The Quarterly Journal of Experimental Psychology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100704

Selective impairment of masked priming in dual-task performance

Rico Fischer[a]; Andrea Kiesel[b]; Wilfried Kunde[c]; Torsten Schubert[d]
[a] Technische Universität Dresden, Dresden, Germany [b] Julius-Maximilians-University, Würzburg, Germany [c] University of Technologies, Dortmund, Germany [d] Ludwig-Maximilians-University, Munich, Germany

First published on: 13 September 2010

To cite this Article Fischer, Rico , Kiesel, Andrea , Kunde, Wilfried and Schubert, Torsten(2011) 'Selective impairment of masked priming in dual-task performance', The Quarterly Journal of Experimental Psychology, 64: 3, 572 — 595, First published on: 13 September 2010 (iFirst)

To link to this Article: DOI: 10.1080/17470218.2010.505984
URL: http://dx.doi.org/10.1080/17470218.2010.505984

THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2011, 64 (3), 572–595

Psychology Press
Taylor & Francis Group

Selective impairment of masked priming in dual-task performance

Rico Fischer
Technische Universität Dresden, Dresden, Germany

Andrea Kiesel
Julius-Maximilians-University, Würzburg, Germany

Wilfried Kunde
University of Technologies, Dortmund, Germany

Torsten Schubert
Ludwig-Maximilians-University, Munich, Germany

This study investigated the impact of divided attention on masked priming. In a dual-task setting, two tasks had to be carried out in close temporal succession: a tone discrimination task and a masked priming task. The order of the tasks was varied between experiments, and attention was always allocated to the first task—that is, the first task was prioritized. The priming task was the second (non-prioritized) task in Experiment 1 and the first (prioritized) task in Experiment 2. In both experiments, "novel" prime stimuli associated with semantic processing were essentially ineffective. However, there was intact priming by another type of prime stimuli associated with response priming. Experiment 3 showed that all these prime stimuli can reveal significant priming effects during a task-switching paradigm in which both tasks were performed consecutively. We conclude that dual-task specific interference processes (e.g., the simultaneous coordination of multiple stimulus–response rules) selectively impair priming that is assumed to rely on semantic processing.

Keywords: Masked priming; Dual task; Psychological refractory period; Divided attention; Task switching.

Evidence from a broad methodological potpourri including behavioural studies (Draine & Greenwald, 1998; Kunde, Kiesel, & Hoffmann, 2003; Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), electrophysiological studies (Eimer & Schlaghecken, 1998; Kiefer, 2002; Kiefer & Spitzer, 2000; Leuthold & Kopp, 1998),

---

Correspondence should be addressed to Rico Fischer, Technische Universität Dresden, Institute of Psychology I, Zellescher Weg 17, 01062, Dresden, Germany. E-mail: fischer@psychologie.tu-dresden.de

The present study was supported by research grants of the Deutsche Forschungsgemeinschaft awarded to A.K. and W.K. (DFG Ki 1388/1–2 and Ku 1964/3–2) and to T.S. (DFG Schu 1397/2–1, 2–3). We would like to thank Ulrich Ansorge, Glen Bodner, Friederike Schlaghecken, and an anonymous reviewer for valuable comments on an earlier version of this manuscript. We also thank Paul Taylor for improving the English.

http://www.psypress.com/qjep

DOI:10.1080/17470218.2010.505984

neuropsychological studies (Pöppel, Held, & Frost, 1973; Schweinberger & Stief, 2001; Weiskrantz, 1986, 2002; Young & de Haan, 1993), and neuroimaging studies (Dehaene et al., 1998) has revealed that unconscious information can affect cognitive processes as well as overt behaviour. The masked priming paradigm has been used widely to demonstrate this phenomenon. In a typical masked priming experiment, participants perform a speeded two-choice response to a clearly visible target stimulus (e.g., is a given number smaller or larger than 5?). Unknown to the participants, a prime stimulus (e.g., another numeral) is briefly presented prior to the target. To prevent conscious identification, this prime is presented for a very short duration (e.g., 20 ms) and is masked. Although the prime does not usually elicit awareness (but see Merikle, Smilek, & Eastwood, 2001, for a detailed discussion) it influences responding to the target by means of congruence effects: Responses to the target are usually faster when the prime is congruent—that is, requires the same response as the target. Conversely, responses are slower when the prime is incongruent—that is, requires a different response than the target (Dehaene et al., 1998; Koechlin, Naccache, Block, & Dehaene, 1999; Kunde et al., 2003; Naccache & Dehaene, 2001; see also Eimer & Schlaghecken, 1998; Verleger, Jaskowski, Aydemir, van der Lubbe, & Groen, 2004, for the observation of reversed congruence effects).

There is a huge body of research concerning the demonstration of masked priming effects and the investigation of the underlying mechanisms (e.g., perceptual facilitation, semantic priming, response priming). Yet only recently researchers have begun to directly investigate the attentional requirements of masked priming. This might be due to the long-standing view that processes below the level of consciousness are independent of attentional modulations per definition. Given the traditional categorization of automatic processes (e.g., Posner & Snyder, 1975), a major hallmark of automatic processing is its independence of conscious awareness. Similarly it has often been argued that congruence effects may not be affected by capacity limitations that are associated with information processing requiring attentional control (Bargh & Chartrand, 1999; Greenwald, 1992).

The aim of the present study was to investigate this particular aspect in more detail by exploring the attentional requirements of different forms of masked stimulus processing. We combined a subliminal priming paradigm with a dual-task setting that allowed us to precisely manipulate the amount of attentional load.

In the following section we first introduce studies that have investigated the attentional requirements of masked priming by manipulating aspects of temporal or spatial attention, and then we discuss previous research investigating the impact of divided attention in dual-task settings on masked priming effects.

Temporal and spatial attention determine effects of masked priming

Naccache, Blandin, and Dehaene (2002) demonstrated that masked priming effects strongly depend on focusing *temporal attention*. In their study, participants categorized target numerals that were presented within a continuous stream of masks as smaller or larger than 5. Unknown to the participants, the same numerals were presented as masked primes prior to target onset. Temporal attention was manipulated by means of the temporal predictability of target onset: In the "fixed prime & fixed target" condition the prime–target interval and the target onset were both constant and thus predictable. In the "fixed prime & variable target" condition, although primes were presented at a fixed time, target stimuli appeared after a random set of additional masks, and so target onset was unpredictable. The authors showed that masked priming effects were found only when target onset was constant and thus predictable across trials. When target onset varied randomly between trials, no masked priming effects were observed (see also Kiefer & Brendel, 2006) because participants did not allocate attention to the point in time of stimulus presentation.

Recently, Fischer, Schubert, and Liepelt (2007b) extended this work by combining a foreperiod manipulation with a masked priming paradigm in order to manipulate the focus of temporal attention in a more fine-grained fashion. In their metacontrast study participants responded to the orientation of left- and right-pointing arrows. Primes were smaller replicas of the arrows, presented at a constant interval (85 ms) prior to target onset. An auditory accessory stimulus presented at various intervals prior to the prime–target pairs was used to reduce temporal uncertainty. Critically, the congruence effects depended on the foreperiod interval of the accessory stimulus. For example, congruence effects were larger in size for longer foreperiod intervals (e.g., >250 ms) than shorter foreperiod intervals (e.g., <250 ms) and when compared to conditions in which no accessory stimulus was presented.

The modulating effect of focusing attention on masked priming has also been demonstrated in manipulations of *spatial* attention (e.g., Lachter, Forster, & Ruthruff, 2004; Schlaghecken & Eimer, 2000; Schmidt & Seydell, 2008). In a study by Sumner, Tsai, Yu, and Nachev (2006), participants responded to the direction indicated by target arrows that were presented either above or below fixation. In addition, masked prime arrows preceded the target arrows and were also randomly presented at one of the two locations. Prior to the prime–target pair an exogenous cue was used to direct attention to the cued location. Crucially, masked priming effects were increased when the location of the invisible prime stimulus was cued and thus when attention was allocated to this location (see also Besner, Risko, & Sklair, 2005; Marzouki, Grainger, & Theeuwes, 2007).

Taken together, it seems that the occurrence (or at least size) of the masked congruence effects depends strongly on the amount to which attention is allocated to the spatial position and/or the time of presentation of the target stimulus. Note, however, that the kind of unconscious processes that are addressed in these studies differ greatly, as congruence effects refer to repetition priming in some studies (e.g., Fischer, et al., 2007b) while they refer to response priming in others (e.g., Naccache et al., 2002).

Masked priming in dual-task settings

Besides manipulations of temporal and spatial attention, recent work has focused on masked priming in the context of divided attention. Ansorge (2004), for example, investigated the impact of additional task load on masked priming effects. Participants responded to the location (above or below screen centre) of a horizontal bar with either left or right key presses, respectively. Valid, invalid, or neutral masked prime-bars preceded the target stimulus. This prime–target relation reflected the congruence effect. In this masked priming task an alternative target stimulus was presented occasionally instead of prime and target bars. The single-task group simply ignored this alternative stimulus and waited for the next trial. The dual-task group, on the other hand, was required to perform a recognition task upon this stimulus. Results showed that an increased number of potentially relevant stimuli and associated responses in the dual-task group reduced the masked priming effects compared to the single-task group. Ansorge concluded that the activation of additional action goals of a task unrelated to the priming task interfered with the masked priming task.

A more detailed analysis of priming effects under dual-task requirements was provided in the study of Schubert, Fischer, and Stelzel (2008) in which the psychological refractory period (PRP) paradigm was applied (see Meyer & Kieras, 1997; Pashler, 1998; Schubert, 1999). In the PRP paradigm participants perform two tasks in close temporal succession. Task load is manipulated by varying the temporal interval (stimulus onset asynchrony, SOA) between the stimulus in Task 1 and the stimulus in Task 2. Performance decrements in Task 2 (e.g., increased response time, RT, and error rates) are typically found at short compared to long SOAs. Traditional dual-task models postulate an attentional capacity limitation on certain stages within the information-processing stream. If this capacity-limited stage is occupied by Task 1 processing, processing in Task 2 is assumed to be interrupted until the critical processing in Task 1 is completed. This interruption is the PRP (see Meyer & Kieras, 1997; Pashler, 1998, for detailed reviews). Schubert et al. (2008) used this paradigm to investigate the effects of response activation (and their limits) in secondary task processing. In their study, participants were asked to categorize tones as high or low in Task 1 and to respond to the direction of left- and right-pointing arrows in Task 2. Using a metacontrast paradigm (see, for example, Vorberg et al., 2003) Schubert et al. presented a masked prime stimulus (prime arrow) prior to the stimulus in Task 2 (target arrow). Consistent with other PRP studies, the authors found the typical performance decrements in Task 2. Importantly, however, the authors could show that subliminally evoked Task 2 response activation processes occurred *during* the PRP. This was shown in cases of spatially arranged left–right responses in Task 1 and in Task 2 (e.g., spatial stimulus–response, S–R, compatibility between tasks). Here, the effects of subliminally triggered Task 2 response activation were found to affect response activation processes in Task 1 (e.g., via backward crosstalk onto Task 1), which then back-propagated onto Task 2 when Task 1 bottleneck processing was finished. This finding demonstrates that Task 2 masked priming effects can be observed (e.g., on the basis of common response activation processes) that otherwise might have been absorbed into the bottleneck (see also General Discussion for further elaboration).

In this setting, reliable masked priming effects were found in Task 1 (at short SOA) and Task 2. At the same time, however, effects of masked priming in Task 2 were smaller in conditions of maximum task overlap at short SOA (and, thus, maximum attentional load) than was the priming effect in conditions of minimum task overlap at long SOA. That is, effects of masked priming and temporal task overlap interacted underadditively. Nevertheless, a preliminary interpretation of this finding suggests that under conditions of divided attention, reduced but still reliable masked priming effects can be found.

The present study

The aim of the present study was to pursue and extend this outlined research strategy by further investigating the attentional requirements/ limitations of masked priming during divided attention. A main focus within this approach is whether different kinds of masked prime information processing are differentially affected by dual-task manipulations. In detail, the above-mentioned studies investigating effects of dual-task load on masked priming concentrated primarily on priming effects that can be explained by perceptual mechanisms (e.g., Scharlau, 2007; Scharlau & Ansorge, 2003), feature repetitions (e.g., repetition priming; Ansorge, 2004; Schubert et al., 2008), and/or on the basis of acquired S–R associations (e.g., response priming; Ansorge, Klotz, & Neumann, 1998; Damian, 2001; Leuthold & Kopp, 1998). Yet, processing of unconscious information is not restricted to acquired S–R associations, as priming effects that are associated with unconscious semantic processing have been repeatedly demonstrated (Abrams, Klinger, & Greenwald, 2002; Kiefer & Spitzer, 2000; Naccache & Dehaene, 2001; Reynvoet, Gevers, & Caessens, 2005).

To the best of our knowledge, previous studies investigating limitations of masked priming in dual-task conditions have not dealt with different forms of masked prime processing. Therefore, in the present study we aimed to contrast masked priming on the basis of acquired S–R associations with masked priming that is related to semantic processing (e.g., Klauer, Musch, & Eder, 2005; Naccache & Dehaene, 2001; Reynvoet, Caessens, & Brysbaert, 2002; Reynvoet et al., 2005) under conditions of divided attention.

A typical approach in the study of masked priming on the basis of S–R associations versus that on a more semantic basis has been put forward in a number comparison task by Naccache and Dehaene (2001; see also Greenwald, Abrams, Naccache, & Dehaene, 2003; Reynvoet et al., 2002, for similar approaches). In this study, participants were required to categorize numbers as smaller or larger than 5. For the study of S–R priming, certain number stimuli (i.e., 1, 4, 6, and 9, respectively) serve as both supraliminal target and as masked prime stimuli. If the same stimuli that are consciously presented as targets are also used as masked primes (*target primes*), these prime stimuli automatically trigger response activation processes via the consciously acquired S–R links (Damian, 2001; Neumann & Klotz, 1994). The idea is that a repeated presentation of a target stimulus and its response results in the formation of S–R associations between this particular stimulus and the response. Throughout the experiment participants practice these S–R associations. If the same target stimulus is presented as a masked prime stimulus it will automatically activate the same response association, thus resulting in masked priming effects. In other words, response codes will be automatically activated upon the encounter of the associated perceptual input. This automatic response code activation by target primes is triggered even faster when prime stimuli repeat as target stimuli, thus creating *repetition priming* (e.g., 1–1, Bodner & Masson, 1997, 2003). In addition to *response priming* (e.g., 1–4), repetition priming might include perceptual and/or sensory effects, because the same stimulus is processed twice.

For the study of semantic priming, on the other hand, additional prime stimuli that were never presented as target stimuli (i.e., 2, 3, 7, and 8, respectively) are included. Without an overt response to these stimuli, no S–R associations can be formed (e.g., Naccache & Deahaene, 2001). Therefore, congruence effects for so-called *novel primes* have often been taken as evidence for semantic processing of unconsciously presented information (see the General Discussion section for alternative discussions and also Kiesel, Kunde, & Hoffmann, 2007a, for an overview). Masked priming by novel primes has been reported to be smaller in size (e.g., Naccache & Dehaene, 2001; see van den Bussche, Van den Noortgate, & Reynvoet, 2009, for a meta-analysis on novel priming effects) than priming by target primes and dependent on certain task conditions such as target set size (Kiesel, Kunde, Pohl, & Hoffmann, 2006a; Pohl, Kiesel, Kunde, & Hoffmann, 2010). Repetition priming cannot contribute to priming effects revealed by novel primes, because novel primes do not occur as target stimuli. In addition, Kunde et al. (2003) challenged the view that novel primes might be processed automatically by demonstrating that masked priming effects revealed by novel primes depend strongly on a priori established action trigger conditions (e.g., the representation of the task requirements). For example, novel prime digits elicited priming effects only when the primes were presented in the same format as the target stimuli, thus, only if the presented format was expected by participants. Based on these potential differences in processing of target versus novel primes we assume that masked priming by novel primes might be more susceptible to dual-task specific interferences than masked priming by target primes (we return to this issue in the General Discussion).

In order to test the attentional requirements of these different forms of masked priming in conditions of divided attention we applied a typical PRP dual-task paradigm similar to that of Schubert et al. (2008). The advantage of the PRP paradigm is that (a) it allows an exact evaluation of task performance in terms of both accuracy and response latency, and (b) it allows the investigation of different forms of dual-task-specific constraints on masked prime processing. In particular, the PRP paradigm provides conditions of measurable interference between the component tasks by manipulating the temporal overlap between tasks. That is, at short SOA (high temporal overlap) the dual-task interference is larger than at long SOA (low temporal overlap). In addition, within a dual-task setting the attentional focus can be allocated to a particular (i.e., primary or secondary) task according to the instruction.

We used these advantages of the PRP paradigm to investigate the influences of dual-task specific attentional constraints on masked priming. In Experiment 1, we implemented masked priming as Task 2 of the PRP paradigm. Instructing Task 1 processing priority, the attentional focus was allocated onto the tone task and therefore away from processing the masked priming task. In Experiment 2, Task 1 priority instruction was maintained but task order was reversed. That is, we allocated the attentional focus towards the masked priming task by presenting it as Task 1 in the PRP paradigm. Finally, in Experiment 3, we studied masked priming effects in an experimental setting in which the two tasks were presented individually, so that performance of only one task at a time was to be expected. This approach further reduced the processing demands of the masked priming task, because performance involved only the preparation for a single task instead of the simultaneous performance of two tasks.

Taken together, the present experimental approach allowed us to study the impact that manipulations of divided attention have on different forms of masked stimulus processing. Based on the distinction of masked priming effects on the basis of acquired S−R associations and of priming effects based on semantic processing, we investigated whether different forms of masked priming are selectively impaired by concurrent task processing and by the deployment of attention to or away from stimulus processing in the priming task.

EXPERIMENT 1

In Experiment 1, participants performed a tone discrimination task and a number categorization task in close succession. That is, participants discriminated the pitch of a tone first and subsequently categorized digits as smaller or larger than 5. The target numbers were the digits 1, 4, 6, and 9, respectively. Importantly, unknown to the participants, the same digits were presented between two masks prior to target onset and denoted the so-called *target primes* (Naccache & Dehaene, 2001). In addition, the prime digits 2, 3, 7, and 8 were included as *novel primes*. These digits were never presented as target stimuli, ruling out that they become associated to a certain response by practice (cf. Naccache & Deheane, 2001).

Following the PRP logic, the temporal overlap between the two tasks was systematically varied (short, middle, and long SOA). Effects of divided attention on information processing should be especially pronounced in conditions of maximum temporal overlap between Task 1 and Task 2 (see Pashler, 1998). Implementing the masked priming task as Task 2 in the PRP context allowed us to further study the effects of masked priming under conditions of maximized divided attention. In particular, participants were clearly instructed to prioritize Task 1 over Task 2 processing. Task 1 prioritization is assumed to allocate the attentional focus (e.g., attentional resources, Tombu & Jolicoeur, 2002, 2003) entirely on the tone task instead of the priming task. Furthermore, we closely modelled the task combination (i.e., auditory−manual tone task and a visual−manual number task) after the study of Schubert et al. (2008) to investigate masked priming effects in conditions of a processing bottleneck in Task 2.

If the processing of masked prime information is affected by manipulations of divided attention, priming effects should be smaller with a high amount of task overlap (short SOA) than with a low amount of task overlap (long SOA). The distinction between novel and target primes was aimed at investigating whether manipulations of divided attention affect priming based on acquired S−R links differentially from priming based on semantics. In this respect, semantic priming is indicated by faster responding when novel primes belong to the same category as the target (e.g., 2−4) than when prime and target belong to opposite categories (e.g., 2−6). In contrast, priming based on acquired S−R links is indicated by faster responding when target primes belong to the same category as the targets (e.g., 1−4) than when target primes and targets belong to opposite categories (e.g., 1−6). In addition, the stimulus set used here allowed us to investigate priming effects based on target primes in some more detail. As mentioned above, within the set of target primes repetitions of identical prime and target stimuli occur in 50% of congruent conditions (e.g., 1−1). Therefore, within the set of target primes we aimed to differentiate priming effects produced by direct stimulus repetitions and priming effects produced by response priming (e.g., Bodner & Masson, 1997, 2003). Using a number priming task allowed us to extend previous research combining masked priming and PRP (e.g., Schubert et al., 2008) by differentiating between forms of masked priming: priming revealed by target primes (repetition priming, response priming) and priming revealed by novel primes (e.g., semantic priming), respectively.

Method

Participants

A total of 32 students (21 female, mean age = 21.4 years) of Würzburg University took part in the experiment. All had normal or corrected-to-normal vision.

Apparatus and stimuli

Stimulus presentation and collection of responses were performed by an IBM-compatible computer with a 17-inch VGA display and the PST response box (Psychology Software Tools) with externally mounted response keys controlled by E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Stimulus presentation was synchronized with the vertical retraces of a 100-Hz monitor, resulting in a vertical refresh rate of approximately 10 ms.

For the auditory task, two clearly discriminable high- and low-pitched tones lasting 50 ms were used. For the visual task, stimuli were the digits 1 to 9 except for 5. All digits were used as primes whereas the digits 1, 4, 6, and 9 were used as targets. Prime stimuli were presented for three refresh cycles of the display—that is, 30 ms. They were preceded and followed by a mask consisting of five randomly chosen symbols (out of §, $, %, &, ?, and #, respectively) with a duration of 70 ms each. The target stimulus was presented immediately after the post mask, thus keeping a constant prime–target interval of 100 ms. All characters were presented in white on black background. The primes were presented in Arial 44; the targets and the symbols for the mask were presented in Arial 48 centrally on the screen. At a viewing distance of approximately 50 cm target stimuli extended to $1.5^\circ \times 0.6-1.0^\circ$ (depending on the width of the digit) and masks approximately to $1.8^\circ \times 6.0^\circ$ in height and width, respectively. Responses were collected by four external response keys; two keys were placed next to each other so that they could be comfortably pressed with the index and the middle finger. Keys for the left and the right hand were placed with a distance of 16.5 cm.

Procedure

In Task 1 (auditory task), participants were asked to indicate the pitch of the tone with left-hand responses. We chose a compatible mapping (i.e., corresponding to a standard piano keyboard) for all participants meaning that low-pitched tones were indicated with the middle finger (i.e., left response) and high-pitched tones with the index finger (i.e., right response of the left hand). Task 2 (visual task) required indicating whether the presented target digit was smaller or larger than 5 with a right-hand response. Half of the participants responded with the index finger if the digit was smaller and with the middle finger if the digit was larger than 5 whereas for the other half of participants the mapping was reversed.[1] Participants were instructed to emphasize performance on Task 1. Nevertheless, they were to respond as fast and as accurate as possible for both tasks.

The visual presentation was the same in each trial: A fixation cross (400 ms) was followed by a blank (600 ms), the foremask (70 ms), the prime (30 ms), the premask (70 ms), and the S2 target stimulus (200 ms). The S1 tone stimulus (50 ms) was presented 70, 170, or 800 ms before the S2 target stimulus. Response times in the priming task were measured from target onset till response execution.

The experiment consisted of 768 trials; each combination of Target Digit (4) × Prime Digit (8) × Tone (2) × SOA (3) was presented four times. It was subdivided into 12 blocks with 64 trials each. Between the blocks participants were allowed a short rest.

At the end of the experiment, we tested prime visibility. Participants were fully informed about the precise structure of the prime stimuli. A total of 96 trials identical to the experimental trials were presented, and participants were asked to discriminate whether the prime was smaller or larger than 5. For the discrimination task, participants

---

[1] In none of the experiments did additional analyses reveal any effect of S–R mapping.

were instructed to take their time and to try to be as accurate as possible. In order to avoid the possibility that unconscious priming effects influenced the free response choice (see Kiesel et al., 2006b; Schlaghecken & Eimer, 2004), there was an interval of 1,000 ms after target onset, in which no response was possible (adopted from Vorberg et al., 2003). Please note that the measure of prime awareness is likely to overestimate prime visibility because participants do not have to respond to any target and can concentrate on the visual prime stimulus in the discrimination task while they had to divide attention between visual and auditory stimuli in the main experiment.

Results

Prime visibility

To assess prime visibility, we computed the signal detection measure d' whereby primes larger than 5 were treated as signal. Overall discrimination for primes was $d' = 0.22$ and deviated from zero, $t(31) = 3.85$, $p < .001$. Discrimination performance did not differ for target and novel primes, $t(31) = 0.06$, $p = .95$; it amounted to $d' = 0.23$ for target primes and $d' = 0.22$ for novel primes. In addition discrimination performance did not differ between SOAs, $F < 1$, amounting to $d' = 0.16$, $d' = 0.27$, and $d' = 0.27$ for SOAs 70, 170, and 800 ms, respectively.

For the RT analyses, all error trials in Task 1 as well as in Task 2 were discarded (11.7%). Repeated measures analyses of variance (ANOVAs) were conducted on median correct RTs and percentage error for both tasks containing the factors SOA (70, 170, 800 ms), congruence (congruent, C, vs. incongruent, IC) and prime type (target vs. novel primes). Greenhouse–Geißer adjustments were applied when appropriate. Results are presented in Figure 1.

Priming task (Task 2)

All trials in which responses in Task 1 (RT1) or responses in Task 2 (RT2) were smaller than 150 ms or larger than 2,000 ms were treated as outliers and were excluded (3.7%). Responses in Task 2 were slower when both tasks were performed in short succession (short SOAs) than when they were performed consecutively (long SOA), $F(2, 62) = 192.60$, $MSE = 36{,}945.66$, $p < .001$. The difference between the shortest and the longest SOA revealed a PRP effect of 334 ms. We observed a reliable congruence effect in Task 2, $F(1, 31) = 11.19$, $MSE = 1{,}423.65$, $p < .01$, which was not affected by SOA ($F < 1$). The factor congruence also interacted with prime type, $F(1, 31) = 6.78$, $MSE = 1{,}344.15$, $p < .05$, suggesting that priming effects for target primes are larger than priming effects for novel primes. To investigate this interaction in more detail, separate ANOVAs were conducted for target and novel primes. The ANOVA on target primes contained the factor SOA and the three-level factor congruence: *repetition* (prime = target), *congruent* (prime and target require the same response but are not identical), and *incongruent* (prime and target are different

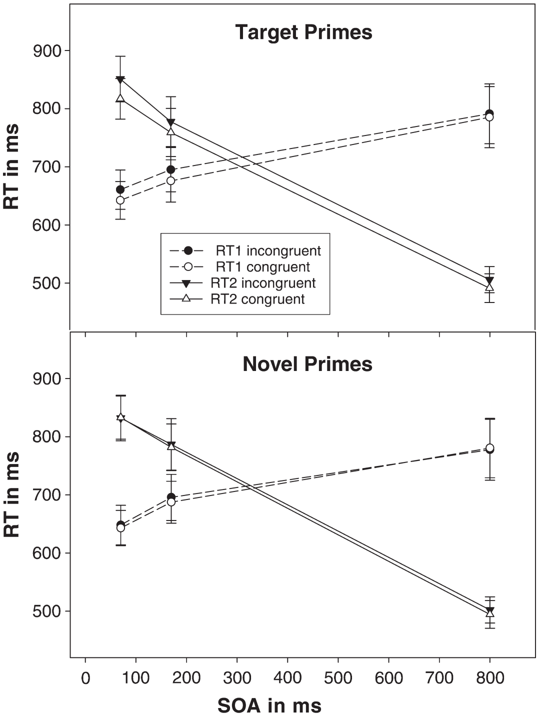

Figure 1. *Response times (RTs, in ms) for target and novel primes in Task 2 (solid lines) and Task 1 (dashed lines) in Experiment 1 depending on stimulus onset asynchrony (SOA) and congruence. Error bars represent standard errors of the mean.*

and require different responses). This allowed us to test whether response priming effects remain significant when identical prime–target repetitions are controlled for (see, e.g., Bodner & Dypvik, 2005; Bodner & Masson, 2003). Importantly, the planned repeated contrasts confirmed a reliable response priming effect of 12 ms (*incongruent–congruent*), $F(1, 31) = 5.03$, $MSE = 976.94$, $p < .05$ (see Figure 2). At the same time, the ANOVA on novel primes did not reveal a priming effect (4 ms), $F < 1$. The size of response prime and novel prime effects did not differ with respect to SOA, both Fs < 1. Yet, the response priming effect alone (without identical repetitions) failed to statistically exceed the novel priming effect, $F(1, 31) = 1.42$, $MSE = 1{,}443.28$, $p = .242$.

Participants produced 8.1% errors in Task 2 (see Table 1). Error rates increased with increasing SOA (7.3, 7.0, and 10.1 for SOAs 70, 170, and 800, respectively), $F(2, 62) = 10.90$, $MSE = 48.66$, $p < .01$. No other effects were significant.

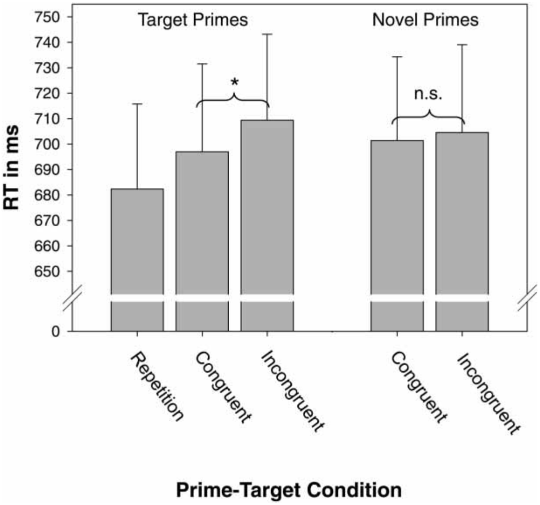

Figure 2. *Response times (RTs, in ms) for target and novel prime conditions in Task 2 of Experiment 1. Repetition denotes a prime–target stimulus repetition. Error bars represent standard errors of the mean. *significant ($p < .05$), n.s. = nonsignificant*

Tone task (Task 1)

RT1 was affected by the factor SOA, $F(2, 62) = 14.44$, $MSE = 80{,}663.07$, $p < .001$. Responses became slower the longer the SOA, which might be due to some response delaying (grouping) strategy (e.g., Pashler & Johnston, 1989). Responses to the tones were faster when prime and target stimuli in Task 2 were congruent (702 ms) rather than incongruent (711 ms), $F(1, 31) = 5.00$, $MSE = 1{,}563.76$, $p < .05$. Task 2 congruence did not interact with SOA, $F < 1$. The influence of Task 2 congruence on Task 1 performance is at least numerically larger for target (15 ms) than for novel primes (3 ms). However, the interaction

Table 1. *Percentage error and standard error in Experiments 1 and 2 for Tasks 1 and 2 depending on SOA, prime condition, and congruence*

			Target primes		*Novel primes*	
Experiment	*Task*	*SOA*	*C*	*IC*	*C*	*IC*
Experiment 1	Task 1	70	4.8 (0.61)	4.9 (0.70)	5.8 (0.91)	5.1 (0.66)
		170	5.2 (0.73)	5.3 (0.81)	5.8 (0.89)	5.1 (0.66)
		800	2.7 (0.50)	2.1 (0.44)	2.1 (0.47)	3.0 (0.66)
	Task 2	70	7.0 (1.05)	7.4 (0.93)	7.8 (0.88)	6.9 (0.96)
		170	6.8 (0.95)	7.0 (1.07)	7.0 (0.83)	7.0 (1.00)
		800	8.3 (1.00)	11.2 (1.60)	10.1 (1.20)	10.7 (1.29)
Experiment 2	Task 1	70	1.9 (0.51)	2.0 (0.51)	1.5 (0.33)	1.8 (0.41)
		170	2.2 (0.53)	1.8 (0.42)	1.5 (0.37)	1.8 (0.41)
		800	1.6 (0.47)	1.6 (0.40)	1.1 (0.32)	2.0 (0.57)
	Task 2	70	5.4 (0.84)	5.2 (0.84)	4.2 (0.80)	5.2 (0.91)
		170	4.3 (0.82)	5.0 (0.71)	5.4 (0.79)	4.4 (0.70)
		800	4.0 (0.56)	4.9 (0.85)	4.3 (0.55)	4.3 (0.90)

Note: SOA = stimulus onset asynchrony (in ms). C = congruent, IC = incongruent. Standard errors in parentheses.

between congruence and prime type on RT1 was not statistically reliable, $F(1, 31) = 1.23$, $MSE = 2{,}401.01$, $p = .277$.

Participants committed 4.3% errors in Task 1. The error rates were affected by the amount of task overlap, which was expressed by the main effect of SOA on percentage error, $F(2, 62) = 24.22$, $MSE = 14.51$, $p < .001$. That is, more errors were produced when SOA was short (i.e., 70 or 170 ms) than when SOA was long (see also Table 1). No other effects were significant.

Discussion

Experiment 1 investigated masked priming effects in Task 2 of a PRP task situation where attention was allocated by instruction to Task 1. The results are straightforward; masked priming that is assumed to rely on the formation of S–R associations was not impaired in Task 2 of the dual-task context. That is, neither conditions of maximum task overlap (short SOA) nor instructed Task 1 priority (drawing attention away from Task 2 processing) led to a reduction of masked priming effects revealed by target primes. Thus, the size of those effects did not depend on manipulations of divided attention. Target prime analyses also showed that even when identical prime–target repetitions were removed, significant effects of response priming were found in conditions of dual-task load irrespective of manipulations of divided attention.

A quite different picture was found for masked priming effects that are based on novel primes and which have been related to semantic priming by several authors (e.g., Naccache & Dehaene, 2001). Apparently, the mere presence of a dual-task context was sufficient to reduce this form of masked priming to a nonsignificant level. That is, we observed no reliable congruence effects irrespective of the amount of task overlap, and even at minimum task overlap at long SOA, novel priming was not found. This is surprising because masked priming that is based on novel primes has been repeatedly demonstrated in single-task settings and seems to be a rather robust phenomenon. For example, Naccache and Dehaene (2001; see also Kunde et al., 2003) demonstrated robust novel priming using the same task and priming procedure as that implemented as Task 2 in the present experiment.

It seems that dividing attention between two tasks has no (or minor) impact on priming via acquired S–R associations (congruence by target primes) while such a manipulation reduces priming effects by novel primes. Thus, the results of Experiment 1 suggest that the two types of priming are related to different processing demands, which suffer to a different degree from the need to share attention with another task. Before speculating more about the nature of these processes, below we further elaborate the attentional requirements of novel priming. As a final result we found that the congruence relation on the basis of target primes in Task 2 also affected tone response latencies in Task 1, which replicates findings from Schubert et al. (2008). We discuss this Task 2–Task 1 priming transfer effect in the General Discussion section.

EXPERIMENT 2

Experiment 2 served the purpose of further investigating the attentional requirements of masked priming based on novel primes. To this aim, Experiment 2 resembles Experiment 1 except for a reversed task order. Participants were to judge the size of numbers first (masked priming task) and only subsequently to determine the frequency of the tone in Task 2 (tone task). Importantly, instructions emphasized Task 1 processing and thus the masked priming task. This change in procedure ensured that attention was now intentionally allocated to the target stimulus in Task 1, which was preceded by a masked prime. Despite Task 1 prioritization participants were still required to secure dual-task specific coordination processes (e.g., appropriate stimulus–response binding) to manage Task 1 processing in the face of attentional capture potentially triggered by the onset of Task 2 stimuli (e.g., Dalton & Lavie, 2004; Yantis & Jonides, 1984). In Experiment 2, we aimed to test whether the mere secondary task performance interferes and thus diminishes effects of novel priming.

Therefore, Experiment 2 was designed to be informative as to whether a change of the allocation of attention to the processing of the masked priming task (Task 1) will suffice to “reestablish” effects of masked priming based on novel primes in the context of dual-task processing.

Method

Participants

A total of 24 students (20 female, mean age = 23.0 years) of Würzburg University took part in the experiment. All had normal or corrected-to-normal vision. None of the participants had participated in Experiment 1.

Apparatus, stimuli, and procedure

Apparatus and stimuli were the same as those in Experiment 1. Procedure was similar to that in Experiment 1 with the exception that task order was reversed. That is, the visual stimulus was presented first, and the auditory tone stimulus was presented 70, 170, or 800 ms after target onset. Participants were instructed to emphasize Task 1 performance (i.e., visual task) but to respond as fast and as accurately as possible in both tasks.

Results

Prime visibility

Overall discrimination for primes was $d' = 0.37$ and deviated from zero, $t(22) = 4.19$, $p < .001$. Discrimination performance did not differ for target and novel primes, $t(22) = 0.53$, $p = .60$; it amounted to $d' = 0.43$ for target primes and $d' = 0.35$ for novel primes. In addition, discrimination performance did not differ between SOA conditions, $F < 1$, amounting to $d' = 0.50$, $d' = 0.32$, and $d' = 0.29$ for SOAs 70, 170, and 800 ms, respectively.

Prior to RT analyses all error trials in Task 1 as well as those in Task 2 were discarded (6.2%). One person was excluded from analyses due to unusually high error rates (>30%). Repeated measures ANOVAs were conducted on correct median responses in Task 1 and Task 2 and percentage error containing the factors SOA (70, 170, 800 ms), congruence (C vs. IC), and prime type (target vs. novel primes).

Priming task (Task 1)

Trials in which RT1 was below 150 ms or above 2,000 ms were not included in the analysis (1.1%). RTs in Task 1 were not significantly affected by the factor SOA, $F(2, 44) = 2.79$, $MSE = 117{,}742.06$, $p = .108$. We found an overall effect of congruence on RT1, $F(1, 22) = 18.23$, $MSE = 670.76$, $p < .001$, which did not depend on the amount of task overlap as the factors congruence and SOA did not show any interaction ($F < 1$).

Figure 3 shows that the congruence effect was most pronounced for target primes (upper panel) but less so for novel primes (lower panel). This observation is captured in the interaction between

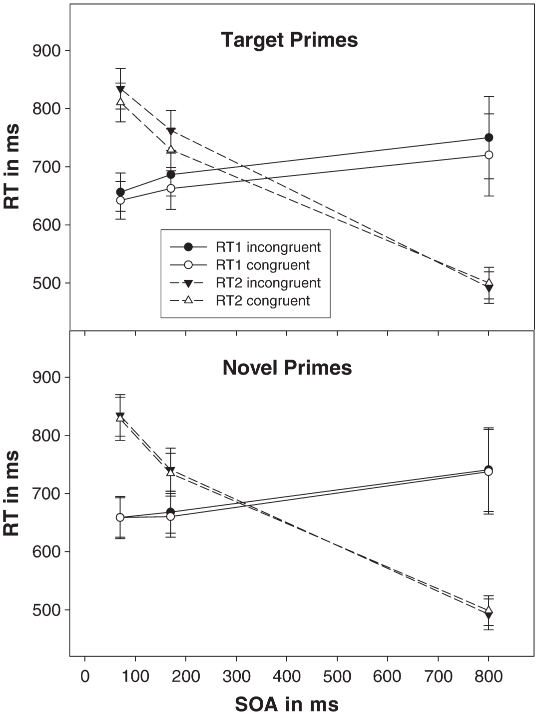

Figure 3. *Response times (RTs, in ms) for target and novel primes in Task 1 (solid lines) and Task 2 (dashed lines) in Experiment 2 depending on SOA and congruence. Error bars represent standard errors of the mean.*

the factors congruence and prime type that marginally missed the level of statistical significance, $F(1, 22) = 4.21$, $MSE = 1{,}020.79$, $p = .052$.

As in Experiment 1, we conducted follow-up analyses separately for each prime type.

The ANOVA on target prime trials contained the three-level factor congruence (repetition, congruent, and incongruent) and the factor SOA. As before, the important repeated contrast incongruent–congruent confirmed a reliable response priming effect (17 ms), $F(1, 22) = 9.14$, $MSE = 698.13$, $p < .01$ (see Figure 4). The ANOVA on novel prime trials, on the other hand, showed that novel prime effects (5 ms) did not deviate from zero, $F(1, 22) = 1.60$, $MSE = 686.91$, $p = .220$. Neither response priming nor novel prime effects interacted with SOA (both Fs < 1). Finally, subsequent testing revealed that the response priming effect alone (without identical repetitions) did not statistically exceed the novel priming effect, $F(1, 22) = 2.33$, $MSE = 854.24$, $p = .141$.

In Task 1, participants committed 1.7% errors (see Table 1). In the ANOVA applied to the error data none of the factors or interactions reached significance (all ps $> .105$).

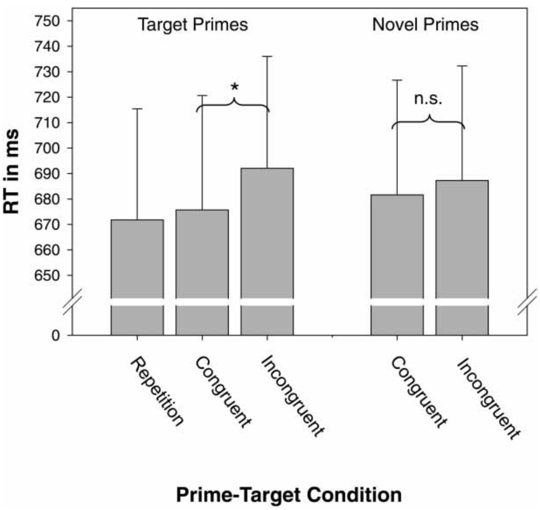

Figure 4. *Response times (RTs, in ms) for target and novel prime conditions in Task 1 of Experiment 2. Repetition denotes a prime–target stimulus repetition. Error bars represent standard errors of the mean. *significant ($p < .01$), n.s. = nonsignificant*

Tone task (Task 2)

Prior to analysis, all trials in which RT1 and RT2 were not within the range between 150 ms and 2,000 ms were excluded from the analysis (2.1%). RT2 was strongly affected by SOA. That is, RT2 decreased with increasing SOA indicating a PRP, $F(2, 44) = 404.86$, $MSE = 9{,}693.50$, $p < .001$. RT2 was also affected by the prime–target congruence relation in Task 1 with faster responses to the tone in congruent (677 ms) than in incongruent (687 ms) conditions, $F(1, 22) = 23.04$, $MSE = 293.25$, $p < .001$. Task 1 congruence affected RT2 only at short and medium SOA but not at long SOA (see Figure 3), which is expressed in the interaction between SOA and congruence, $F(2, 44) = 4.48$, $MSE = 1{,}007.16$, $p < .05$. Importantly, transfer effects of Task 1 congruence onto Task 2 performance were only found for target primes but not for novel primes as shown in the interaction between congruence and prime type on RT2, $F(1, 22) = 5.37$, $MSE = 569.26$, $p < .05$. More specifically, at SOA 70 and 170 ms target prime congruence effects of 25 ms, $t(22) = 2.41$, $p < .05$, and 29 ms, $t(22) = 2.40$, $p < .05$, were transferred onto Task 2 processing.

Participants committed 4.7% errors in Task 2. The repeated measures ANOVA with the same factors as those for the RT ANOVA revealed no significant effects on error rates (all ps $> .193$).

Discussion

In Experiment 2, participants performed a masked primed number categorization task as Task 1 while subsequently responding to the frequency of a tone in Task 2. Task instructions emphasized Task 1 processing over Task 2 processing and thus ensured that attention was allocated to the number task. Results showed that secondary task performance had virtually no influence on masked priming effects revealed by target primes. The effects of masked response priming (i.e., excluding identical prime–target repetitions) remained substantial under dual-task load and were also not affected by SOA. Furthermore, responses in Task 2 were affected by Task 1 congruence (target primes only) especially at short

SOA. These propagated priming effects from Task 1 onto RT2 support the RT pattern from Task 1 and confirm the existence of reliable masked priming effects by target primes even under conditions of high task load (short SOA).

In contrast to this, and quite surprisingly, neither at short nor at long SOA was any evidence of masked priming revealed by novel primes found. This pattern of results replicates and extends findings from Experiment 1. First, it suggests that merely performing the secondary task interferes and thus diminishes effects of novel priming. It seems irrelevant whether certain parts of the secondary task have to be performed simultaneously to Task 1, as is the case at short SOA, or whether both tasks are performed with little task overlap as in conditions of long SOA. Second, it particularly raises the question of what exactly places the attentional limitations upon the occurrence of masked priming by novel primes. Experiment 3 was conducted to shed further light on this question.

EXPERIMENT 3

So far we observed that manipulations of divided attention revealed differential effects upon the occurrence of masked priming effects by novel or target primes. However the lack of masked priming effects by novel primes needs further clarification. For instance, it is known that masked priming effects by novel primes are usually smaller than effects revealed by target primes (e.g., Kiesel et al., 2006a; see van den Bussche et al., 2009, for a meta-analysis). Therefore, one could argue that the mere expectation and preparation of subsequent secondary task performances (e.g., long SOA, Experiment 2) represent attentional constraints that already limit the occurrence of masked priming effects by novel primes. On the other hand, and before drawing conclusions about the preconditions of novel prime effects it seems inevitable to demonstrate such effects in the first place. It is conceivable, for example, that factors of the present experimental design (e.g., masking procedure) prevent novel primes from being effective.

In order to "reestablish" masked priming effects by novel primes, we reduced the attentional requirements in Experiment 3 even further. We created a single-task condition in which the number task and the tone task were performed sequentially. We changed the previous dual-task setting from Experiments 1 and 2, in which S−R rules had to be coordinated simultaneously, to a conventional task-switching setting (Meiran, 1996; Rogers & Monsell, 1995; for a recent overview see Kiesel et al., in press) in which different S−R rules were applied serially one at a time. That is, the number task as well as the tone task were presented individually and randomly within the experiment. In addition, in separate blocks of trials we distinguished between task switching and single-task conditions. In task-switching blocks both the number task and the tone task were performed. In single-task blocks, on the other hand, only the number task was performed, and the tone task was ignored. This served to compare priming effects in a task-switching setting with priming effects in a more conventional single-task setting (see also Ansorge, 2004). Participants received a brief task cue to indicate which S−R rule was required for the upcoming task. Although the experimental setting of the task-switching block can also be viewed as a dual-task setting, participants did at no time expect the simultaneous coordination of multiple S−R rules as in Experiments 1 and 2.

Method

Participants

A total of 23 students (18 female, mean age = 23.5 years) of Würzburg University took part in the experiment. All had normal or corrected-to-normal vision. None of the participants had participated in Experiment 1 or Experiment 2.

Apparatus, stimuli, and procedure

Apparatus and stimuli were the same as those in Experiments 1 and 2. Procedure was similar to that in Experiments 1 and 2 with the exception that participants performed the visual and auditory task as single tasks. In each trial one of the two tasks was chosen randomly. The word "*Ziffer*" (German for digit) or "*Ton*" (German for tone) was presented for 500 ms to inform participants about the currently relevant task. This task cue was followed by a blank screen for 200 ms and a fixation cross for 500 ms. Then either the tone stimulus or the visual stimulus (including premask, prime, postmask, and target) was presented. We used the same stimulus–response mappings as before for both tasks—that is, participants indicated low-pitched tones with the middle finger (i.e., left response) and high-pitched tones with the index finger (i.e., right response) of the left hand. For the visual task, half of the participants responded with the right hand with the index finger if the digit was smaller and with the middle finger if the digit was larger than 5 whereas for the other half of participants the mapping was reversed. The next trial started 1,500 ms after responding. In case of errors an error signal was presented for 500 ms after the response; thereby the two possible error types—that is, errors when using the wrong hand and errors when pressing the wrong key (while using the correct hand)—were fed back separately.

Participants performed 12 blocks with 64 trials (i.e., 32 trials per task). In each block, the combination of Target Digit (4) × Prime Digit (8) was presented once, and each tone stimulus was presented 16 times. In half of the blocks, participants responded to digit and tone stimuli (task-switching blocks) while in the other half of the blocks, participants responded to digits only but did not respond to tone tasks (single-task blocks). The order of whether participants started with 6 task-switching blocks or with 6 single-task blocks was counterbalanced across participants.

Similar to Experiments 1 and 2 we tested prime visibility at the end of the experiment. A total of 128 trials identical to the experimental trials were presented, and participants were asked to discriminate whether the prime was smaller or larger than 5.

Results

Prime visibility

Overall discrimination for primes was $d' = 0.48$ and deviated from zero, $t(22) = 6.79$, $p < .001$. Discrimination performance did not significantly differ for target and novel primes, $t(22) = 1.87$, $p = .074$; it amounted to $d' = 0.56$ for target primes and $d' = 0.41$ for novel primes. Target primes but less so novel primes were detected somewhat better in Experiment 3 than in Experiment 1, $t(53) = 2.49$, $p < .05$ for target primes and $t(53) = 1.85$, $p = .070$ for novel primes, respectively. Importantly, comparing discrimination performance for target and novel primes between Experiment 2 and Experiment 3, which yields the closest condition of comparison, no differences for the detection of target primes, $t(44) = 0.99$, $p = .328$, or for the detection of novel primes, $t(44) = 0.33$, $p = .744$, was found between the experiments.[2]

In the following, we solely report analysis for the visual task, because only the visual task can yield priming effects. Prior to analyses all trials with RT faster than 150 ms or slower than 2,000 ms were discarded (0.3%). The first trial of each block was also omitted (1.6%), since it does not contain N-1 history of task repetitions or task switches. Repeated measures ANOVAs were conducted on correct median RTs and percentage error containing the factors task switch (switch vs. repetition), block (task switch vs. single task), congruence (C vs. IC), and prime type (target vs. novel primes); the corresponding mean RTs and error rates are shown in Table 2.

Priming task

Participants responded faster following congruent primes (572 ms) than following incongruent primes (585 ms), $F(1, 22) = 18.59$, $MSE = 847.73$, $p < .001$. Additionally they responded faster in task repetition (574 ms) than task switch trials (584 ms), $F(1, 22) = 6.10$, $MSE = 1{,}587.83$,

---

[2] Although we tested new participants in each experiment, we cannot exclude that participants may have gained prior experience at prime detection by participating in other masked priming studies. Such experience might increase prime visibility. We thank Friederike Schlaghecken for mentioning this possibility.

Table 2. *Mean RT, percentage error, and standard error in Experiment 3 depending on block, task transition, prime condition, and congruence*

			Target primes		*Novel primes*	
	Block	*Task transition*	*C*	*IC*	*C*	*IC*
RT	Task switch	Repetition	576 (19)	587 (18)	573 (19)	588 (16)
		Switch	591 (20)	596 (17)	583 (17)	595 (20)
	Single task	Repetition	552 (13)	577 (13)	560 (14)	576 (15)
		Switch	571 (15)	586 (14)	571 (16)	578 (14)
PE	Task switch	Repetition	4.1 (0.94)	5.4 (1.42)	3.4 (1.16)	6.0 (1.43)
		Switch	4.7 (1.06)	6.5 (1.95)	5.9 (1.41)	3.9 (1.27)
	Single task	Repetition	3.8 (0.75)	5.1 (1.18)	2.2 (0.76)	4.0 (1.21)
		Switch	3.7 (0.93)	5.6 (1.10)	4.6 (1.16)	3.4 (1.31)

Note: C = congruent, IC = incongruent. RT = response time (in ms). PE = percentage error. Standard errors in parentheses.

$p < .05$. No further effects reached statistical significance. In particular, congruence effects were not affected by block, $F(1, 22) = 1.24$, $MSE = 481.20$, $p = .277$, task switch, $F(1, 22) = 2.44$, $MSE = 546.60$, $p = .132$, or Block × Task Switch, $F < 1$. Furthermore, no interactions were found for Congruence × Prime Type × Block, $F(1, 22) = 2.19$, $MSE = 461.31$, $p = .153$, nor for Congruence × Prime Type, or Congruence × Prime Type × Task Switch, both Fs < 1.

These results reveal that the target prime effect did not exceed the novel prime effect. Despite the lack of interaction between congruence and prime type, we conducted follow-up analyses separately for each prime type to show the robustness of the findings. The ANOVA on target prime trials contained the three-level factor congruence (repetition, congruent, and incongruent, respectively). The planned repeated contrast incongruent−congruent revealed a significant response congruence effect (12 ms), $F(1, 22) = 9.19$, $MSE = 312.70$, $p < .01$. The ANOVA conducted on novel prime trials proved an identical significant novel prime effect (12 ms), $F(1, 22) = 14.47$, $MSE = 473.97$, $p < .01$ (see Figure 5). None of the priming effects interacted with task switch (Fs < 1) or any other factors.

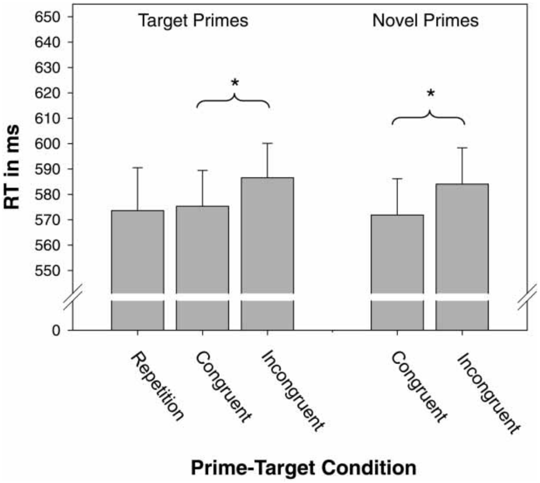

Figure 5. *Response times (RTs, in ms) for target and novel prime conditions in Experiment 3. Repetition denotes a prime−target stimulus repetition. Error bars represent standard errors of the mean. *significant ($p < .01$)*

Participants committed 4.5% errors. The ANOVA applied to the error data revealed that participants committed slightly more errors in incongruent (5.0%) than in congruent (4.1%) trials, which, however, failed the level of statistical significance, $F(1, 22) = 2.26$, $MSE = 32.45$, $p = .147$. Congruence did not differ between prime types, $F(1, 22) = 1.62$, $MSE = 24.30$, $p = .216$. However, the factors prime type, switch, and congruence interacted significantly, $F(1, 22) = 7.16$, $MSE = 14.79$, $p < .05$. Whereas in task repetition trials the congruence effects in error rates was present for target and for novel primes alike, in the task switch condition novel primes revealed slightly reversed congruence effect—that is, more errors in congruent than in incongruent trials (see Table 2). No other effect reached significance.

Discussion

In Experiment 3, we demonstrated masked priming effects by novel primes under conditions of reduced attentional requirements in the priming task. For this reason the previous dual-task setting from Experiment 2 was changed into a task-switching setting. Results are straightforward: Significant masked priming effects were found for target primes and for novel primes alike. Furthermore, the size of the masked priming effects for novel and for target primes did not differ between trials of S–R rule repetition (task-repetition trials) and trials in which the previously active S–R rule had to be dismissed in favour of a new one (task-switch trials). In addition, priming effects also did not differ between task-switching blocks and blocks of single-task trials. These findings demonstrate first that masked priming by novel primes can also be established with the current experimental design and secondly that the limiting factor in demonstrating masked priming by novel primes in conditions of divided attention (Experiments 1 and 2) seems to be associated with dual-task-specific processing characteristics such as the simultaneous coordination of multiple S–R rules. The demonstration of reliable masked priming effects for both target and novel primes in conditions of switching task sets, on the other hand, shows that both kinds of masked priming effect can rapidly adapt to changing S–R mappings (see also Kiesel, Kunde, & Hoffmann, 2007b; Reynvoet et al., 2005).

GENERAL DISCUSSION

The present study aimed to investigate the impact of different manipulations affecting the degree of divided attention on masked priming effects. For the attentional manipulation, we combined a PRP paradigm with a masked priming task and tested whether dual-task-specific interference eliminates effects of masked priming. In Experiment 1, the masked priming task served as Task 2 in the PRP paradigm, and instructions emphasized Task 1 processing to ensure that attention was indeed drawn away from processing the priming task. That is, Experiment 1 implemented task conditions with the least amount of attention allocated to the priming task. Under this specific condition of divided attention, semantically mediated priming but not response priming effects were removed irrespective of SOA. Even in Experiment 2, in which task order was reversed, and Task 1 prioritization led to allocation of attention onto the masked priming task, the same pattern emerged. Again, whereas masked priming by target primes was virtually unaffected by attentional modulations, no effects at all were found for masked priming by novel primes. Only in Experiment 3, in which tasks were presented individually in randomized order, were masked priming effects observed for both kinds of prime. Moreover, the size of the priming effects was the same irrespective of target or novel primes. This indicates that a sequential preparation/activation of S–R rules according to permanently changing task requirements (e.g., task repetition vs. task switch) did not affect the occurrence of masked priming, be it mediated by S–R links or by semantic relations. The simultaneous preparation of more than one S–R rule, however, limits the effectiveness of novel primes while target primes still prime corresponding responses.

Priming effects by target primes

The present results show that priming effects based on well-practised target and unpractised novel primes seem to differ in their susceptibility to attentional limitations.[3] Our observation that

---

[3] Given that effects by novel primes are often smaller than those of target primes, it is also conceivable that dual-task load reduces the effects of both novel and target primes. This could also result in a nonsignificant novel prime effect and a significant target prime effect. However, we do not think that this explanation can account for our findings. In particular, we did not find evidence of a reduction of masked priming by target primes under dual-task load. Target prime effects were the same for short and for long SOA and were identical between Experiment 1 and Experiment 2. We thank an anonymous reviewer for this suggestion.

priming on the basis of acquired S−R associations is virtually unaffected by dual-task load is in accordance with recent findings from Bodner and Stalinski (2008) and Schubert and colleagues (2008). Bodner and Stalinski investigated masked repetition priming in a lexical decision task. In the condition with high additional task load participants rehearsed a particular 8-digit string that was presented prior to each trial. After responding to the target, a second 8-digit string was presented, and participants had to decide whether the current digit string matched the previous one. Importantly, repetition priming effects obtained under conditions of increased cognitive load were similar to repetition priming effects obtained in a control condition without additional cognitive load. Bodner and Stalinski therefore concluded that repetition priming is automatic. Schubert and colleagues (2008) demonstrated that reliable repetition priming occurs in a metacontrast paradigm despite strong manipulations of divided attention in a PRP paradigm. Extending these results, the present study shows that not only direct repetition priming but also priming effects based on response priming can occur in conditions of limited attention. In particular, excluding all identical prime−target repetitions (repetition priming effects), we still found reliable response priming effects in all three experiments irrespective of the implemented task load manipulations. It should be noted though, that in Experiments 1 and 2 response priming alone only numerically exceeded the effect of novel priming, but failed to do so statistically. This could be due to the fact that the exclusion of identical prime−target repetitions makes 50% of all congruent target prime trials, and removing such a large proportion of trials is likely to limit the power of the statistical analyses. Indeed, increasing the power by analysing the data of Experiments 1 and 2 together, the difference between response priming (no identical repetitions) and novel priming comes close to statistical significance, $F(1, 54) = 3.41$, $MSE = 1{,}176.98$, $p = .070$. However, at the moment this is speculative. Therefore, based on the present results, we cannot exclude that at least some of the observed differences between target and novel prime effects are driven by identical prime−target repetitions.

In the present study the priming effect based on target primes did not differ between different SOA conditions and thus between different task load conditions. First of all, this indicates that target prime processing is not impaired in conditions of maximum task load (short SOA). Second, it is also conceivable that strategic components may have delayed secondary task processing until Task 1 bottleneck processing is finished, thus accounting for the additive effect of congruence and SOA. At the same time, we found Task 2 congruence-related cross-talk effects onto Task 1 processing, which suggests that at least some parts of prime−target-related processing occurs during the assumed response selection bottleneck. However, even if relevant prime−target processing may have been significantly delayed, the finding of strong priming effects at each SOA suggests that masked priming produced from target primes is little if at all affected by manipulations of divided attention in a PRP setting.

At a first glance, this conclusion might seem at odds with findings reported by Ansorge (2004). Ansorge showed that the activation of alternative and nonmatching action goals of a task unrelated to the priming task resulted in interference, eventually decreasing masked priming effects. Besides fundamental differences in methodological approaches in the two studies, it is worth noting that in Ansorge's study the dual-task situation was not perfectly predictable. In particular, most of the time participants performed the priming task. Only occasionally and unpredictably did an alternative task have to be performed instead of the priming task. At least two possibilities might be responsible for Ansorge's result: First, it is conceivable that this procedure may involve additional monitoring processes that guide participants' expectations about which task might come next. Second, the eventual experience of performing the alternative task might result in a subsequent shift in the priority of task control settings. These two components, additional monitoring and/or shifts in control settings, might account for the finding of decreased masked priming effects in the dual-task condition of Ansorge's study. In contrast, task order, task likelihood, and priority of control settings were perfectly determined and thus predictable in our Experiments 1 and 2, resulting in reliable masked priming effects. Further research might follow up on those differences and explore the role of additional task monitoring and/or priority shifts in control settings for reduced masked priming effects by, for example, varying the likelihood of alternative (tone) task presence in the PRP methodology as used in the present study.

A further important result of our study is the finding that masked target primes not only affected RTs in the visual task but also affected RTs in the tone task virtually to the same extent (Experiments 1 and 2). At least two possibilities can account for such cross-task transfer priming effects. The first is based on assumptions of the response selection bottleneck (RSB) model of dual-task performance proposing that the bottleneck is located at central stages (e.g., Pashler, 1994; Pashler & Johnston, 1989). This is plausible in Experiment 2, in which the visual priming task served as Task 1 and the tone task as Task 2. Here, the masked priming effect revealed by target primes in Task 1 completely propagated to Task 2 when both tasks temporally overlapped (short SOAs, see Figure 3, top panel). This means that target prime effects occur at or before the bottleneck process (i.e., at central stages but not motor execution stages) in order to propagate to Task 2 (see also Ferreira & Pashler, 2002; Miller & Reynolds, 2003; Ruthruff, Johnston, & Van Selst, 2001). A second possibility for cross-task priming effects to occur is based on the assumption that subliminal prime stimuli facilitate early response activation processes (e.g., Leuthold & Kopp, 1998; Neumann & Klotz, 1994). In the present dual-task context, subliminal prime stimuli specify not only manual response parameters of the priming task but also interact with the specification of manual response parameters of the tone task (Schubert et al., 2008). Evidence for such a cross-task transfer priming effect onto the tone task was also found in Experiment 1. Prime–target congruence relations in the visual number categorization task (Task 2) affected the tone categorization (Task 1) at short SOAs (see Figure 1, top panel).[4] This finding is in fact expected based on previous results reported by Schubert et al. (2008). These authors showed that the congruence between masked arrow prime and arrow target stimuli in Task 2 of a PRP situation influenced S–R activation processes in Task 1. How does the congruence relation between prime and target in Task 2 influence pre-bottleneck processing of the auditory stimulus in Task 1? One of the mechanisms suggested by Schubert et al. (2008) is based on backward cross-talk effects between Task 2 and Task 1 (e.g., Hommel, 1998; Koch & Prinz, 2002; Lien & Proctor, 2002; Logan & Schulkind, 2000; Miller, 2006; Miller & Alderton, 2006; Navon & Miller, 2002). Backward cross-talk effects typically occur due to informational overlap between both tasks such as spatial R2–R1 compatibility (Logan & Gordon, 2001). In the present study, spatially R2–R1 compatible responses reflect, for example, right-finger responses in the tone task and right-finger responses in the visual task (or vice versa). Accordingly, spatially R2–R1 incompatible responses denote, for example, right-finger responses in the tone task and left-finger responses in the visual task (or vice versa). Note, that such cross-talk effects would only be expected when sufficient temporal overlap between Task 1 and Task 2 is available (i.e., at short SOAs). Therefore, the dimensional overlap on the basis of spatially assigned responses in both tasks

---

[4] The cross-task transfer priming effect is difficult to explain by the original RSB account, because response activation of Task 2 cannot start until central processing stages in Task 1 are finished. A better explanation is provided in recent modified versions of the RSB model in which response selection is divided into two subprocesses, an automatic response activation process that occurs during the bottleneck and a response identification process that is bottleneck dependent (for detailed reviews see Hommel, 1998; Lien & Proctor, 2002).

might give rise to backward cross-talk effects in the present study and might explain why Task 2 priming effects were also found in Task 1. In line with Schubert et al. (2008) we assume that in a congruent prime–target condition of Task 2, the critical spatial R2 information (i.e., R2 is spatially compatible/incompatible to R1) is activated earlier than in incongruent prime–target conditions. Consequently, if this information is provided earlier, cross-talk between R2 and R1 can also start earlier. Therefore, a congruent prime–target condition in Task 2 can lead to a faster completion of determining the final R1 parameter. Analogously, in incongruent prime–target conditions of Task 2 the critical spatial information of R2 (i.e., R2 is spatially compatible/incompatible to R1) is provided later, which might also delay the cross-talk between R2 and R1 and thus the determination of R1 parameters.

Importantly, when the prime–target relation in Task 2 can affect the determination of R1 parameters via influencing the onset of backward cross-talk onto Task 1, prime–target-related RT differences will also be found in Task 1. Moreover, if the prime–target relation in Task 2 affects prebottleneck/bottleneck stages of Task 1, these effects will eventually back-propagate onto Task 2 after completion of bottleneck stage processing in Task 1. This can explain why masked priming effects were found at short SOA in both tasks and provide a hint of why Task 2 priming effects at short SOA were not absorbed by the slack. Of course this argument rests on the assumption of the presence of backward cross-talk effects on the basis of spatial R2–R1 compatibility denoting the importance of the chosen task combination in the dual-task setting.[5] In Experiment 1, an ANOVA conducted on RT1 for the two short SOAs (i.e., 70, 170 ms) and for target primes only provided at least some preliminary support for this claim. Specifically, RT1 was 22 ms faster in R2–R1-compatible than in R2–R1-incompatible conditions, $F(1, 31) = 3.57$, $MSE = 8{,}188.59$, $p = .068$. This result suggests that backward cross-talk effects on the basis of spatial R2–R1 correspondence occurred in the present study. Although the statistical measures do not entirely back up this argument, it nevertheless provides a clue of how cross-task priming effects might occur in Experiment 1 (see also Schubert et al., 2008, for the discussion of further possibilities). That is, transfer priming effects found in Task 1 of Experiment 1 can result as a direct consequence of Task 1 and Task 2 cross-talk interactions. Further research is needed at this point to clearly disentangle the mechanisms that give rise to these effects.

Priming effects by novel primes

Whereas priming effects revealed by target primes are generally associated with mechanisms of repetition and/or response priming on the basis of acquired S–R links (Damian, 2001; Naccache & Dehaene, 2001), priming effects revealed by novel primes are at present less well understood. The present findings of a lack of effects of masked novel primes during dual tasks may add to the understanding of the specificity of the conditions under which such effects occur (see also Fischer, 2006). Interestingly, neither in Experiment 1 nor in Experiment 2 was any reliable evidence of novel priming effects to be found even at the longest SOA (the conditions of minimum load). We conclude, therefore, that the situation of performing two tasks at once results in strong reduction of novel prime effects below the level of statistical significance. The mere expectation and execution of two temporally paired tasks induces sufficient load to result in an apparent elimination. Further research might explore this issue in more detail—for example, by extending the chosen SOAs to even longer intervals in order to study the point of reemerging effects of novel primes in a dual-task setting.

Some authors attribute priming effects by novel primes to semantic processing of unconsciously presented information (Naccache & Dehaene,

---

[5] For example, Schubert et al. (2008) could show that transfer priming effects from Task 2 onto Task 1 did not occur without spatial R2–R1 compatibility.

2001; Reynvoet et al., 2005). In this view, stimuli are generally processed on a perceptual, semantic, and motor level irrespective of whether they are presented consciously or unconsciously. Semantic processing occurs because a subliminally presented prime stimulus automatically triggers activation in its semantic network. Target stimuli will benefit from this preactivation if they belong to the same semantic network but not if they do not (see Neely, 1991; Neely & Kahan, 2001, for overviews of spreading activation accounts). Following this argument, some authors argue that automatic activation triggered by a particular stimulus should be unaffected by manipulations of divided attention (Kahneman & Chajczyk, 1983; Posner & Snyder, 1975). Accordingly, conscious semantic processing has been shown to occur despite attentional limitations in dual-task settings (Fischer, Miller, & Schubert, 2007b; Fischer & Schubert, 2008; Oriet, Tombu, & Jolicoeur, 2005). In contrast to this, the present results seem to suggest that masked stimuli in particular may not be able to trigger semantic activation processes when participants perform two tasks at once or even expect, prepare, and/or coordinate the execution of multiple S−R rules (Experiments 1 and 2). Only when dual-task load is further decreased by performing both tasks sequentially in a task-switching setting are novel primes back in action. However, at the same time we are aware that the putative absence of semantic processing under dual-task load may be interpreted with caution, since semantic effects may still show up in electrophysiological measures despite their absence in RT data (e.g., Heil & Rolke, 2004; Mari-Beffa, Valdes, Cullen, Catena, & Houghton, 2005; Vogel, Luck, & Shapiro, 1998).

A somewhat different view of masked priming effects revealed by novel primes comes from studies demonstrating that prime processing in general depends crucially on current task affordances (e.g., Ansorge, Heumann & Scharlau, 2002; Bodner & Dypvik, 2005; Kunde et al., 2003; Schlaghecken & Eimer, 2004). Kunde and colleagues, for example, suggested that priming effects revealed by novel primes are not based on automatic semantic activation processes, but instead depend on the representation of the task requirements. In other words, only prime information that is relevant for the required behaviour can reveal an impact on target processing (see Kunde et al., 2003). According to this account, it is assumed that participants form action triggers for expected stimulus identities to prepare for an upcoming task (for similar ideas of task preparation see Ach, 1905; Hoffmann, 2003; Hommel, 2000; Neumann, 1990). That is, participants form expectations about expected stimulus identities and prepare themselves to perform a specific response according to each stimulus. Masked primes activate responses via these programmed S−R links if they fit to one of the existing action triggers. Thus, according to these ideas, it is not necessary to assume semantic processing of masked primes to account for priming by novel primes. In these terms, the present results suggest that participants may not be able either to sufficiently set up or to maintain action triggers when such triggers have to be coordinated for several tasks. Of course, these assumptions are speculative and cannot be tested on the basis of the present results. Further research is needed in this respect. In any case, the present experiments refine our understanding of the impact of attentional demands on masked priming effects. That is, the susceptibility of masked priming effects to manipulations of divided attention seems to be determined by the mechanisms underlying the masked priming effects.

Original manuscript received 18 August 2009
Accepted revision received 21 June 2010

REFERENCES

Abrams, R. L., Klinger, M. R., & Greenwald, A. G. (2002). Subliminal words activate semantic categories (not automated motor responses). *Psychonomic Bulletin & Review*, *9*, 100–106.

Ach, N. (1905). *Über die Willenstätigkeit und das Denken* [Willing and thinking]. Göttingen, Germany: Vandenhoeck & Ruprecht.

Ansorge, U. (2004). Top-down contingencies of nonconscious priming revealed by dual-task interference. *Quarterly Journal of Experimental Psychology*, *57A,* 1123–1148.

Ansorge, U., Heumann, M., & Scharlau, I. (2002). Influences of visibility, intentions, and probability in a peripheral cuing task. *Consciousness & Cognition*, *11,* 528–545.

Ansorge, U., Klotz, W., & Neumann, O. (1998). Manual and verbal responses to completely masked (unreportable) stimuli: Exploring some conditions for the metacontrast dissociation. *Perception*, *27,* 1177–1189.

Bargh, J. A., & Chartrand, T. L. (1999). The unbearable automaticity of being. *American Psychologist*, *54,* 462–479.

Besner, D., Risko, E. F., & Sklair, N. (2005). Spatial attention as a necessary preliminary to early processes in reading. *Canadian Journal of Experimental Psychology*, *59,* 99–108.

Bodner, G. E., & Dypvik, A. T. (2005). Masked priming of number judgments depends on prime validity and task. *Memory & Cognition*, *33,* 29–47.

Bodner, G. E., & Masson, M. E. J. (1997). Masked repetition priming of words and nonwords: Evidence for a nonlexical basis for priming. *Journal of Memory and Language*, *37,* 268–293.

Bodner, G. E., & Masson, M. E. (2003). Beyond spreading activation: An influence of relatedness proportion on masked semantic priming. *Psychonomic Bulletin & Review*, *10,* 645–652.

Bodner, G. E., & Stalinski, S. M. (2008). Masked repetition priming and proportion effects under cognitive load. *Canadian Journal of Experimental Psychology*, *62*(2), 127–131.

Dalton, P., & Lavie, N. (2004). Auditory attentional capture: Effects of singleton distractor sounds. *Journal of Experimental Psychology: Human Perception and Performance*, *30,* 180–193.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance*, *27,* 154–165.

Dehaene, S., Naccache, L., Le Clec'h, G., Koechlin, E., Müller, M., Dehaene-Lambertz, G., et al. (1998). Imaging unconscious semantic priming. *Nature*, *395,* 597–600.

Draine, S. C., & Greenwald, A. G. (1998). Replicate unconscious semantic priming. *Journal of Experimental Psychology: General*, *127,* 286–303.

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *24,* 1737–1747.

Ferreira, V. S., & Pashler, H. (2002). Central bottleneck influences on the processing stages of word production. *Journal of Experimental Psychology: Learning, Memory & Cognition*, *28,* 1187–1199.

Fischer, R. (2006). *Parallel memory retrieval in dual-task situations?* Lengerich, Germany: Pabst Science Publishers.

Fischer, R., Miller, J. O., & Schubert, T. (2007a). Evidence for parallel semantic memory retrieval in dual-tasks. *Memory & Cognition*, *35,* 1685–1695.

Fischer, R., & Schubert, T. (2008). Valence processing bypassing the response selection bottleneck? *Experimental Psychology*, *55,* 203–211.

Fischer, R., Schubert, T., & Liepelt, R. (2007b). Accessory stimuli modulate effects of nonconscious priming. *Perception and Psychophysics*, *69,* 9–22.

Greenwald, A. G. (1992). Unconscious cognition claimed. *American Psychologist*, *47,* 766–779.

Greenwald, A. G., Abrams, R. L., Naccache, L., & Dehaene, S. (2003). Long-term semantic memory versus contextual memory in unconscious number processing. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *29,* 235–247.

Heil, M., & Rolke, B. (2004). Unattended distractor induced priming in a visual selective attention task: N400 effects in the absence of RT effects. *Journal of Psychophysiology*, *18,* 164–169.

Hoffmann, J. (2003). Anticipatory behavioral control. In M. Butz, O. Sigaud, & P. Gerard (Eds.), *Anticipatory behavior in adaptive learning systems* (pp. 44–65). Heidelberg, Germany: Springer.

Hommel, B. (1998). Automatic stimulus–response translation in dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *24,* 1368–1384.

Hommel, B. (2000). The prepared reflex: Automaticity and control in stimulus–response translation. In S. Monsell & J. Driver (Eds.), *Attention and Performance XVIII: Control of cognitive processes* (pp. 247–273). Cambridge, MA: MIT Press.

Kahneman, D., & Chajczyk, D. (1983). Tests of the automaticity of reading: Dilution of Stroop effects by color-irrelevant stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *9,* 497–509.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for a spreading activation account of N400 priming effects. *Cognitive Brain Research*, *13,* 27–39.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious "automatic" processes: Evidence from event-related potentials in a masked priming paradigm. *Journal of Cognitive Neuroscience*, *18,* 184–198.

Kiefer, M., & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activation. *Cognitive Neuroscience*, *11,* 2401–2407.

Kiesel, A., Kunde, W., & Hoffmann, J. (2007a). Mechanisms of subliminal response priming. *Advances in Cognitive Psychology*, *3,* 307–315.

Kiesel, A., Kunde, W., & Hoffmann, J. (2007b). Unconscious priming according to multiple S–R rules. *Cognition*, *104,* 89–105.

Kiesel, A., Kunde, W., Pohl, C., & Hoffmann, J. (2006a). Priming from novel masked stimuli depends on target set size. *Advances in Cognitive Psychology*, *2,* 37–45.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Phillip, A., et al. (in press). Control and interference in task switching—a review. *Psychological Bulletin*.

Kiesel, A., Wagener, A., Kunde, W., Hoffmann, J., Fallgatter, A. J., & Stöcker, C. (2006b). Unconscious manipulation of free choice in humans. *Consciousness & Cognition*, *15,* 397–408.

Klauer, K. C., Musch, J., & Eder, A. B. (2005). Priming of semantic classifications: Late and response related, or earlier and more central? *Psychonomic Bulletin & Review*, *12,* 897–903.

Koch, I., & Prinz, W. (2002). Process interference and code overlap in dual-task performance. *Journal of Experimental Psychology: Human Perception & Performance*, *28,* 192–201.

Koechlin, E., Naccache, L., Block, E., & Dehaene, S. (1999). Primed numbers: Exploring the modularity of numerical representations with masked and unmasked semantic priming. *Journal of Experimental Psychology: Human Perception and Performance*, *25,* 1882–1905.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, *88,* 223–242.

Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after Broadbent (1958): Still no identification without attention. *Psychological Review*, *111,* 880–913.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event-related brain potentials. *Psychological Science*, *9,* 263–269.

Lien, M. C., & Proctor, R. W. (2002). Stimulus–response compatibility and psychological refractory period effects: Implications for response selection. *Psychonomic Bulletin & Review*, *9,* 212–238.

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

Logan, G. D., & Schulkind, M. D. (2000). Parallel memory retrieval in dual-task situations: I. Semantic memory. *Journal of Experimental Psychology: Human Perception and Performance*, *26,* 1072–1090.

Mari-Beffa, P., Valdes, B., Cullen, D. J. D., Catena, A., & Houghton, G. (2005). ERP analyses of task effects on semantic processing from words. *Cognitive Brain Research*, *23,* 293–305.

Marzouki, Y., Grainger, J., & Theeuwes, J. (2007). Exogenous spatial cueing modulates subliminal masked priming. *Acta Psychologica*, *126,* 34–45.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *22,* 1423–1442.

Merikle, P. M., Smilek, D., & Eastwood, J. D. (2001). Perception without awareness: Perspectives from cognitive psychology. *Cognition*, *79,* 115–134.

Meyer, D. E., & Kieras, D. E. (1997). A computational theory of executive cognitive processes and multiple-task performance: Part 2. Accounts of psychological refractory-period phenomena. *Psychological Review*, *104,* 749–791.

Miller, J. (2006). Backward crosstalk effects in psychological refractory period paradigms: Effects of second-task response types on first-task response latencies. *Psychological Research*, *70,* 484–493.

Miller, J., & Alderton, M. (2006). Backward response-level crosstalk in the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, *32,* 149–165.

Miller, J., & Reynolds, A. (2003). The locus of redundant-targets and nontargets effects: Evidence from the psychological refractory period paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, *29,* 1126–1142.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, *13,* 416–424.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, *80,* 215–229.

Navon, D., & Miller, J. (2002). Queuing or sharing? A critical evaluation of the single-bottleneck notion. *Cognitive Psychology*, *44,* 193–251.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic progress in reading—visual word recognition* (pp. 264–333). Hillsdale, NJ: Lawrence Erlbaum Associates.

Neely, J. H., & Kahan, T. A. (2001). Is semantic activation automatic? A critical re-evaluation. In H.L. Roediger (Ed.), *The nature of remembering: Essays in honor of R. G. Crowder* (pp. 69–93). Washington, DC: American Psychological Association.

Neumann, O. (1990). Direct parameter specification and the concept of perception. *Psychological Research*, *52,* 207–215.

Neumann, O., & Klotz, W. (1994). Motor responses to non-reportable masked stimuli: Where is the limit of direct motor specification? In C. Umilta & M. Moscovitch (Eds.), *Attention and Performance XV* (pp. 123–150). Cambridge, MA: MIT Press.

Oriet, C., Tombu, M., & Jolicoeur, P. (2005). Symbolic distance affects two processing loci in the number comparison task. *Memory & Cognition*, *33,* 913–926.

Pashler, H. E. (1994). Graded capacity-sharing in dual-task interference? *Journal of Experimental Psychology: Human Perception and Performance*, *20,* 330–342.

Pashler, H. E. (1998). *The psychology of attention*. Cambridge, MA: MIT Press.

Pashler, H. E., & Johnston, J. C. (1989). Chronometric evidence for central postponement in temporally overlapping tasks. *The Quarterly Journal of Experimental Psychology*, *41A,* 19–45.

Pohl, C., Kiesel, A., Kunde, W., & Hoffmann, J. (2010). Early and late selection in unconscious information processing. *Journal of Experimental Psychology: Human Perception and Performance*, *36,* 268–285.

Pöppel, E., Held, R., & Frost, D. (1973). Letter: Residual visual function after brain wounds involving the central visual pathways in man. *Nature*, *243,* 295–296.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55–85). Hillsdale, NJ: Lawrence Erlbaum Associates.

Reynvoet, B., Caessens, B., & Brysbaert, M. (2002). Automatic stimulus−response associations may be semantically mediated. *Psychonomic Bulletin & Review*, *9,* 107–112.

Reynvoet, B., Gevers, W., & Caessens, B. (2005). Unconscious primes activate motor codes through semantics. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *31,* 991–1000.

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

Ruthruff, E., Johnston, J. C., & Van Selst, M. (2001). Why practice reduces dual-task interference. *Journal of Experimental Psychology: Human Perception & Performance*, *27,* 3–21.

Scharlau, I. (2007). Perceptual latency priming: A measure of attentional facilitation. *Psychological Research*, *71,* 678–686.

Scharlau, I., & Ansorge, U. (2003). Direct parameter specification of an attention shift: Evidence from perceptual latency priming. *Vision Research*, *43,* 1351–1363.

Schlaghecken, F., & Eimer, M. (2000). A central/peripheral asymmetry in subliminal priming. *Perception & Psychophysics*, *62,* 1367–1382.

Schlaghecken, F., & Eimer, M. (2004). Masked prime stimuli can bias “free” choices between response alternatives. *Psychonomic Bulletin & Review*, *11,* 463–468.

Schmidt, T., & Seydell, A. (2008). Visual attention amplifies response priming of pointing movements to color targets. *Perception & Psychophysics*, *70,* 443–455.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime user's guide*. Pittsburgh, PA: Psychology Software Tools.

Schubert, T. (1999). Processing differences between simple and choice reactions affect bottleneck localization in overlapping tasks. *Journal of Experimental Psychology: Human Perception and Performance*, *25,* 1–18.

Schubert, T., Fischer, R., & Stelzel, C. (2008). Response activation in overlapping tasks and the response-selection bottleneck. *Journal of Experimental Psychology: Human Perception & Performance*, *34,* 376–397.

Schweinberger, S. R., & Stief, V. (2001). Implicit perception in patients with visual neglect: Lexical specificity in repetition priming. *Neuropsychologia*, *39,* 420–429.

Sumner, P., Tsai, P. C., Yu, K., & Nachev, P. (2006). Attentional modulation of sensorimotor processes in the absence of perceptual awareness. *Proceedings* *of the National Academy of Sciences of the United States of America*, *103,* 10520–10525.

Tombu, M., & Jolicoeur, P. (2002). All-or-none bottleneck versus capacity sharing accounts of the psychological refractory period phenomenon. *Psychological Research*, *66,* 274–286.

Tombu, M., & Jolicoeur, P. (2003). A central capacity sharing model of dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *29,* 3–18.

Van den Bussche, E., Van den Noortgate, W., & Reynvoet, B. (2009). Mechanisms of masked priming: A meta-analysis. *Psychological Bulletin*, *135,* 452–477.

Verleger, R., Jaskowski, P., Aydemir, A., van der Lubbe, R. H., & Groen, M. (2004). Qualitative differences between conscious and nonconscious processing? On inverse priming induced by masked arrows. *Journal of Experimental Psychology: General*, *133,* 494–515.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *24,* 1656–1674.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Sciences of the United States of America*, *100,* 6275–6280.

Weiskrantz, L. (1986). Some aspects of memory functions and the temporal lobes. *Acta Neurologica Scandinavica*, *109*(Suppl.), 69–74.

Weiskrantz, L. (2002). Prime-sight and blindsight. *Consciousness and Cognition*, *11,* 568–581.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10,* 601–621.

Young, A., & de Haan, E. H. F. (1993). Impairments of visual awareness. In M. Davies & G. Humphreys (Eds.), *Consciousness: Psychological and philosophical essays. Readings in mind and language* (Vol. 2, pp. 58–73). Malden, MA: Blackwell.