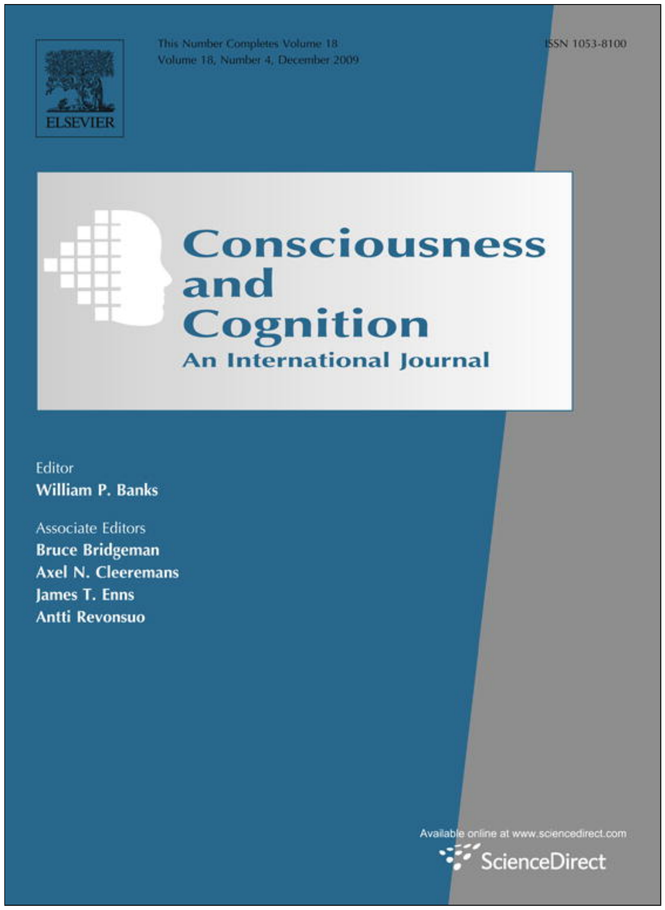
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Context-specific prime-congruency effects: On the role of conscious stimulus representations for cognitive control

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ABSTRACT

Recent research suggests that processing of irrelevant information can be modulated in a rapid online fashion by contextual information in the task environment depending on the usefulness of that information in different contexts. Congruency effects evoked by irrelevant stimulus attributes are smaller in contexts with high proportions of *incongruent* trials and larger in contexts with high proportions of *congruent* trials (e.g., Corballis & Gratton, 2003; Lehle & Hübner, 2008). The present study investigates these context-adaptation effects in a masked-priming paradigm. Context-specific adaptation effects transfer to stimulus identities that are equiprobale in all contexts – an observation that renders explanations in terms of event-learning processes unlikely. Yet, context-specific effects vanished when the irrelevant information remained unconscious. The results suggest that context-specific adaptation of congruency effects reflect cognitive control operations that alter the processing of irrelevant information depending on the experienced utility of that information for action control.

1. Introduction

One of the most important capabilities of the human cognitive system is to limit information processing to relevant information and to shield processing against irrelevant information. In Cognitive Psychology this capability is often studied in so-called interference tasks. In these tasks, a stimulus is presented that requires a speeded response. This relevant stimulus is accompanied by some sort of irrelevant stimulation that is related to the same response or to a different response. The type of this irrelevant stimulation depends on the specific interference task employed. For example, interference may result from the irrelevant location of the stimulus in the Simon task (Simon, 1969), the irrelevant meaning of a color word in the Stroop task (Stroop, 1935), the identity of irrelevant distractors in the Eriksen Flanker task (Eriksen & Eriksen, 1974), or the identity of a prime stimulus that precedes a target in a priming task (Klotz & Neumann, 1999; Marcel, 1983, 1988). Still, the basic structure in all these interference tasks, and also the basic pattern of performance, is the same. Responding is slower and less accurate when relevant and irrelevant (to-be-ignored) stimulus attributes are related to different (in this case we talk about incongruent conditions) rather than identical responses (congruent conditions). The performance difference that is called congruency effect shows that information processing cannot be shielded entirely from task-irrelevant information. The size of the congruency effect is often interpreted as a measure of the impact of irrelevant information on behavior.

A couple of recent observations revealed that the impact of irrelevant information is not constant but varies flexibly with task conditions. Specifically, when the nominally irrelevant stimulation is detrimental for response selection, its impact on

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performance is smaller than when the irrelevant stimulation is helpful. As a result, the sizes of congruency effects differ. In conditions in which irrelevant stimuli are frequently response-incongruent (i.e., signal a different response than the target), the congruency effect is typically smaller than in conditions in which irrelevant stimuli are frequently congruent (e.g., Bodner, Masson, & Richard, 2006; Gratton, Coles, & Donchin, 1992; Tzelgov, Henik, & Berger, 1992). Further, congruency effects are smaller when an incongruent trial preceded the current trial, and thus irrelevant stimulation was experienced as detrimental, than when a congruent trial preceded the current trial, and thus irrelevant stimulation was experienced as helpful (e.g., Gratton et al., 1992; Kiesel, Kunde, & Hoffmann, 2006; Kunde, 2003; Kunde & Wühr, 2006; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). Such findings have been considered as evidence that some kind of cognitive control processes either allow or shut down processing of irrelevant stimulation depending on the usefulness of that information (cf. Botvinick, Braver, Barch, Carter, & Cohen, 2001; Verguts & Notebaert, 2008).

Recently, a specific type of context-specific modulation of congruency effects has been reported that suggests a remarkable flexibility and promptness of such control operations: the context-specific proportion congruent (CSPC) effect. The basic observation is that congruency effects vary depending on context-features that appear more or less simultaneously with the response-affording stimuli and that vary unpredictably trial-by-trial (e.g., Corballis & Gratton, 2003; Crump, Gong, & Milliken, 2006; Lehle & Hübner, 2008; Vietze & Wendt, 2009). It seems that these context features determine the impact of irrelevant information "on the fly", i.e., concurrently with the processing of the irrelevant information itself.

To illustrate the basic finding, consider a recent study by Lehle and Hübner (2008) who applied the Eriksen Flanker task. Participants were asked to categorize a digit (1–4, 6–9) as odd or even. The target digit was flanked left and right by two copies of a distractor digit that was either response congruent (e.g., 242) or incongruent (e.g., 272) to the target. Target and distractor digits were presented in red or in green color. With one stimulus color there were 80% congruent and 20% incongruent trials, whereas there were 80% incongruent and 20% congruent trials with the other color. Thus, color was the context feature that signalled whether the irrelevant distractors were likely congruent or incongruent. Participants first performed practice blocks in which the stimuli were always presented in one color to acquire the association between context and proportion of target-distractor congruency. In the subsequent test blocks the contexts were randomly chosen trial-by-trial. Lehle and Hübner (2008) observed larger congruency effects with the color that signalled a high proportion of congruent trials compared to the color that signalled a low proportion of congruent trials. This CSPC effect was interpreted as a sign of cognitive control processes that modify stimulus processing on the fly.

The present study asks two important questions about the CSPC effect. First, does the CSPC effect reflect a strategic adaptation of information processing to the conflict setting or does it merely result from more simple event-learning processes (Hommel, 1998; Logan, 1988; cf. Crump & Milliken, 2009; Schmidt & Besner, 2008)? Second, does the CSPC effect depend on awareness of irrelevant helpful or detrimental information in varying contexts?

To investigate these two questions, we used a masked-priming paradigm. The structure of the task is essentially the same as in an Eriksen Flanker task, yet, the distractor precedes the target at the same location rather than flanking it simultaneously. Research with this task has focussed on the benefits of response-congruent distractors, and calls the distractor a "prime", even though response-incongruent primes often delay responding more than congruent primes benefit responding (e.g., Kinoshita & Hunt, 2008; Klotz & Neumann, 1999). The main advantage of this procedure is that congruency effects reliably occur even when the primes are presented only briefly and masked so that they cannot be consciously identified. Consequently, masked-priming paradigms allow creating conditions in which participants have no clue as to whether a prime is congruent or incongruent, or whether in a certain context the proportion of congruent primes is higher than in another context.

The first purpose of the present study was to explore the role of context-specific frequency imbalances of specific prime-target identities for CSPC effects. One has to keep in mind that increasing the proportion of congruent trials in a certain context requires increasing the proportion of certain combinations of targets and distractors in that context (namely congruent combinations such as 242 in the Lehle & Hübner, 2008 study). The same is true when increasing the proportion of incongruent trials. Here incongruent target-distractor combinations are more frequent in this context than in the other context (e.g., the prime-target combination 272). This setting allows an interpretation of conflict adaptation effects simply by assuming facilitated responding to frequent displays, that is, to frequent context-distractor-target combinations (Hommel, 1998; Logan, 1988; Schmidt & Besner, 2008). In frequently incongruent contexts, distractor-target combinations with incongruent distractor-target relations are frequent and consequently responding is especially fast in incongruent conditions, thus *decreasing* the congruency effect. In contrast, in frequently congruent contexts, distractor-target combinations with congruent distractor-target relations are frequent and consequently responding is especially fast in congruent conditions, thus *increasing* the congruency effect. Thus, the proportion effect may result due to reasons that have nothing to do with cognitive control. Mean RTs for congruent trials in the congruent context and mean RTs for incongruent trials in the incongruent context are *underestimated* because they are not only influenced by the congruency of target and distractor and the respective context but also by the frequency of the trials. One might expect that the crucial interaction between context and congruency simply vanishes if this speed up of responding due to the frequency of specific distractor-target combinations was controlled for. Only recently Crump and Milliken (2009) tested this suspicion for location-specific adaptation effects in a Stroop task. They restricted the analysis of congruency effects to distractor-target pairs that occurred equally frequent in the high and low proportion congruent context and nevertheless observed a CSPC effect. This rules out that CSPC effects, at least in the task employed by Crump and Milliken (2009), ensue only because of context-specific frequency imbalances of certain target-distractor combinations.

Table 1
Frequency of prime-target combinations in high-interference and low-interferences contexts. Prime-target combinations that are frequent in one of the contexts are inducing trials. Prime-target combinations with equal frequency in both contexts are test trials.

Prime	Target	# in low-interference context	# in high-interference context	Inducing trial	Test trial
2	1	7	1	X	
2	4	1	1		X
2	6	1	7	X	
2	9	1	1		X
3	1	1	1		X
3	4	7	1	X	
3	6	1	1		X
3	9	1	7	X	
7	1	1	7	X	
7	4	1	1		X
7	6	7	1	X	
7	9	1	1		X
8	1	1	1		X
8	4	1	7	X	
8	6	1	1		X
8	9	7	1	X	

To control for frequency effects in our prime-target paradigm, we used four prime digits and four target digits. Eight of the sixteen possible prime-target combinations were congruent and eight were incongruent. In the low-interference context, there were 80% congruent trials and 20% incongruent trials. In the high-interference context, there were 80% incongruent and 20% congruent trials. This congruency imbalance was induced by a subset of prime-target combinations, the so-called *inducing* trials (Miller, 1987, 1988), whereas other prime-target combinations, the *test* trials, occurred equally often in both contexts (cf. Table 1). In the low-interference context four out of the eight possible congruent prime-target combinations were presented seven times per experimental block while the other four congruent combinations were presented only once per block. Likewise, in the high-interference context four out of the eight possible incongruent prime-target combinations were presented seven times while the other four incongruent prime-target combinations were presented only once per block. To measure CSPC effects that are not contaminated by frequency manipulations, we restricted the analyses to the test trials that were presented equally often in both contexts. The CSPC manipulation was implemented by the same prime and target pairings for all participants. By doing so, the same prime-target test pairs occurred in high- and low-interference contexts as test trials. Thus, different congruency effects in test trials in the high-interference and low-interference contexts cannot be ascribed to different prime-target identities. We also took great care to equalize a factor that sometimes affects response times in this paradigm, namely the numerical distance of the target to the standard 5 (Koechlin, Naccache, Block, & Dehaene, 1999; Moyer & Landauer, 1967). This distance is the same with congruent and incongruent trials and in the low-interference and high-interference context.

The second question addressed in the present study concerns the nature of cognitive control processes that regulate the processing of irrelevant information depending on context. It is often assumed, or at least implied, that higher order control functions are linked to consciousness (Baars, 1988, 2002; Dehaene & Naccache, 2001). Within this line of reasoning, one would assume that cognitive control processes will be prompted only by interfering stimuli (i.e., primes in our case) that participants in principle can become aware of. Conversely, without conscious experience of potentially interfering stimuli, cognitive control processes might not step in. However, the question whether or not cognitive control processes are triggered by unconscious information is currently lively debated (Dehaene, Piazza, Pinel, & Cohen, 2003; Eimer & Schlaghecken, 2003; Jacoby, 1991; Kunde, 2003; Mayr, 2004; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). While some supposed signs of cognitive control, such as sequential modulations of congruency effects, may require a conscious representation of the conflict event (an incongruent event in the preceding trial, Kunde, 2003), other control operations, such as response inhibition following a no-go- or a stop-signal stimulus, may not (van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009).

2. Experiment 1

Experiment 1 explores the possibility of context-specific changes of interference effects for prime-target combinations that are equiprobable in contexts with high or low proportions of interference trials. Observing such an effect would render explanations of context-specific adaptations in terms of RT facilitation due to repetition or frequency effects like suggested by Logan (1988), Hommel (1998), or Schmidt and Besner (2008) unlikely.

We used a priming procedure with digits as primes and targets. Participants categorized target digits as smaller or larger than 5. The target digit was preceded by a prime digit that required the same (i.e., congruent) or the alternative response (i.e., incongruent) as the target. To implement different contexts we used a colored rectangle that was presented in one of two possible colors as the background for all stimuli in each trial.

Our task differed in two respects to a "standard" masked priming procedure. First, in Experiment 1 the primes were masked rather weakly so that their identity and congruency relation to a subsequent target was consciously discernible. Second, we used a speed instruction that forced participants to respond within a certain time window. This was done to encourage participants to use all available information that might help for response selection (including the varying congruency proportions in the different contexts). In contrast to a very restricted "response window procedure" that urges participants to respond within a narrow time interval after target onset (e.g., Greenwald, Draine, & Abrams, 1996) our deadline procedure allowed participants to respond within 250 ms from target offset. With this more liberal time window, we expected congruency effects to manifest primarily in RTs and not in accuracy data as with the strict response window procedure of Greenwald et al. (1996).

2.1. Method

2.1.1. Participants

Sixteen undergraduate students (15 female, mean age: 22.4 years, range: 19–29) participated for course requirement or for pay. Three participants were excluded from all analyses because they performed two sessions with different S-R mappings. However, the results do not change substantially when including these participants.

2.1.2. Apparatus and stimuli

An IBM-compatible computer with a 19-in. VGA display was used. Stimuli were digits presented in the center of the screen in 20 pt. Arial font. The digits 2, 3, 7, and 8 served as primes, the digits 1, 4, 6, and 9 served as targets. Masks were three symbols randomly chosen (without replacement) out of six possible symbols (%, ?, &, β, #, §). The context was set by a colored rectangle (lime or cyan), approximately 9 cm $\times$ 7 cm in width and height. It was presented in the center of the screen and served as background for all following stimuli.

2.1.3. Procedure

Participants were instructed to place their index fingers on the "*F*" and "*J*" key of a standard QWERTZ keyboard. Each trial consisted of a fixation cross (presented for 700 ms), a pre-mask (70 ms), a prime (26 ms), a blank (60 ms), a post-mask (10 ms) and a target (130 ms). The target was followed by a blank (that lasted until response onset or for a maximum of 1000 ms). Simultaneously with the fixation cross, the colored rectangle that indicated the context appeared and remained on screen until the feedback was given. Each trial was followed by a 700 ms blank.

Participants were instructed to respond within 250 ms after target offset. Error feedback was given for 700 ms directly after the response. Premature responses were indicated by an error message presented for 700 ms. Late responses were indicated 1000 ms after target offset. Incorrect responses that were made during the response window were indicated by a red exclamation mark in the center of the screen.

Each block consisted of 80 trials (see Table 1). The overall number of trials per context was 40 and the overall proportion of congruent trials in the low-interference context was 80% and 20% in the high-interference context. Trials in each block were chosen randomly without replacement.

The experiment consisted of two sessions that were conducted within 4 days. Session one started with two practice blocks for each context. Each of the practice blocks consisted of 80 trials that were all presented in the same context. Thus, participants conducted 2 blocks in the low-interference context (mostly congruent trials) and 2 blocks in the high-interference context (mostly incongruent trials). The order of practice blocks was counterbalanced across participants. After the practice blocks five test blocks with 80 trials each followed. Participants were encouraged to take short breaks between the blocks. Session two consisted of two practice blocks (one per context) that were followed by six test blocks. The mapping between context and proportion congruent was held consistent between sessions.

2.2. Results

The analysis was confined to the test trials because they provide an unbiased measure of the CSPC effect. Trials with RTs lower than 200 ms or higher than 1000 ms (3.9%) were excluded from the analysis. Error trials (32.9%) were not included in the RT analysis. In order to increase the trial number, we included correct responses that occurred after the response deadline in the analysis. An additional analysis revealed that the data pattern did not change substantially when excluding these responses. Mean RTs for correct responses and mean error rates (percentages of errors, PEs) were submitted to an Analysis of Variance (ANOVA) with the within-subject factors congruency (congruent vs. incongruent) and context (low-interference context vs. high-interference context). Initial analyses revealed no significant influences of the factors block or session, which is why they were not included in the following analyses.

2.2.1. Response times

Participants responded 43 ms faster to congruent than incongruent trials (324 vs. 367 ms), $F(1, 12) = 28.01$, $p < .001$, and 7 ms faster in the high-interference context than in the low-interference context (342 vs. 349 ms), $F(1, 12) = 6.23$, $p < .05$. In the low-interference context RTs amounted to 322 ms for congruent trials and to 376 ms for incongruent trials. In the high-interference context RTs amounted to 326 ms for congruent trials and to 358 ms for incongruent trials. Thus, the response priming effect was larger in the low-interference context than in the high-interference context (54 vs. 32 ms), $F(1, 12) = 7.12$, $p < .05$ (cf. Fig. 1A).

2.2.2. Errors

Participants committed fewer errors in congruent than in incongruent trials (17.1% vs. 49.0%), $F(1, 12) = 65.24$, $p < .001$. Error rates did not differ in the interference contexts ($F < 1$). In the low-interference context PEs amounted to 17.0% for congruent trials and to 50.3% for incongruent trials. In the high-interference context PEs amounted to 17.2% for congruent trials and to 47.7% for incongruent trials. Thus, the response priming effect in error rates was numerically but not statistically larger in the low-interference context than in the high-interference context (33.3% vs. 30.5%), $p > .26$.

2.2.3. Prime visibility

Although the good visibility of the primes in Experiment 1 was almost self-evident, we employed 16 new participants to obtain an objective measure of prime discrimination performance. Participants were fully informed about the presentation of the primes and were asked to identify whether the prime digit presented in a trial had been smaller or larger than 5. They were told that the possibility for a smaller or larger than 5 prime-digit is exactly 50%. This binary response mode enabled us to compute the signal detection measure d' (Tanner & Swets, 1954) as a measure of prime visibility. If participants answered correct and the prime was indeed smaller than 5, this was considered a hit. If participants answered incorrect although the prime was smaller than 5, this was considered a false alarm. Hits or false alarms proportion of zero or one of a participant were corrected using the log-linear rule (Goodman, 1970; cited according to Hautus, 1995). The prime categorization task consisted of two blocks with 64 trials each. Each prime-target combination was presented equally often (2 times) in the visibility task. The trial structure was identical to the experimental blocks.

As expected, the discrimination performance was very good. The d'-measure amounted to 2.14 and deviated significantly from 0, $t(15) = 7.22$, $p < .001$.

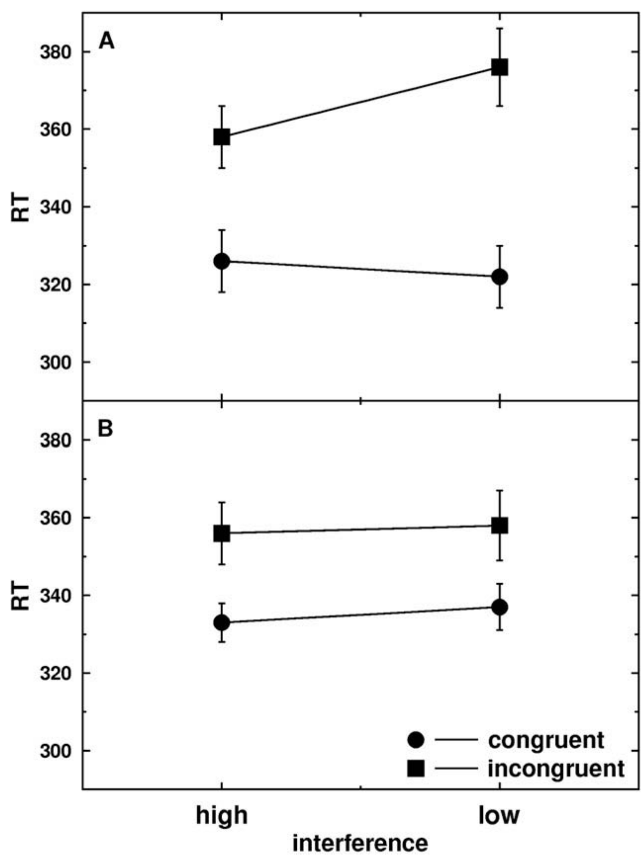

Fig. 1. Mean RTs and standard errors for congruent and incongruent trials in the high- and low-interference contexts. Fig. 1A shows results for Experiment 1, Fig. 1B shows results for Experiment 2. The two-way interaction between the factors context and congruency that was found in Experiment 1 vanished in Experiment 2 due to heavier masking of the primes.

2.3. Discussion

Experiment 1 tested whether CSPC effects reflect strategic adaptation of information processing to the conflict setting or whether CSPC effects merely result from frequent repetitions of specific distractor-target combinations. To explore this, we used a masked-priming paradigm and implemented a high-interference context and a low-interference context with so-called inducing trials. These inducing trials were specific prime-target combinations that were presented more frequently in one context and thus, changed the proportion of congruent or incongruent trials in this context. In addition, there were test trials, which are other prime-target combinations that were equally frequent in both contexts. These test trials were diagnostic for frequency-unbiased CSPC effects.

In line with recent results of Crump and Milliken (2009), we found a larger congruency effect for test trials in a context with mainly congruent trials as compared to a context with mainly incongruent trials. Although it is hard to estimate to which extent previous reports of context-specific congruency effects are mediated by other factors, such as trial frequency, it can be ruled out that such factors account for the CSPC effect in the present priming task. Therefore the idea that these effects are brought about by control processes that regulate the impact of irrelevant information context-specifically remains a viable explanation.

Although non-diagnostic for unbiased CSPC effects, it might nevertheless be interesting to take a look at the inducing trials, i.e., those prime-target combinations that were more frequent in one context than in the other. An inspection of the data from these inducing trials revealed that the CSPC effect was not larger but if anything smaller than in test trials (in fact non-significantly negative). In the high-interference context the congruency effects amounted to 47 ms whereas it amounted to 41 ms in the low-interference context. Interestingly, a similar pattern has emerged in the study by Crump and Milliken (2009, Experiment 2). These authors observed a slightly positive CSPC effect in the test trials (transfer trials) and a slightly negative effect in inducing trials (context trials) in the beginning of the experiment. This data pattern suggests that the creation of associations between specific primes, contexts, and target identities did not play a big role here; otherwise the CSPC effect would be larger with inducing trials than with test trials. Yet, future research is certainly necessary to confirm the reliability and to investigate potential causes of this somewhat unexpected data pattern.

Finally, a comment on error rates seems warranted. Due to the use of a response deadline, error rates were relatively high (e.g., 50.3% and 47.7% for incongruent items in the low-interference and high-interference contexts, respectively). This should not be misinterpreted that participants were guessing. In fact, it is not uncommon for interference tasks that with very fast responses error rates in incongruent trials considerably exceed the 50% guessing probability (Stins, Polderman, Boomsma, & de Geus, 2007). This simply shows that the primes exert a very strong impact on responding. If responding was entirely determined by prime information, error rate would approach 100% in incongruent trials.

3. Experiment 2

When do control processes that regulate the context-specific impact of irrelevant information step in? As explained in the introduction, some theories link cognitive control to consciousness (Baars, 1988, 2002; Dehaene & Naccache, 2001). These theories postulate that only a conscious representation of the conflict event has the capability to call for cognitive control processes and a change of information processing. Yet, such claims are not undisputed. Consider for example the model of Botvinick and colleagues (2001). In this model, cognitive control regulates the impact of irrelevant information on responding as an automatic consequence of preceding response conflict. Consciousness of the conflict does not play any role.

To explore the role of consciousness for context-specific adaptation effects we slightly modified the procedure of Experiment 1. The irrelevant information that was helpful or detrimental for response selection (i.e., the prime) was now masked more heavily. Numerous studies demonstrate that masked primes that are not perceived consciously influence responding nevertheless (e.g., Dehaene et al., 1998; Eimer & Schlaghecken, 2003; Kiesel, Kunde, & Hoffmann, 2007; Klotz & Neumann, 1999; Kunde, Kiesel, & Hoffmann, 2003, 2005; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). When the irrelevant information is not consciously represented, participants have no clue whether the irrelevant information is more helpful in one context than the other. If the control processes responsible for the CSPC effect run entirely out of consciousness, we expect the same result pattern as in Experiment 1. If, however, the CSPC effect depends on consciousness of the conflict information, we expect no context-adaptation effects.

3.1. Method

3.1.1. Participants

Sixteen undergraduate students (12 female, mean age: 24.5 years, range: 19–44 years) participated for course requirement or for pay.

3.1.2. Apparatus and stimuli and procedure

Experiment 2 differed from Experiment 1 only in one regard. The 60 ms blank that was presented after the prime in Experiment 1 was now also filled by the post-mask. Thus, the post-mask directly followed the prime and was presented for 70 ms.

3.2. Results

3.2.1. Response times

The same outlier criterion as in Experiment 1 was used. RT outliers (3.8%) were excluded from the analysis. As in Experiment 1, no significant influences of the factors block or session were found, which is why these factors were not included in the following analyses.

RTs and PEs from the test trials were submitted to an ANOVA with the within-subject factors congruency (incongruent vs. congruent) and context (high or low proportion of congruent trials). Participants responded 22 ms faster in congruent than in incongruent trials (335 vs. 357 ms), $F(1, 15) = 18.36$, $p < .001$. Context had no effect on RTs, $F(1, 15) < 1$. In the low-interference context RTs for congruent trials amounted to 337 ms and RTs for incongruent trials amounted to 358 ms. In the high-interference context RTs amounted to 333 ms for congruent trials and to 356 ms for incongruent trials (cf. Fig. 1B). Thus, the congruency effects in both contexts did not differ, $F(1, 15) < 1$.

3.2.2. Errors

Participants committed fewer errors in congruent than in incongruent trials (17.6% vs. 37.0%), $F(1, 15) = 35.74$, $p < .001$. Participants responded equally fast in both contexts, $F(1, 15) = 1{,}21$, $p > .28$. In the frequently congruent context PEs amounted to 17.4% for congruent trials and to 35.1% for incongruent trials. In the frequently incongruent context PEs amounted to 17.8% for congruent trials and to 38.9% for incongruent trials. The congruency effects did not differ between the two contexts, $F(1, 15) < 1$.

3.2.3. Prime visibility

In contrast to Experiment 1 the prime visibility test in Experiment 2 was conducted at the end of session 2 and not by a novel group of participants. The signal detection measure d' was computed as described in Experiment 1 and amounted to $d' = 0.79$. This d' was smaller than in Experiment 1 ($t(15) = 4.01$, $p < .01$ for the difference between Experiment 1 and 2) but still different from 0, $t(15) = 6.43$, $p < .001$.

To test whether the observed congruency effects were related to prime visibility, we conducted regression analyses as proposed by Draine and Greenwald (1998) (see also Greenwald, Klinger, & Schuh, 1995; Greenwald et al., 1996). Therefore, we computed individual d' values as well as mean RTs for each congruency condition (congruent vs. incongruent). A congruency index was computed for each participant, with *index* = 100 × (RT incongruent–RT congruent)/RT congruent.

The individual congruency indices were regressed onto the individual d' value of each participant. It was tested, whether the intercept and the correlation between d' and the priming index deviated significantly from 0. An intercept larger than 0 indicates that a congruency effect also occurs with zero visibility. If the correlation does not differ from 0, this indicates that the congruency effect does not increase (or decrease) with prime visibility.

The regression of the congruency index on d' revealed a significant intercept of 11.89, $t(15) = 2.40$, $p < .05$. The correlation did not differ significantly from 0 ($r = -.082$, $t(15) = -.31$, $p > .76$). Thus, there was a congruency effect even in the range of zero prime visibility, and there was no correlation between prime visibility and congruency effect.

3.3. Discussion

Experiment 2 was conducted to test whether CSPC effects are observed for masked primes or whether conflict events have to be consciously represented to induce context-specific adaptation of congruency effects. Even though the masking procedure of the primes in Experiment 2 did not fully prevent prime visibility, the reduction of prime visibility compared to Experiment 1 sufficed to entirely remove the context-specific adaptation effect observed for the test trials in Experiment 1. This finding indicates that consciousness of the stimuli that induce response conflicts is a pre-requisite for context-specific cognitive control processes.

4. General discussion

The present study investigated two major research questions regarding context-specific cognitive control processes. First, we wanted to find out whether CSPC effects actually reflect modulation of information processing or merely reflect frequency effects for specific distractor-target combinations. Second, we investigated the role of a conscious compared to a non-conscious representation of the conflicting information on context-specific adaptation processes. In two experiments, we used a masked-priming paradigm with a smaller/larger than 5 task instruction.

Primes in Experiment 1 were masked rather weakly. We aimed at finding a CSPC effect that is not attributable to frequency effects but supports the notion of cognitive control processes that regulate context-specific trial-by-trial adaption of stimulus processing. In the past years, several studies have shown CSPC effects depending on the proportion of congruent and incongruent trials (Corballis & Gratton, 2003; Crump, Gong, & Milliken, 2006; Jacoby, Lindsay, & Hessels, 2003; Lehle & Hübner, 2008; Wendt, Kluwe, & Vietze, 2008; Wendt & Luna-Rodriguez, 2009). These effects have been assumed to result from cognitive control processes, i.e., to reflect a modulation of selective attention, depending on context features. A possible alternative explanation regarding frequency effects of specific distractor-target combinations (Hommel, 1998; Logan, 1988;

Schmidt & Besner, 2008) has recently been ruled out by Crump and Milliken (2009). The present results replicate their findings and extend them in two ways. First, we transferred the "pure" CSPC effect to a masked-priming paradigm. Second, we showed that the CSPC effect depends on conscious stimulus representation of the conflicting information.

We assume that the CSPC effect results from a reduced impact of irrelevant prime information on responding in high-interference contexts and an increased impact in low-interference contexts. This modification of prime processing might be brought about by several possible mechanisms that have been proposed in the literature, such as attentional amplification of target processing and/or inhibition of prime processing (Botvinick et al., 2001; Egner & Hirsch, 2005; Gratton et al., 1992; Kerns et al., 2004) or the blocking of prime-induced response activation (Kunde & Wühr, 2006; Stürmer et al., 2002). Thus, basically the same mechanisms that have been proposed to step in after response conflict in a preceding trial might also step in depending on context information. The important point is that these mechanisms have to be triggered rather quickly, as the context becomes apparent only in the same trial in which these mechanisms shall affect performance.

For the proposed mechanisms to work, two conditions have to be met. First, the system needs to represent whether a trial (in a given context) is congruent or incongruent. Second, the system has to accumulate the frequencies of such episodes over trials. Basically, consciousness might be relevant for both types of knowledge, namely "local" knowledge (or better memory instances) about the congruency in a given trial, as well as "global" knowledge about the frequency of such events depending on contexts. We conjecture that masking the primes prevents already the creation of sufficiently strong representations about congruency in a given trial, and that a lack of such representations eliminates CSPC effects. In other words, a sufficiently strong and presumably conscious representation of the interfering (or helpful) prime information in a given trial and context is a necessary condition for CSPC effects to occur. Interestingly, it seems that the global knowledge about the frequency of congruent and incongruent events in different contexts is no pre-requisite for CSPC effects. Neither does the presence of explicit knowledge of such congruency imbalances correlate with CSPC effects, nor does providing participants with such knowledge amplify CSPC effects (Crump, Vaquero, & Milliken, 2008; Crump et al., 2006). Hence the learning processes that bring about CSPC effects require sufficiently strong (i.e., conscious) codes of prime, target, and context but they need not necessarily end in, or depend on, abstract explicit knowledge of frequency relations.

Basically this inference mirrors observations from the learning literature. For example, learning a covariation between a target dimension and a distractor dimension is hindered when the distractor dimension is more salient than the target dimension (Dishon-Berkovits & Algom, 2000). Frensch and Runger (2003) have suggested that procedural learning in general does not depend on awareness of the task structure - but on attention to the to-be-learned-task-structure. With regard to our findings, it seems feasible that a heavily masked prime is less salient and attracts less attention, and thus prompts less learning, than a weakly masked prime.

Most importantly, our findings support a recently proposed episodic account of CSPC effects (Crump et al., 2006). This account proposes that episodes of performance are stored that include incidental context information and control settings for the processing of task-irrelevant information in specific trial instances. When a certain context is encountered later on, the control settings linked to that context are retrieved automatically. The present results suggest that the crucial ingredients of such episodes, namely relevant target information, irrelevant prime information, and context have to be consciously accessible, or at least have to be sufficiently strong, to become stored in such an episodic buffer.

This episodic account suggests that control settings for the processing of irrelevant prime information are retrieved automatically (depending on a certain context) rather than strategically (depending on intention). Yet, it should be noted that in our study the context was presented already at the beginning of the trial and not just with onset of the target. Hence, in the present study there was in principle more time for a strategic use of the context information than in previous studies. Yet, given that first CSPC effects do not depend on intention (Crump et al., 2006) and second interference by irrelevant information in general can barely be controlled strategically (Kleinsorge, 2007; Wühr & Kunde, 2008) we consider a strategic use of context information unlikely. Still, a closer examination of the time required for context information to take effect is certainly warranted, since it will help to scrutinize characteristics of the context-driven retrieval of attentional control settings.

In the following we discuss three further aspects that might be crucial for the findings of the present study, namely the role of sequential trial-to-trial variations of congruency effects, the role of the size of interference, and the role of context-specific prime-response associations.

First, the observed CSPC effect might be driven by sequential, trial-to-trial modulations of the interference effect (i.e., a reduction of congruency effects after incongruent trials) rather than context-specific modulations of the interference effect (e.g., Gratton et al., 1992). This is, because there are more congruent trials in the low-interference context, leading on average to increased congruency effects in the following trials and more incongruent trials in the high-interference context leading on average to reduced congruency effects in the following trials. To check this possibility, we conducted a further analysis including the factors congruency in trial $n-1$, context in trial $n-1$, congruency in trial n, and context in trial n (Experiment 1). There was no interaction between congruency of trial $n-1$ and congruency of trial n (i.e., "Gratton effect"), $F < 1$. This observation is interesting as such, since it may suggest that changing contexts destroy otherwise robust sequential effects. Yet, since sequential modulations were not the purpose of the present paper we refrain from discussing this topic in more detail. In any case, this result rules out the suspicion that the present CSPC effects were mediated by sequential effects.

A second, to be discussed issue, concerns the size of interference for CSPC effects. Specifically, one may argue that the crucial differentiating factor between Experiments 1 and 2 was not the visibility of the irrelevant information as such, but the impact of that information on response selection. In fact, even though the prime-target stimulus-onset asynchrony, which is the main determinant of congruency effects (Vorberg et al., 2003) was identical, the prime's impact on responding in terms of the congruency effect was larger in Experiment 1 than in Experiment 2 (43 vs. 22 ms). For some reason, the system might be more willing to take into account context-specific variations of congruency the more interfering or helpful the irrelevant information is.[1] In fact we consider it a novel and interesting question whether the general impact of primes (i.e., the size of observed congruency effects) might determine the occurrence of CSPC effects.

Although the present study was not designed to disentangle the contribution of size of interference and awareness of interference for CSPC effects we conducted a regression analysis of the data of both experiments combined. The dependent variable was the size of the CSPC effect in RTs (i.e., congruency effect in the low-interference context minus congruency effect in the high-interference context). The independent variables were 'experiment' (coded as 0 and 1) and mean congruency effect of each participant. The predictor experiment was almost significant, $\beta = .35$, $t = 1.86$, $p = .07$. This reflects the presence of a CSPC effect in Experiment 1 and the lack thereof in Experiment 2. Importantly, the mean congruency effect of each participant did not come close to significance, $\beta = .21$, $t = 1.12$, $p > .27$. This lack of significance does not seem to be due to unreliability of the independent or dependent variables. To obtain an index of re-test reliability we correlated the congruency effects and the CSPC effects between sessions 1 and 2. The congruency effects in both experiments correlated significantly between sessions (all $r > .51$, all $p < .05$), as did the CSPC effect in Experiment 1 ($r = .56$, $p < .05$).

Given the outcome of this analysis, we favor the interpretation that the accessibility of context-related congruency frequencies rather than the overall interference level determines the size of CSPC effects. This conclusion accords with recent studies on sequential modulations of congruency effects that were also considered to reflect cognitive control processes. Like the CSPC effect in our study, sequential modulations have been obtained with visible but not with invisible conflicting information despite roughly equivalent congruency effects (Frings & Wentura, 2008; Kunde, 2003). Yet, other proposed instances of cognitive control, such as the stopping of primed responses seem to run out of consciousness of the control-triggering event (van Gaal et al., 2009). At present it seems that there is a diversity of alleged control processes that do not uniformly depend on a conscious representation of the stimulus that triggers the process. Therefore more research is needed to clarify which processes can be triggered without consciousness and which cannot.

Finally, we have to consider the role of response-related associations for the present CSPC effect. Although the present frequency manipulations do not allow the building up of associations between responses on the one hand and individual primes, targets, or contexts on the other hand (cf. Table 1), it is possible that responses became associated with certain combinations of primes *and* contexts irrespective of the presented target stimulus in the trial. Consider, for example, that in the low-interference context the prime number 2 appears 4 times as often in conjunction with a left response as in conjunction with a right response, and this ratio is reversed in the high-interference context. It seems therefore possible that context-specific prime-response associations might contribute to the present CSPC effect. If we follow this interpretation, the present findings show that such proposed context-specific prime-response links are acquired only for sufficiently well perceptible primes. Yet, there are reasons to doubt the contribution of such links in the first place. First, such links have to be established between a response and an *ensemble* of context and prime. Wendt and Luna-Rodriguez (2009) explored the potential impact of frequency differences between stimulus ensembles (target and flanker identities in their case) with a negative outcome. The inefficiency of frequency differences between event ensembles might also be inferred from the analysis of our inducing trials. As noted in the Discussion of Experiment 1, frequent ensembles of context, prime, and target (e.g., 2–1 in the low-interference context, cf. Table 1) did not generally fasten responding compared to trials with the same level of congruency but a lower frequency (e.g., 2–4). For congruent prime-target pairs RTs amounted to 324 ms with test trials and 320 ms with inducing trials. For incongruent prime-target pairs RTs amounted to 367 ms with test-trials and 368 ms with inducing trials. Second, Crump and Milliken (2009) observed CSPC effects despite equal frequencies of distractor identities in different contexts. Admittedly this does not rule out the contribution of context-specific prime-response links for the present study but it shows that CSPC effects can occur in principle even when such links are impossible.

In summary, we found support for the notion that context features change the processing of irrelevant information rather quickly and flexibly –more or less on the fly. Yet, the acquisition of such flexible control requires that irrelevant information is encountered consciously.

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[1] Alternatively, the system might be more willing to take into account context-specific variations of congruency if the risk of responding incorrectly is higher (high-interference context). We conducted a regression analysis with the independent variables Experiment (coded 0, 1) and error rate and the dependent variable CSPC effect. No significant results were obtained (all $p > .1$). It seems that the overall error rate does not influence the CSPC effect.

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