli (e.g., irrelevant flanker stimuli and irrelevant stimulus location, Stürmer, Seiss, & Leuthold,

2005; Wendt, Kluwe, & Peters, 2006) and analyzing the size of congruency effect regarding one stimulus type as a function of previous congruency of the same or of the other stimulus type (Funes, Lupianez, & Humphreys, 2010a, 2010b; Notebaert & Verguts, 2008; for an overview see Egner, 2008). Although trials involving different types of irrelevant stimuli are frequently referred to as different tasks – and thus allow for a distinction of task repetitions and task switches – it is important to note that these manipulations lack a crucial feature regarding the research interest of the current study. More precisely, following up on the vast majority of task switching studies, we were primarily interested in task combinations associated with divergent stimulus-response (S-R) mappings, thereby necessitating some form of task-set reconfiguration on task switch trials. Consequently, studies that investigated different conflict types while maintaining the same task instruction (e.g., Funes et al., 2010a, 2010b) or studies that involve task switches, yet with univalent stimulus sets that do not require a reconfiguration of the S-R mapping (e.g., Fischer, Plessow, Kunde, & Kiesel, 2010; Notebaert & Verguts, 2008), do not allow predictions for actual task switching situations that necessitate a reconfiguration of the S-R mapping.

## Experiment 1

In our first experiment we contrasted interference evoked by flanker stimuli taken from the set of the currently irrelevant task and from the set of the currently relevant task on task switch and task repetition trials. To this end, we administered two tasks comprising different sets of stimuli (i.e., digits vs. letters). To compare within-task and between-task interference, the target character – which was always presented at a central location – was flanked by an instance of the same or of the other stimulus category. Using the same set of responses for both tasks, a flanker taken from the irrelevant task could be congruent or incongruent to the current target stimulus, similar as a flanker taken from the relevant task could be congruent or incongruent to the current target stimulus, thereby allowing us to compare between-task and within-task congruency effects.

It should be noted that using a classical flanker paradigm, in which participants have pre-knowledge about the location of the target and flankers, allowing them to support task selection by spatial attention, is liable to yield lower between-task interference effects than more usual task switching make-ups, in which the locations of the characters of the relevant and the irrelevant task are chosen randomly on each trial (e.g., Rogers & Monsell, 1995) or in which the stimulus features associated with the relevant and the irrelevant task are presented in an integrated stimulus object (e.g., Fagot, 1994). Because the certainty of the target location provided an unambiguous task cue, no additional information was necessary to indicate the currently relevant task. We presented the experiment in two versions, one without explicit task cues, and one including the presentation of additional explicit task cues, in advance of the imperative stimulus, which allowed for preparation of the upcoming task.

Comparing interference effects between conditions associated with different amounts of preparation of the upcoming task is interesting here because between-task congruency effects have been unaffected by preparation in several task switching studies (e.g., Allport et al., 1994; Fagot, 1994; Meiran, 1996; Rogers & Monsell, 1995), indicating that preparatory activation of the set for an upcoming task does not necessarily include increased shielding from interference.

Regarding between-task interference, we expected to replicate previous findings of larger task cuing and congruency effects on switch than on repetition trials (e.g., Kiesel et al., 2007; Meiran & Kessler, 2008; Rogers & Monsell, 1995). (Lacking a specific type of neutral flankers, task cuing effects could be assessed by comparing performance on trials with flankers taken from the irrelevant task with performance on trials with flankers from the relevant task.) The critical question was whether within-task congruency effects would also increase on switch trials.

## Method

### Participants

Forty students of the Helmut Schmidt University/University of the Federal Armed Forces Hamburg participated in exchange for fulfillment of partial course requirements. Seven female and thirteen male participants, ranging in age from 22 to 28 years, were assigned to the cuing group, and another 7 female and 13 male participants, ranging in age from 22 to 28 years, were assigned to the no-cuing group.

### Apparatus and Stimuli

An IBM-compatible computer, equipped with a 17-inch LCD monitor with a refresh rate of 60 Hz, was used for stimulus presentation and response sampling. Participants viewed the screen from a distance of about 60 cm. All letter and digit stimuli were presented in white color on a dark gray background and occurred inside a rectangular frame, outlined in white color, which was centered on the screen and extended 13.0 cm horizontally and 7.5 cm vertically. The digits 1–9 (except 5) and the letters A, E, I, U, G, K, L, and M served as stimulus characters. The target stimulus was always presented in the center of the screen between two flanker stimuli, thus forming a horizontal three-character string. Both flankers were identical and could belong to either the relevant or the irrelevant task. Targets and flankers extended 0.3–0.9 cm horizontally and 1.1 cm vertically.

Responses were given by pressing one of two response keys which were mounted on an external rectangular keyboard (10 cm × 18 cm) providing 0.1 ms timing accuracy. The response keys had a size of 1.0 × 1.0 cm and were spaced by 8.0 cm apart (parallel to the keyboard's long axis). Participants pressed the response keys with the index

or middle fingers of their left and right hand. Participants were instructed to classify the central character as odd or even, when it was a digit, and as vowel or consonant, when it was a letter. They pressed the left key to indicate even and vowel, and the right key to indicate odd and consonant.

### Procedure

On each trial, the target and the flanker character were chosen randomly. They were presented simultaneously and remained on the screen until a response key was pressed. Throughout each block of trials, the rectangular frame was shown. In the cuing group, it was filled with red or cyan color to indicate the upcoming task. Red indicated the digit task and cyan indicated the letter task. These task cues were shown immediately after a response key was pressed, and remained on the screen for 300 ms, followed by a blank screen (except for the rectangular frame) for 200 ms, after which the imperative stimulus was presented. In the no-cuing group, only the white rectangular frame was shown during the response-stimulus interval, which was 500 ms.

At the start of the experiment, participants received instructions for the digit task, followed by a 20-trial practice block of the digit task only. The flankers were chosen at random from both tasks. Likewise, instructions and a 20-trial practice block were given for the letter task. The final practice block consisted of both tasks mixed in random order and comprised 30 trials. After the practice phase, ten mixed blocks, each comprising 99 trials, were administered. Between blocks, participants were informed about their mean reaction time, error rate, and number of blocks left.

Participants were instructed to identify the target by pressing the assigned response key as quickly as possible while avoiding errors. In case of an incorrect response, the German word "falsch" ("incorrect") occurred for 800 ms slightly below the center of the screen. Then the trial was repeated with an identical stimulus. Such repetitions of incorrect trials were not counted as trials. A complete session took approximately an hour.

## Results

The first three trials of each experimental block were considered "warm-up" trials and did not enter the statistical analyses. In addition, trials with RTs deviating more than 2.5 standard deviations from the mean RT of each experimental condition per participant were considered outliers and were excluded from the analysis. To avoid stimulus priming, we also excluded data from trials in which a digit or a letter was repeated from the preceding trial.

An analysis of variance (ANOVA) with repeated measures on the factors Task Transition (2: repetition, switch), Flanker Type (2: from relevant task, from irrelevant task),

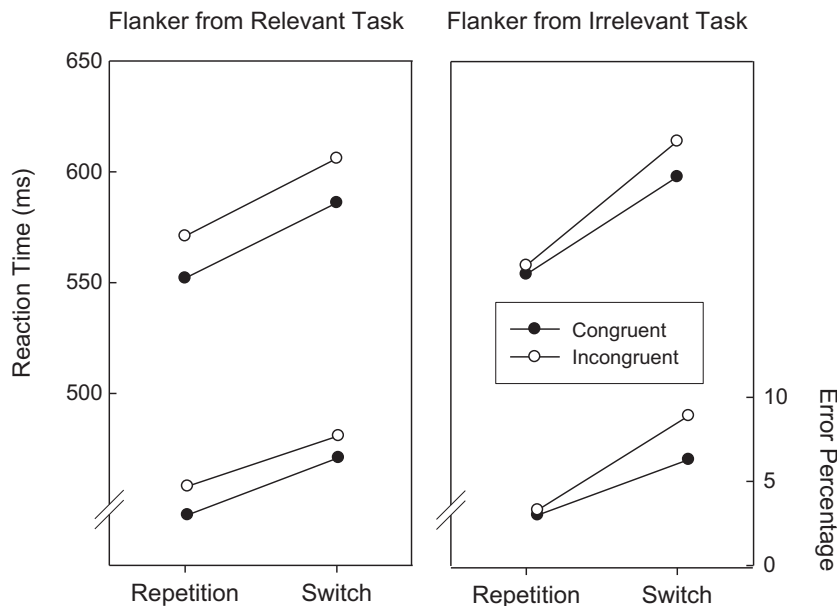


Figure 1. Mean reaction times and error percentages of Experiment 1 as a function of task transition, flanker type, and congruency.

Flanker Congruency (2: congruent, incongruent), and Response Sequence (2: repetition, alternation),<sup>1</sup> and the between-subjects factor Task Cuing, on the mean RTs yielded significant main effects of Task Sequence, and Flanker Congruency,  $F(1, 38) = 70.14$ ,  $p < .001$ , and  $F(1, 38) = 50.17$ ,  $p < .001$ , indicating task switch costs of 40 ms and a flanker congruency effect of 16 ms. Also the two-way interaction of Task Transition and Flanker Type reached significance,  $F(1, 38) = 9.96$ ,  $p = .003$ , indicating that on task switch trials but not on task repetition trials flankers from the irrelevant task impaired performance relative to flankers from the relevant task. Figure 1 displays these results. There was also a two-way interaction of Task Transition and Response Sequence,  $F(1, 38) = 30.05$ ,  $p < .001$ , resulting from a response repetition advantage of 7 ms on task repetition trials and a response alternation advantage of 11 ms on task switch trials. The between-task congruency effect was overall smaller than the within-task congruency effect (10 ms vs. 19 ms),  $F(1, 38) = 5.86$ ,  $p = .020$ . Despite the fact that, as shown in Figure 1, the between-task congruency effect was numerically larger on task switch trials than on task repetition trials (16 ms vs. 4 ms) whereas the within-task congruency effect was not affected by task transition (20 ms vs. 19 ms), neither the interaction of Task Transition and Flanker Congruency, nor the three-way interaction with Flanker Type reached significance,  $F(1, 38) = 1.85$ ,  $p = .181$ , and  $F(1, 38) = 1.71$ ,  $p = .198$ , respectively. There was, however, a five-way interaction involving all factors,

$F(1, 38) = 12.74$ ,  $p < .001$ , reflecting that the between-task congruency effect was larger on task switch trials than on task repetition trials in some of the conditions. More precisely, in the cuing group the between-task congruency effect was larger on task switch trials than on task repetition trials when the response had to be switched but not when the response had to be repeated, whereas the opposite pattern occurred in the no-cuing group.

An analogous ANOVA on the mean percentages of error (PEs) replicated the significant main effects and two-way interactions of the RT analysis. Task switch trials were associated with more errors than task repetition trials (7.3% vs. 3.5%),  $F(1, 38) = 67.05$ ,  $p < .001$ , incongruent trials were associated with more errors than congruent trials (6.1% vs. 4.7%),  $F(1, 38) = 22.47$ ,  $p < .001$ , flankers from the irrelevant task provoked more errors than flankers from the relevant task on switch trials (7.6% vs. 7.1%), whereas the reversed pattern occurred on task repetition trials (3.1% vs. 3.8%),  $F(1, 38) = 4.63$ ,  $p = .038$ , and response repetitions were associated with a large disadvantage compared to response alternations when the task switched (9.6% vs. 5.1%),  $F(1, 38) = 28.15$ ,  $p < .001$ . In addition, there was a significant three-way interaction involving Task Sequence, Flanker Type, and Flanker Congruency,  $F(1, 38) = 4.59$ ,  $p = .039$ . This was because the between-task congruency effect was larger on task switch trials than on task repetition trials, whereas the within-task congruency effect was not affected by task sequence (as revealed by planned

<sup>1</sup> We included the response sequence factor in the analysis because one of the most robust findings in task switching studies relates to an interaction of task sequence and response sequence, that is a (relative) advantage of response repetitions on task repetition trials and a (relative) advantage of response switches on task switch trials (e.g., Hübner & Druey, 2006; Rogers & Monsell, 1995). Given the procedural deviations of Experiment 1 from standard task switching studies (i.e., the possibility to identify the currently relevant task by evaluating the type of the centrally presented stimulus character), it seemed useful to check on the occurrence of this commonly found “signature” of task switching.

comparisons,  $F(1, 38) = 6.95$ ,  $p = .012$ , and  $F(1, 38) < 1$ , respectively).<sup>2</sup>

## Discussion

Experiment 1 was designed to compare flanker interference from stimuli taken from the currently relevant task and from the temporarily irrelevant task. This arrangement deviates from standard task switching experiments regarding two possibly important aspects. First, no additional information about the identity of the relevant task must be provided to the participants because the centrally presented character constitutes an unambiguous task cue. Second, processing of information related to the irrelevant task can be reduced by means of spatial attention. In spite of these modifications, standard findings from task switching paradigms, that is, task switch costs and response sequence effects were replicated.

Although performance did not generally differ when flankers were taken from the relevant or the irrelevant task, the two-way interactions with task transition obtained in RTs and PEs indicated that flankers from the irrelevant task interfered more than flankers from the relevant task on task switch trials, whereas there was a tendency for the opposite effect on task repetition trials. Moreover, in the error rates, the between-task congruency effect evoked by flankers from the irrelevant task was substantially larger on task switch trials than on task repetition trials, whereas the within-task congruency effect was unaffected by task transition. These findings are much in line with the proactive interference account and lend no support to the notion of generally increased susceptibility to irrelevant stimulus processing when switching between tasks.

The experiment was run in two groups of participants that differed regarding the option to use cues indicating the upcoming task for task preparation. Although the lack of a difference in congruency effects between the two groups replicates the often found absence of a reduction of between-task interference with preparation, the fact that task cuing did not improve task performance overall suggests that this was simply a result of participants refraining from using the cues. Given that the type of the central character provided an unambiguous task cue, it might not be surprising that participants were reluctant to engage in effortful task preparation in this situation. On the other hand, it would seem plausible that contingently pairing a task with an advance color cue would result in automatic activation of the corresponding mental set (Rubin & Koch, 2006; Schneider & Logan, 2006). The results of our experiment, however, argue against such automatic task-set activation.

## Experiment 2

A potential shortcoming of Experiment 1 relates to the fact that interference of the flankers of the relevant task was brought about by the relevant task's S-R translation rules. A low degree of activation of these rules, as was possibly the case on switch trials, might therefore have counteracted a generally increased susceptibility on switch trials. That is, the lack of a modulation of the within-task congruency effect by task sequence in Experiment 1 may have resulted from the coincidence of a lower degree of flanker-response translation and a higher degree of general susceptibility to irrelevant stimulus processing on task switch trials than on task repetition trials. To overcome this possible shortcoming, we aimed to explore the effect of irrelevant stimulus information which is independent of both the activation of the relevant and the irrelevant task set in Experiment 2. A second purpose of this experiment was to prohibit minimizing interference by means of spatial attention.

The SNARC effect seems to be a useful tool for both purposes. It was first demonstrated by Dehaene et al. (1993). Participants categorized the digits 0–9 as odd or even by pressing left and right response keys. They responded faster if small digits were responded to with the left hand and large digits were responded to with the right hand rather than if small digits were responded to with the right hand and large digits with the left hand. The SNARC effect was explained by a mental left-right oriented number line with small numbers represented on the left and large numbers represented on the right side of the number line. Responding is fast if response codes (left-right) and number size (small-large) are congruent rather than incongruent.

In Experiment 2, participants again switched between classifying a target digit as odd or even and classifying a target letter as vowel or consonant. In each trial, a letter and a digit were presented so that the characters were either congruent or incongruent. Again, we expected to replicate previous findings of larger between-task congruency effects on switch than on repetition trials. In addition, we assessed the SNARC effect, that is, whether responding to odd or even digits with left and right responses is modulated by the size of the target digits. Critically, we asked whether the size of the SNARC effect is increased in switch compared to repetitions trials.

Contrasting with Experiment 1, in which interference from the flankers could be reduced by means of spatial attention, Experiment 2 precludes this possibility by presenting the target and the distractor character at uncertain locations. Moreover, because the SNARC effect is based on semantic information (i.e., numerical value) needed for execution of the digit task, it could not be reduced by

<sup>2</sup> Two task switching studies (i.e., Brown et al., 2007; Kiesel et al., 2006) found a reduction of the congruency after an incongruent predecessor trial, selectively on task repetition trials. To check for such modulations, additional ANOVAs were conducted on RTs and error proportions, including the factors flanker type on the preceding trial and congruency on the preceding trial (we dropped the factor response sequence). There were generally no significant interactions involving congruency of the current and the preceding trial (all  $ps > .18$  and  $> .15$ , for RTs and error proportions, respectively).

any kind of perceptual selection. Experiment 2 thus constitutes an improvement regarding the likelihood of obtaining large interference effects.

## Method

### Participants

Participants were 24 volunteers ranging in age from 17 to 39 years with normal or corrected-to-normal vision. Participants took part in the experiment in partial fulfillment of a course requirement or in exchange for pay. Each participant attended two experimental sessions lasting approximately 80 min each.

### Apparatus and Stimuli

An IBM-compatible computer equipped with a 17-inch VGA display and the software package E-Prime (Schneider, Eschman, & Zuccolotto, 2002) was used for stimulus presentation and response sampling.

The digits 2–9 and the letters A, E, I, U, G, K, L, and M were used as targets. In each trial, a digit and a letter was presented simultaneously. The left-right order of the two stimuli was counterbalanced (letter-digit or digit-letter). Throughout the whole experiment, a white rectangle (5.8 cm × 7.7 cm) was presented centrally on a black background. This rectangle turned red or cyan to indicate the currently required task. The targets were displayed in 32-point Arial typeface in black, centered within the white rectangle. Responses were executed with the index fingers of both hands and collected with external response keys positioned in front of the screen at a distance of approximately 18 cm.

### Procedure

At the beginning of each trial, the rectangle turned either red or cyan for 200 ms. The color of the rectangle served as task cue and informed participants whether the digit task (red color) or the letter task (cyan color) was required in this trial. Then the rectangle turned white and was presented for 300 ms before the target (letter and digit) appeared. The target remained on the screen until a response was recorded or for a maximum of 5,000 ms. Errors were indicated by the German word for error (“Fehler!”); in case of missing responses participants were requested to respond faster (“Bitte schneller!”) presented in white below the white rectangle. Both error feedbacks remained on the screen for 500 ms. The next trial started 500 ms after response onset.

At the beginning of the experiment, participants were instructed how to respond for the digit and the letter tasks whereas the stimulus-response mapping (i.e., odd digits = left-hand keypress, even digits = right-hand keypress, consonant = left-hand keypress, vowel = right-hand key-

press) was counterbalanced over participants. At the end of each block, participants received feedback about the mean RT and number of errors in the block and they were asked to try to respond faster without making more errors.

Each participant started with a practice block of 16 trials to exercise the digit task followed by another practice block of 16 trials to exercise the letter task. In a third practice block of 32 trials, participants exercised switching between both tasks. Then participants performed 7 experimental blocks with 256 trials each. In each experimental block, each target letter (8) and each target digit (8) was presented once in each horizontal positioning order (2: letter-target or target-letter) and in each of the two tasks (2).

## Results

All trials asking for the letter task were excluded from the analysis. In addition, the first trial of each block as well as trials with RTs deviating more than 2.5 standard deviations from the mean RT of each experimental condition per participant were considered outliers and were excluded from the analysis. In a first analysis, we aimed to assess between-task congruency effects and the SNARC effect depending on task switch and repetition trials. For this, we coded SNARC congruency in two categories: Trials with small digits (2–5) that afforded a left response and trials with large digits (6–9) that afforded a right response were coded SNARC congruent while trials with small digits that afforded a right response and trials with large digits that afforded a left response were coded SNARC incongruent. We then computed mean RTs for correct trials and PEs for each participant and separately for each combination of the factors task transition (task repetition vs. task switch), between-task congruency (congruent vs. incongruent), and SNARC congruency (SNARC congruent vs. SNARC incongruent) and computed corresponding ANOVAs.

The averages of mean RTs and mean error rates across participants are shown in Table 1.

In a second analysis, we aimed to elaborate in more detail on the SNARC effect and its dependency on task transition. For this analysis we computed mean RTs for correct trials and PEs for each participant and separately for each combination of the factors task transition, SNARC bin (4: 2/3, 4/5, 6/7, 7/9), and response (left-handed keypress vs. right-handed keypress). To quantify the impact of SNARC effects, we computed regression analyses (e.g., Fias, 2001; Müller & Schwarz, 2007; see also Kiesel & Vierck, 2009; Vierck & Kiesel, 2010 for similar regression analysis on magnitude bins, and Lorch & Myers, 1990 for regression analysis in general). Therefore, we computed right-left response differences by subtracting RTs and error rates for left keypress responses from right keypress responses for each SNARC bin, separately for task switches and task repetitions. We then regressed these right-left response differences on the SNARC bin separately for each participant for task repetition and task switch whereby SNARC bin was dummy coded as 1, 2, 3, and 4. As a

Table 1. Mean RTs (in ms) and mean PEs (in %) depending on task transition, target congruency, and SNARC congruency

	Task repetition		Task switch	
	Target		Target	
	Congruent	Incongruent	Congruent	Incongruent
RT				
SNARC congruent	653	664	814	835
SNARC incongruent	668	684	821	858
PE				
SNARC congruent	5.4	9.1	8.0	15.0
SNARC incongruent	7.2	10.8	8.0	15.6

result, we obtained an individual slope for each participant and each type of task transition. We expected negative slopes to be efficient indices for the SNARC effect: If keypress response (left vs. right) is associated with number magnitude, then RT and error rate differences for response differences should be negatively related to the SNARC bin, that is, for small numbers, RTs and error rates are presumably smaller for a left-handed compared with a right-handed keypress response resulting in a positive difference for right-left keypress response differences, whereas for large numbers, RTs and error rates are increased for a right-handed compared with a left-handed keypress response, resulting in a negative difference. The right-left differences on RTs and error rates and the corresponding linear regressions are shown in Figure 2.

### Reaction Times

The repeated-measures ANOVA on the factors task transition (2: task repetition vs. task switch), between-task congruency (2: congruent vs. incongruent), and SNARC congruency (2: SNARC congruent vs. SNARC incongruent) revealed that participants responded faster in task repetition (667 ms) compared to switch trials (832 ms),  $F(1, 23) = 41.37, p < .001$ . Further, participants responded faster to congruent targets (739 ms) than to incongruent targets (760 ms),  $F(1, 23) = 6.60, p = .017$ . And participants responded faster to SNARC congruent digits (742 ms) than to SNARC incongruent digits (758 ms),  $F(1, 23) = 10.92, p < .003$ .

The size of the between-task congruency effect was descriptively larger in task switch trials (congruent: 818 ms; incongruent: 847 ms) than in task repetition trials (congruent: 661 ms; incongruent: 674 ms), however the interaction between the factors task transition and between-task congruency failed to reach significance,  $F(1, 23) = 2.62, p < .12$ . The size of the SNARC effect was not modulated by task transition,  $F(1, 23) < 1, p = .859$ , between-task congruency,  $F(1, 23) = 1.05, p = .317$ , or the interaction of Task Transition  $\times$  Between-Task Congruency,  $F(1, 23) < 1, p = .686$ .

The regression analysis revealed that for task repetitions RTs for right-left keypress response differences decreased by 18 ms per SNARC bin and this slope of the regression differed significantly from 0,  $t(23) = -3.13, p = .005$ . For task switches the right-left keypress response differences on RTs decreased by 9 ms per SNARC bin and this slope did not reach significance,  $t(23) = -1.20, p = .241$ . The slopes for task repetition and task switch trials did not differ significantly,  $t(23) = -.84, p = .411$ .

### Error Rates

The same ANOVA on error rates revealed that participants responded less erroneously for task repetitions (8.1%) in comparison to task switches (11.7%),  $F(1, 23) = 23.15, p < .001$ . Further, participants made less errors when the target was congruent (7.1%) compared to incongruent trials (12.6%),  $F(1, 23) = 18.78, p < .001$ . And participants responded more often correct to SNARC congruent digits (9.4%) than to SNARC incongruent digits (10.4%),  $F(1, 23) = 5.08, p = .034$ .

The size of the between-task congruency effect was larger in task switch trials (congruent: 8.0%; incongruent: 15.3%) than in task repetition trials (congruent: 6.3%; incongruent: 9.9%),  $F(1, 23) = 18.68, p < .001$ . The SNARC effect was not modulated by between-task congruency,  $F(1, 23) < 1, p = .666$ , or the interaction of Task Transition  $\times$  Between-Task Congruency,  $F(1, 23) < 1, p = .543$ . Yet, the SNARC effect was modulated by task transition because the size of the SNARC effect was smaller in task switch trials (congruent: 11.5%; incongruent: 11.8%) than task repetition trials (congruent: 7.2%; incongruent: 9.0%),  $F(1, 23) = 9.16, p = .006$ .

The regression analysis revealed that for task repetitions the right-left keypress response differences decreased by 1.9% per SNARC bin and the slope of the regression differed significantly from 0,  $t(23) = -3.68, p = .001$ , whereas for task switches the right-left keypress response differences on error rates decreased 0.8% per SNARC bin and this slope did not differ significantly from 0,  $t(23) = -1.43, p = .165$ . The slope for task repetitions and task switches differed significantly,  $t(23) = -2.15,$

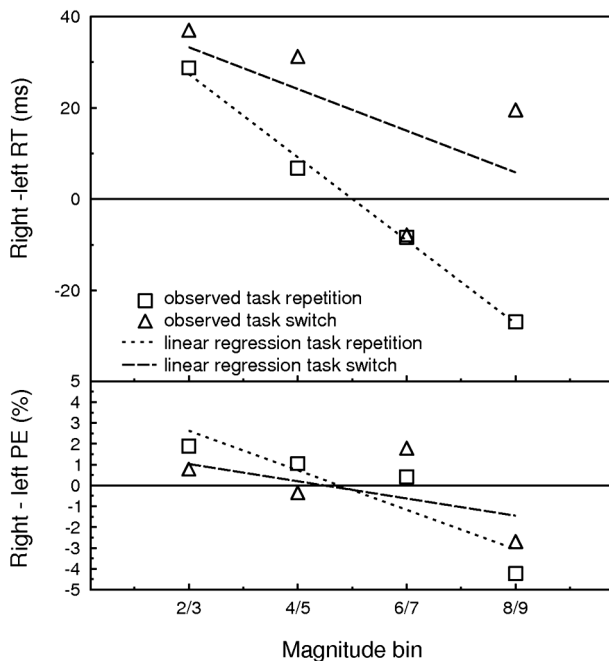


Figure 2. Observed right-left response differences and regression of differences on the magnitude bin separately for task switches and task repetitions for RTs and error rates .

$p = .042$ , indicating that the SNARC effect was larger in task repetition trials than in task switch trials.<sup>3</sup>

## Discussion

Experiment 2 was designed to compare interference from stimulus processing that is independent from activation of the current or previous task in task repetition and task switch trials. We chose SNARC interference and assessed its impact in a regular task switching setting. In this setting, we additionally assessed between-task congruency effects and we were able to replicate usual effects. First, we observed switch costs. Second, we observed between-task congruency effects and third, we observed that between-task congruency effects were larger on switch than on repetition trials (albeit not significantly in RTs).

Most importantly for the current research question, we observed the usual SNARC interference, yet the size of the SNARC effect was not larger in switch compared to

repetition trials. This observation speaks against the assumption that task switch trials are associated with overall increased susceptibility to irrelevant stimulus information.

In contrast to the predictions of this account, we even observed that the SNARC effect was somewhat larger on repetition trials than on switch trials (albeit only significantly for error rates). Intriguingly, Hübner, Futterer, and Steinhauser (2001) conjectured that switch trials are characterized by more controlled processing to ensure reliable performance under conditions of increased between-task interference. The fact that the SNARC effect was smaller on switch trials might support this notion. An alternative account of this result relates to recent findings of abolishment of the SNARC effect under conditions of additional verbal working memory load (van Dijck, Gevers, & Fias, 2009). Given that this abolishment was found for parity judgments but not for magnitude judgments, future research might compare the effect of task sequence on the SNARC effect for these two types of tasks.

## General Discussion

Task switching studies usually comprise stimuli which afford both tasks, evoking interference (exogenous task cuing and between-task congruency effects). Such interference is usually more pronounced on switch than on repetition trials. Although such enhancement would be expected if it is assumed that critical representation of the irrelevant task has higher activation on switch trials (e.g., Allport et al., 1994; Gilbert & Shallice, 2002), it is also conceivable that processing in task switch and repetition trials differs more generally regarding susceptibility to irrelevant stimulus information (e.g., Dreisbach & Wenke, 2011). To investigate whether larger interference effects on switch trials are confined to stimulus information related to the irrelevant task, we conducted two experiments in which additional irrelevant stimulus information, unrelated to the irrelevant task, was presented. Whereas in Experiment 1, this information was presented in the form of flanker stimuli from the set of the relevant task – analogous to the presentation of the irrelevant information related to the irrelevant task – in Experiment 2 semantic information inherent in the target stimulus was used.

Both experiments replicated previous findings of larger between-task interference on switch trials. More precisely, Experiment 1 allowed us to assess exogenous task cuing

<sup>3</sup> An additional ANOVA on RTs and error proportions, including the factors task transition, between-task congruency, between-task congruency in  $n - 1$ , and SNARC congruency, revealed that between-task congruency was modulated by the congruency level of the predecessor trial in task repetitions but not in task switches (RTs reveal this effect only descriptively,  $F(1, 23) = 2.47$ ,  $p = .129$ ; error proportion  $F(1, 23) = 6.94$ ,  $p = .015$ ). Thus, this analysis confirms findings of Kiesel et al. (2006). The RT analysis did not reveal any further modulation by the factor congruency of the preceding trial. Regarding error rates, there was a trend for a four-way interaction with SNARC congruency,  $F(1, 23) = 3.33$ ,  $p = .081$ . In task repetition trials, the SNARC effect was increased when the congruency level repeated (incongruent→incongruent: 2.50%, congruent→congruent: 2.34%) rather than switched (congruent→incongruent: 0.88%, incongruent→congruent: 1.25%). In task switch trials, the SNARC effect was slightly reversed (–.42%) in congruent→congruent transition trials and amounted to 0.57%, 0.57%, and 0.35% for incongruent→incongruent, congruent→incongruent, and incongruent→congruent transitions, respectively. Thus, the important finding that SNARC effects are not increased in switch compared to repetition trials is corroborated by this analysis.



by comparing overall interference (disregarding congruency) from flankers from the irrelevant and from the relevant task. A two-way interaction occurred in both RTs and PEs, demonstrating that the task cuing effect was confined to task switch trials. In addition, regarding PEs, between-task congruency effects were larger on task switch trials than on task repetition in both Experiments 1 and 2.

Contrasting with these modulations, interference evoked by the other source was constant across task transitions (Experiment 1) or even larger on repetition trials than on switch trials (Experiment 2). Whereas the lack of an interaction with task transition in Experiment 1 could be explained in terms of a lower activation of the relevant task's S-R rules on switch trials, the SNARC effect used in Experiment 2 was unrelated to the S-R assignment of the relevant task. Together, the results support the proactive interference account and lend no support to the notion of generally enhanced susceptibility to processing irrelevant stimulus information on switch trials.

Recent studies have attempted to specify the processes of proactive interference in more detail. Although it would seem a plausible option that between-task congruency effects are mediated by S-R translation according to the rules of the irrelevant task in working memory, Kiesel et al. (2007) failed to find larger congruency effects under conditions of additional working memory load. Together with other findings (cf. Meiran & Kessler, 2008), this suggests that between-task congruency effects are mainly brought about by long-term memory associations between a current stimulus and representations of the irrelevant task acquired during previous task execution. Increased between-task congruency on switch trials therefore suggests that long-term memory retrieval regarding aspects of the competitor task set is enhanced on switch trials. (Given the fact that between-task congruency effects are often unaffected by task preparation, task preparation apparently does not reduce this specific susceptibility.)

The results of the current study contrast with the notion that shielding against processing irrelevant stimulus information is decreased on task switch trials, as put forward by Dreisbach and Wenke (2011). As noted in the Introduction, these authors observed that the sequence of an irrelevant stimulus feature, which was unrelated to both tasks, modulated the effect of response sequence on task switch trials but not on task repetition trials. More precisely, whereas on task repetition trials a response repetition benefit occurred regardless of whether the irrelevant stimulus feature repeated or alternated from the preceding trial, on task switch trials the usually found response repetition cost (e.g., Rogers & Monsell, 1995) was only obtained when the irrelevant feature repeated. Although these findings suggest that the irrelevant feature was more strongly processed on switch trials than on repetition trials, a possible resolution with the conclusion suggested by the results of our study lies in assuming that the response repetition cost is brought about by suppression of the previously given response to avoid the risk of erroneous re-execution (Hübner & Druey, 2006) and that this suppression is confined to task switch trials. In the experiments of Dreisbach and Wenke, a task

switch was signaled by a change in the category of the imperative stimulus (i.e., digits vs. letters). Assuming that an additional change regarding a salient stimulus feature reduces the perceived risk of erroneous response re-execution, response suppression may be prevented in this condition. This reasoning is admittedly speculative; further research is needed to clarify the precise mechanisms underlying response repetition effects on task switch trials.

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