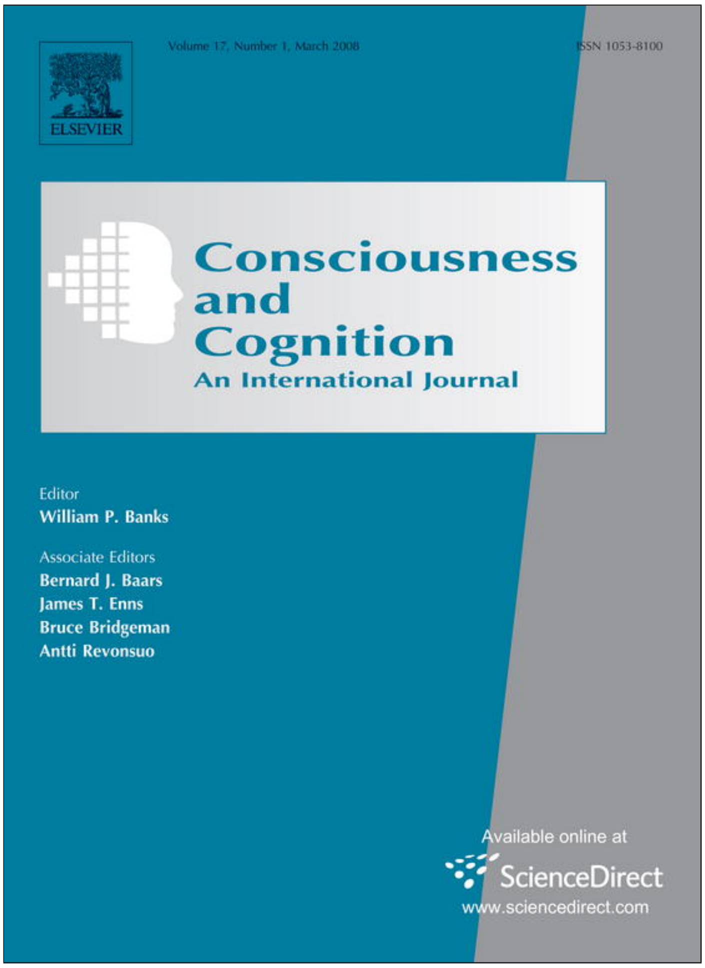
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Negative congruency effects: A test of the inhibition account

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Abstract

Masked priming experiments occasionally revealed surprising effects: Participants responded slower for congruent compared to incongruent primes. This negative congruency effect (NCE) was ascribed to inhibition of prime-induced activation [Eimer, M., & Schlaghecken, F. (2003). Response faciliation and inhibition in subliminal priming. *Biological Psychology*, *64*, 7–26.] that sets in if the prime activation is sufficiently strong. The current study tests this assumption by implementing manipulations designed to vary the amount of prime-induced activation in three experiments. In Experiments 1 and 3, NCEs were observed despite reduced prime-induced activation. Experiment 2 revealed no NCE with at least similar prime strength. Thus, the amount of prime activation did not predict whether or not NCEs occurred. The findings are discussed with regard to the inhibition account and the recently proposed account of mask-induced activation [cf. Lleras, A., & Enns, J. T. (2004). Negative compatibility or object updating? A cautionary tale of mask-dependent priming. *Journal of Experimental Psychology: General*, *133*, 475–493; Verleger, R., Jaskowski, P., Aydemir, A., van der Lubbe, R. H. J., & 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].

Keywords: Negative congruency effects; Negative compatibility effects; Subliminal priming; Inhibition; Mask-induced activation

1. Introduction

Stimuli that remain unconscious nevertheless influence performance to subsequently presented target stimuli. This phenomenon has been repeatedly demonstrated in masked priming experiments. In these experiments, participants usually are required to choose between two response alternatives according to consciously presented target stimuli. A prime stimulus is presented prior to each target. Prime and target are either assigned to identical or different motor responses, that is, the prime is congruent[1] or incongruent

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[1] Different terms have been used to describe the relation between target and prime stimuli. The terms congruency, compatibility, consistency, congruity, or correspondence can be considered as synonyms in this field of research. We decided to use the terms congruency, congruent, and incongruent to refer to the prime-target relationship as according to our view this is the most commonly used one.

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to the target. In order to make sure that the prime is not consciously perceived, prime presentation time is rather short (usually 10–50 ms) and the prime is followed by a mask. Participants respond faster and commit fewer errors when the prime is congruent rather than incongruent (cf. Dehaene et al., 1998; Kunde, Kiesel, & Hoffmann, 2003, 2005; Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). This positive difference between RTs and error rates for incongruent and congruent trials is termed (positive) congruency effect (PCE).

2. Negative congruency effect (NCE)

However, in special settings that will be discussed in detail below, this congruency effect is reversed, participants respond faster when incongruent compared to congruent prime stimuli are presented. This astonishing effect has first been reported by Eimer and Schlaghecken (1998; Schlaghecken and Eimer, 1997). In their original studies, participants were instructed to press a left key according to a left pointing arrow ($\ll$) and a right key according to a right pointing arrow ($\gg$, see Fig. 1). Prior to the target stimulus, a prime was presented that was either identical to or the opposite of the target. This prime was presented for 16 ms and followed by a mask that consisted of both prime arrows superimposed on each other (see Fig. 1). Unexpectedly, participants responded slower for identical prime target pairs than for opposite ones.

This NCE has been replicated in many different studies (Eimer, 1999; Eimer & Schlaghecken, 2002, 2003; Eimer, Schubö, & Schlaghecken, 2002; Klapp & Hinkley, 2002; Lingnau & Vorberg, 2005; Lleras & Enns, 2004, 2005; Schlaghecken & Eimer, 2000, 2002; Verleger, Jaskowski, Aydemir, van der Lubbe, & Groen, 2004). However, the processes underlying the NCE are quite controversial. Currently, two hypotheses are discussed: One account assumes that prime-induced activation is inhibited in order to avoid premature

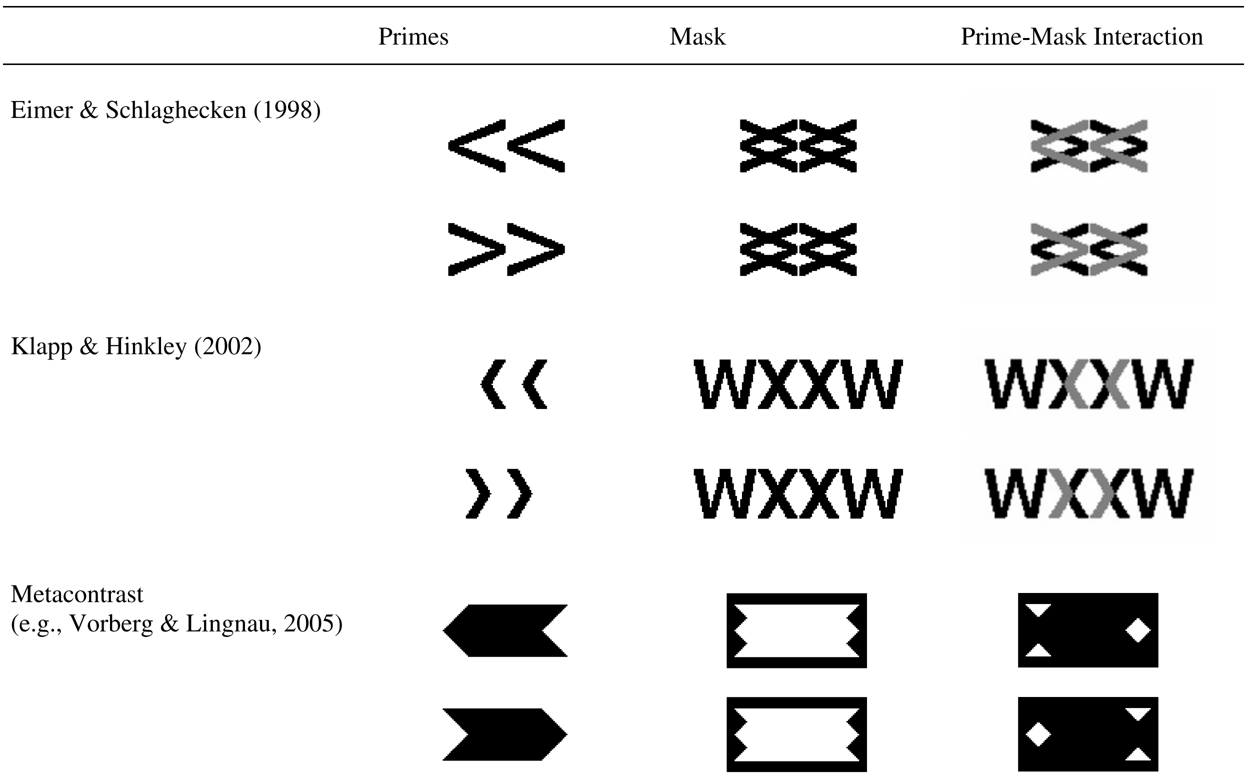

Fig. 1. Stimulus materials that were used in studies reporting negative compatibility effects. Please note that the depiction of the stimuli used by Klapp and Hinkley (2002) is idealized. It is not possible to infer from their method section whether primes were presented exactly at the same location as the masking letters "X". However, even if the locations of the prime arrows and the masking "X"s differ, the object updating account would assume that the newly appearing features are processed to update the scene. The depiction of prime-mask interactions is idealized to approximately illustrate object updating.

responding to the prime. The other account assumes that the mask itself induces activation due to the newly given perceptual input.

3. Inhibition account

Eimer and Schlaghecken (1998, p. 1746) ascribed the NCE to ''a selective inhibition of the response that was initially triggered by the prime or a successive activation of both potentially relevant responses''. They assume that the prime initially activates its associated response. This activation is followed by inhibition in order to avoid premature responding to the prime. Responding in congruent trials then requires re-activating the just inhibited response. This takes longer than responding in incongruent trials in which the non-inhibited response is required. The activation-followed-by-inhibition hypothesis is corroborated by the following observations:

First, measurements of LRPs (lateralized readiness potentials) show exactly the response activation pattern that would be predicted by the inhibition account. Eimer and Schlaghecken (1998) reported that 200–270 ms after prime onset, there is an initial activation of the prime-related response. This activation gets reversed and the non-primed response is activated approximately 280 ms after prime onset. For incongruent prime-target pairs, this non-primed response activation increases as the incongruent response is executed. For congruent prime-target pairs, the non-primed response activation gets reversed again and response activation of the performed response shows up. Thus, the LRP pattern is completely in line with the assumption that prime induced response activation gets inhibited and thus reversed.

Second, the occurrence of NCEs or PCEs depends on the temporal relation between prime and target (cf. Eimer, 1999; Lingnau & Vorberg, 2005; Schlaghecken & Eimer, 2000). If the target is presented in close succession to the prime, PCEs arise. NCEs are observed only for sufficiently long prime target intervals. It seems that for short prime target intervals, the target elicits the response while prime-induced response activation is still going on so that responding is facilitated in congruent trials. In contrast, for long prime target intervals, inhibition of the primed response has already set in making it harder to perform the primed response at the time of target presentation.

However, there are also empirical findings demonstrating that activation-followed-by-inhibition is no ubiquitous mechanisms but that there are boundary conditions to which the occurrence of inhibition seems to be restricted.

First, Schlaghecken and Eimer themselves observed that not NCEs but PCEs result when the primes are presented peripherally or in a degraded fashion (Schlaghecken & Eimer, 2000, 2002). They concluded that prime stimuli with low perceptual strength do not trigger inhibition, because the prime induced activation is not strong enough. Only when the prime-induced motor activation is sufficiently strong to exceed an ''inhibition threshold'', an active inhibition mechanism is elicited to suppress the motor activation (Eimer & Schlaghecken, 2003).

Second, NCEs seem to be restricted to particular prime stimuli. They appear to be most robust and have indeed been replicated predominantly with arrow primes like those that have been originally used by Eimer and Schlaghecken (1998) or those that have been used by Lingnau and Vorberg (2005, see Fig. 1). While there have been reports of NCEs with non-arrow prime stimuli (Eimer, 1999, Exp. 3; Eimer & Schlaghecken, 1998), NCEs have never been obtained in studies using digits, letters, words, or pictures as primes, even for similar temporal relations between prime, mask, and target (e.g., Bodner & Dypvik, 2005; Damian, 2001; Dehaene et al., 1998; Kiesel, Kunde, Pohl, & Hoffmann, 2006; Kunde et al., 2003; Reynvoet, Gevers, & Caessens, 2005).

The fact that NCEs are easily obtained with arrow primes whereas they are elusive with non-arrow stimuli might be due to arrow stimuli inducing more response activation than digit, letter, word, or picture primes because arrow stimuli are mapped compatibly to the response alternatives (left arrow requires left response, right arrow requires right response) whereas the S–R mapping for the other stimuli is more arbitrary. Therefore, activation induced by prime stimuli of the latter types might not be sufficient to exceed the inhibition threshold and trigger inhibition. In accordance with this argument, responses to arrow targets are usually faster than to number or word stimuli reflecting easier S–R translation, and PCEs that are observed for short prime target intervals are usually stronger for arrow stimuli than for number or word stimuli reflecting more initial prime-induced activation. Additionally, in studies reporting NCEs usually two stimuli (arrows pointing to the left or right) were used as primes and targets. In contrast, studies investigating priming by digits, letters, words, or pictures mostly used several different stimulus exemplars as primes and targets (e.g., for digits usually the digits from 1 to 9 except the 5 are used). Given that S–R links are stronger the less stimulus and response alternatives exist in an experimental context, prime-induced activation might have been less in studies with digits, letters, words, or picture stimuli than in studies with arrow stimuli because of the number of existing S–R links.

Third, the occurrence of NCEs also depends on the masking conditions as they have been observed mostly for particular masks, like mask stimuli that are composed of the prime arrows (e.g., Eimer & Schlaghecken, 1998), that are structurally similar to the prime arrows (e.g., Klapp & Haas, 2005; Klapp & Hinkley, 2002), or for metacontrast masks (Lingnau & Vorberg, 2005) as depicted in Fig. 1. For masks that did not resemble the primes or in trials without masks, PCEs and not NCEs were reported (e.g., Eimer & Schlaghecken, 2002; Klapp & Hinkley, 2002; but see Schlaghecken & Eimer, 2004, 2006, or Klapp, 2005, for examples of masks at most slightly resembling the primes). Therefore, Eimer and Schlaghecken (2002; see also Klapp and Hinkley, 2002) concluded that inhibition and thus the occurrence of NCEs is restricted to cases with subliminal prime presentation (but see Schlaghecken & Eimer, 2002). If the masks do not prevent conscious prime identification because they are ineffective (or even absent) no inhibition takes place, and therefore PCEs emerge.

4. Mask-induced activation

The alternative account explaining NCEs is directly built on the observation that NCEs seem to be restricted to particular masking conditions. It assumes that the mask does not just prevent conscious prime processing but is itself capable of inducing motor activation when it contains features relevant to the task (Lleras & Enns, 2004, 2006; Verleger et al., 2004). According to the "object updating hypothesis" new information within a scene is integrated into the existing representation of the scene (Lleras & Moore, 2003). In the context of masking experiments this means that the mask is not processed independently of the prime, but that the information that the masks adds to the prime is processed to update the scene. If the mask is composed of both primes or contains features of them, the mask adds information of the opposite, that means currently not presented prime (see Fig. 1). When further assuming that each stimulus that resembles the target or that is strongly associated with specific responses activates motor processes, NCEs might arise because the information newly introduced by the masks activates the opposite response than the prime.

This mask-induced activation account was directly tested by Lleras and Enns (2004). In a series of experiments they compared congruency effects when using masks that were either relevant or irrelevant to the given task, that is masks that contained features of the targets or not. NCEs were only observed for masks that contained target-like features, whereas for target-unlike masks PCEs emerged (for similar results see, Verleger et al., 2004).

Moreover, the findings of NCEs that have been interpreted in favor of the inhibition account are also in line with the assumption of mask-induced activation: First, the observed LRP data, that is, early activation of the primed response followed by activation of the opposite response, might reflect prime-induced motor activation followed by mask-induced motor activation (Verleger et al., 2004) instead of inhibition. Second, NCEs have been observed only if the interval between prime and target was sufficiently long. Usually, varying the prime-to-target interval was accomplished by prolonging the mask-to-target intervals, whereas the prime-mask interval remained stable (cf. Eimer, 1999; Lingnau & Vorberg, 2005; Schlaghecken & Eimer, 2000). One would expect that mask induced motor activation affects performance to the target only if the mask-to-target interval is sufficiently long enabling motor activation to build up. Thus, the time dependency of NCEs is in line with mask-induced motor activation as well as with inhibition.

Currently, in our view the mask-induced activation account seems somewhat more appealing than the inhibition account for the following reasons: It appears more parsimonious in assuming only activation processes by primes and masks instead of assuming two processes, namely prime-induced activation and inhibition. Furthermore, it can explain most existing data without any additional assumptions whereas the inhibition account has to assume an inhibition-threshold and the necessity of subliminal prime presentation to deal with the observation that NCEs appear to be restricted to particular prime and mask stimuli.

However, the mask-induced activation account cannot easily explain findings of NCEs obtained with masking stimuli containing no task-relevant features (Eimer, 1999, Exp. 3; Klapp, 2005; but see Lleras & Enns, 2006). Moreover, advocates of the inhibition account (e.g., Klapp, 2005) can easily argue against evidence for the mask-induced activation account because using task-irrelevant masks usually changes prime perceptibility. In the study of Lleras and Enns (2004) participants identified primes better with irrelevant compared to relevant masks. Verleger et al. (2004) observed similar prime detection rates for irrelevant and relevant masks, but proper tests of prime visibility were conducted only in one experiment (Exp. 1) with 11 participants. Thus, the inhibition account that assumes inhibition to be restricted to subliminal prime presentation is still in line with current evidence. Even more so as Klapp (2005, Exp. 2) showed that NCEs with target-unlike masks were only observed in a setting with rather limited prime identification but that they vanished in a setting with almost perfect prime identification.

To conclude, the inhibition account was recently confronted by experiments in which masking conditions were manipulated. Although the results of these experiments contradict the inhibition account and speak for mask-induced activation, there remain doubts mainly because changing masking conditions might also change prime visibility and prime induced motor activation.

5. Overview of experiments

In order to put the inhibition account to the test, we opted for another strategy. We investigate whether varying the amount of prime-induced activation has an impact on the occurrence of NCEs. Thus in principle, we elaborate the same research question as Schlaghecken and Eimer (2002). They manipulated the amount of prime-induced activation by varying the visual presentation of primes. Peripherally presented primes and primes that were presented in a degraded fashion were assumed to induce less activation and consequently not NCEs, but PCEs resulted. However, manipulating sensory input does not only influence the amount of prime-induced activation but also the possibility of prime-mask interactions and therewith possible mask-induced activation. The goal of the current study was to manipulate prime-induced activation without simultaneously eliminating the possibility of mask-induced activation. To this end, we applied priming settings that typically result either in NCEs (Exp. 1) or PCEs (Exp. 2 and 3) and created conditions designed to reduce (Exp. 1) or increase (Exp. 2 and 3) the amount of prime-induced activation. In Experiment 1, we used prime arrows and metacontrast-masks as stimuli that typically induce NCEs, but we chose a setting in which the prime induced activation should be reduced because prime and target stimuli differed. To anticipate the results, NCEs were observed. In Experiments 2 and 3, digits were used as primes and targets and the primes were masked by random character strings. This setting usually induces PCEs, but participants extensively trained the stimulus response mappings in order to increase the prime-induced activation. Even after extensive training, no NCEs but PCEs were observed. In Experiment 4, the same digits were used as primes but now metacontrast masks were implemented. Although the prime-induced activation could not have been exceeding that in Experiment 2 or 3, NCEs were observed.

6. Experiment 1

In the first experiment, we aimed to reduce the prime induced activation while using prime and mask stimuli that usually induce NCEs. The procedure and the used stimuli were closely modeled after Lingnau and Vorberg (2005). Left and right pointing arrows were used as primes that were masked by metacontrast (see Fig. 2). Targets were small circles appearing left or right from fixation. Participants pressed left or right response keys according to the location of the circles. Thus, primes and targets both share spatial features (left- or right-orientation) with the responses. Therefore, we suppose that primes should activate spatially corresponding responses. However, as primes and targets are not identical the prime induced activation is presumably reduced (cf. Bodner & Dypvik, 2005; Bodner & Masson, 2003).

As mentioned before, the occurrence of NCEs depends on the time structure of stimulus presentation. Therefore, we varied the prime target SOAs (stimulus onset asynchronies) in five steps ranging from 110 to 270 ms to assess the time course of congruency effects. The chosen stimulus material allows varying the prime

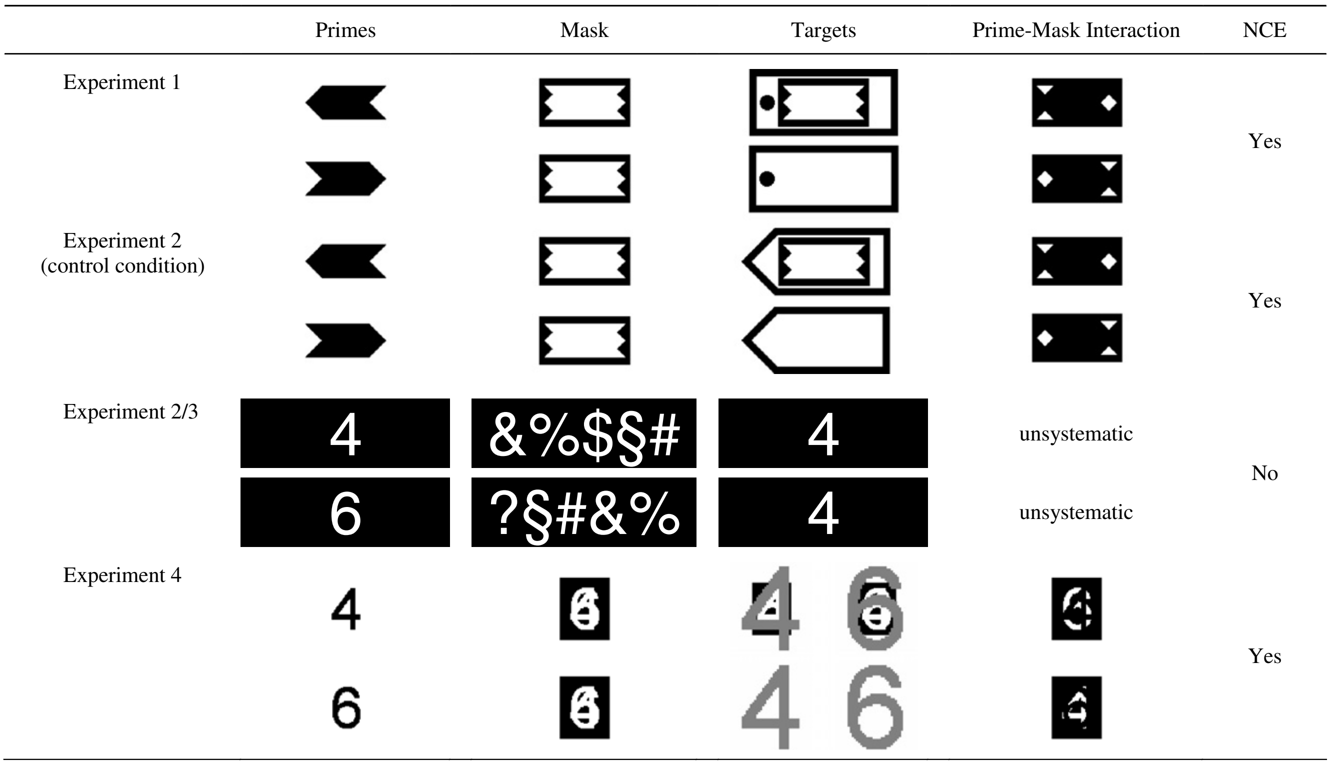

Fig. 2. Stimulus materials in Experiments 1–4. In Experiment 1, (control condition) and 4, masks and targets could be presented simultaneously or with a delay depending on prime target SOA. The depiction of prime-mask interactions is idealized to approximately illustrate object updating.

target SOA in any step without changing prime, mask, or the target durations. Therefore, we preferred this material over the stimuli originally used by Eimer and Schlaghecken (1998).

6.1. Method

6.1.1. Participants

Twelve volunteers (7 female, mean age 22.7) took part in an individual session of approximately 60 min either in partial fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

6.1.2. Apparatus and stimuli

Stimulus presentation and collection of responses were performed by an IBM-compatible computer with a 17 in. VGA-Display and the PST response box (Psychology Software Tools) 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.

Left and right arrows, extending 2.3 × 1.0 cm, served as primes (see Fig. 2). A somewhat larger rectangle, extending 2.7 × 1.4 cm, with a cutout in form of both prime arrows served as mask. To enhance perceptual masking, the outer contour of the prime stimuli touched the inner contour of the cutout of the mask. Targets were circles appearing to the left or the right of the mask surrounded a larger frame (4.3 × 2.0 cm).

Each trial started with the presentation of a fixation cross that remained on screen for 300 ms. Then, a prime was presented for 1 refresh cycle of the display (i.e., 10 ms). After prime presentation a blank screen was displayed for 60 ms followed by the mask that was presented for 110 ms. After a variable mask target SOA (40, 80, 120, 160, 200 ms) the target circle was presented either to the left or to the right of fixation. That means, for short SOAs the target was presented while the mask still remained on the screen. With this procedure we introduced five prime target SOAs (110, 150, 190, 230, and 270 ms). After response execution a fixed time interval of 1900 ms elapsed. In this interval possible errors were indicated by a beep sound.

6.1.3. Design and procedure

Participants were instructed to respond as fast as possible according to the location of the target circle by pressing a left or a right response key with the index finger of each hand.

The experiment consisted of eight blocks with 100 trials. In every block each possible combination of prime (left or right pointing arrow), target (left or right circle), and prime target SOA (110, 150, 190, 230, 270 ms) was presented five times.

After the experiment, participants performed a detection task to test whether they were able to consciously perceive the primes. Participants were fully informed about the precise structure of the prime and mask stimuli and were then presented with 120 trials identical to the experimental trials. Participants were asked to discriminate whether the presented prime was pointing to the left or the right side by pressing the same response keys as in the experiment. In order to not assess any priming effects in this discrimination task, responses were recorded starting 1000 ms after prime presentation.

6.2. Results

6.2.1. Congruency effects

RTs deviating more than 2.5 standard deviations from the individual mean RT of each experimental condition (1.75%) were considered as outliers and excluded from the analysis. For the remaining trials, mean RTs for correct trials and mean percentages of error (PEs) were computed for each participant and each combination of the factors Congruency and prime target SOA. Separate ANOVAs on RTs and PEs were computed. For this and all subsequent analysis, we report Greenhouse–Geisser-adjusted p and MSe values if appropriate.

The ANOVA on RTs revealed a significant interaction of SOA and Congruency, $F(4, 44) = 8.66$, $p < .001$, $MSe = 1053.5$. For short SOAs, PCEs were obtained that got reversed for longer SOAs (see Fig. 3). Separate t-tests confirmed this pattern: The resulting congruency effects were 16 ms for SOA 110, $t(11) = 3.99$, $p < .01$,

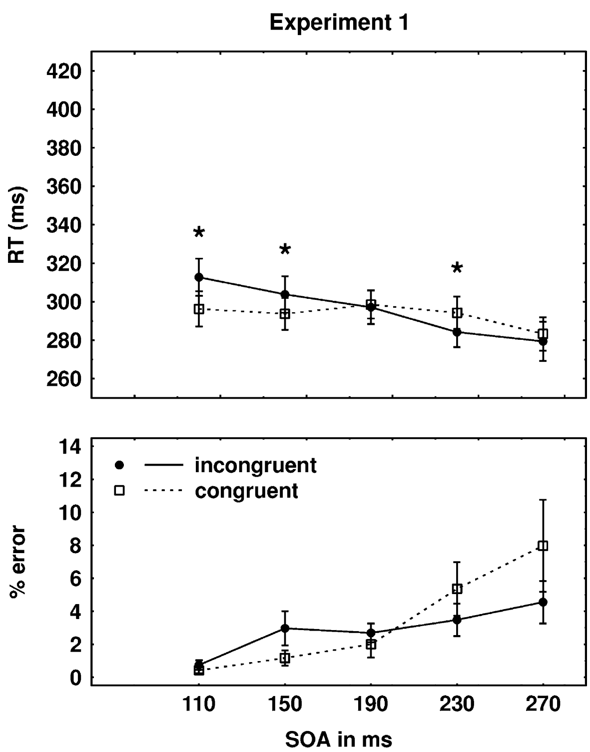

Fig. 3. Congruency effects in Experiment 1. Mean RTs (top panel) and error rates (bottom panel) for congruent and incongruent trials depending on prime target SOA. Standard error bars are ±1 standard error of each mean.

and 10 ms for SOA 150, $t(11) = 2.60$, $p < .05$. For SOA 230, there was a reversed congruency effect of -10 ms, $t(11) = -2.55$, $p < .05$. The main effect of Congruency was not significant ($p > .41$), but the main effect of SOA was, $F(4, 44) = 23.86$, $p < .001$, $MSe = 2{,}600.4$. Mean RT decreased with longer SOAs amounting to 305 ms with SOA of 110 ms, 299 ms with SOA 150, 298 ms with SOA 190, 289 ms with SOA 230, and 281 ms with SOA 270.

The same ANOVA on PE also brought about a significant interaction between SOA and Congruency, $F(4, 44) = 3.68$, $p < .05$, $MSe = 55.9$. At each SOA level the difference between PEs on congruent and incongruent trials is in the same direction as the corresponding difference for RTs, that is, error rates are increased for incongruent compared to congruent trials for short SOAs and the reversed pattern is observed for longer SOAs. Although separate *t*-test did not reveal significant congruency effects (*p*s > .08), the PCEs and NCEs observed in RT data are evidently not the result of a speed-accuracy trade-off. Again, the main effect of Congruency was not significant ($p > .56$). The significant main effect SOA, $F(4, 44) = 6.95$, $p < .01$, $MSe = 310.2$, indicated that participants made more errors the longer the SOA (SOA 110: 0.6%, SOA 150: 2.1%, SOA 190: 2.3%, SOA 230: 4.4%, and SOA 270: 6.3%). Obviously, generally faster responses for longer SOAs went along with generally higher error rates, reflecting a speed accuracy trade-off when collapsing RT and PE data across congruent and incongruent trials. Please note that this speed accuracy trade-off does not strike the main results: Congruency effects in RTs and error rates were similar in direction at each SOA level.

6.2.2. Prime visibility

To compute the signal detection value d', the log-linear correction suggested by Hautus (1995) was applied if participants had 0% or 100% hits or false alarms. Participants' discrimination performance was .75, .39, .62, .51, and .76 for the prime target SOA of 110, 150, 190, 230, and 270 ms, respectively. *t*-Tests revealed that while only two of these d' measures differed significantly from zero two others approached significance and only one was clearly not significant (SOA 110: $t(11) = 2.31$, $p < .05$, SOA 150: $t(11) = 1.53$, $p < .16$, SOA 190: $t\ (11) = 2.13$, $p < .06$, SOA 230: $t(11) = 1.87$, $p < .09$, SOA 270: $t(11) = 2.62$, $p < .05$).

6.3. Discussion

The observed congruency effect sizes at each SOA do not exceed 16 ms. Thus, they are much smaller than in settings in which both primes and targets were arrows (e.g., Lingnau & Vorberg, 2005) and we can be fairly confident that using non-identical prime and target stimuli indeed reduced prime-induced activation.

Nevertheless, PCEs that were observed for short prime target SOAs turned into NCEs for longer prime target SOAs. Of course, the prime-induced activation might still have been strong enough to exceed the inhibition threshold. We will return to this issue when comparing the results of Experiment 1 with those of Experiments 2 and 4.

Interestingly, NCEs were observed although prime visibility was not clearly subliminal. This is in line with a recent study of Klapp (2005) who observed NCEs for primes that were identified with 70% accuracy. Remarkably, primes that were perfectly visible (i.e., identified with an accuracy of more than 90%), did not evoke NCEs in Klapp's study. Thus, the occurrence of NCEs might be influenced by prime visibility. But obviously, NCEs are not restricted to completely subliminally presented primes (see also Lleras & Enns, 2004, 2005, 2006).

7. Experiment 2

Experiment 2 was conducted to further test the assumption that NCEs do rely on sufficient prime induced motor activation. As mentioned in the introduction, NCEs have been reported mostly for particular prime stimuli (like arrows) under particular masking conditions. Number, letter, word, or picture primes, which are usually masked with random letter strings or random pattern masks, induce PCEs. According to the inhibition account, even these prime stimuli should produce NCEs if the amount of prime-induced motor activation is high enough.

Arrow primes are supposed to cause sufficient motor activation because they are more strongly linked to the responses than other stimuli with more abitrary S–R mappings. This is because arrow primes inherit the same spatial feature (pointing to the left or right) as the response alternatives (usually participants are asked to either press left and right response keys) and generally they are mapped to the responses in a compatible manner (e.g., a left arrow target requires pressing the left response key).

In order to create a setting in which the stimuli are strongly linked to the responses we decided to use two digits as primes, namely the digits "4" and "6". Digits also inherit a spatial feature as they are mentally represented on a number line in ascending order from left to right (e.g., Galton, 1880; Göbel, Walsh, & Rushworth, 2001). We mapped the digits to the responses in a compatible manner, that is, participants were to press the left key for the "4" and the right key for the "6". In order to strengthen the links between stimuli and responses, participants trained the stimulus–response-mappings extensively in three separate sessions comprising a total of 2400 trials.

A standard masking procedure for digit primes was used (e.g., Dehaene et al., 1998; Kunde et al., 2003): Each prime stimulus was preceded and followed by a random string of 5 characters (chosen out of &, %, $, ?, #, and §, see Fig. 2). Premasks were presented for 50 ms, followed by the prime for 30 ms, and the postmask for 40 ms. Then a variable blank (ranging from 10 to 160 ms) was presented that was followed by the target. The resulting prime target SOAs ranged from 80 to 230 ms.

Furthermore, we included a control condition with prime arrows, metacontrast mask, and target arrows that is known to result in NCEs (Lingnau & Vorberg, 2005). This allows to compare results of our experimental condition with a standard control condition for the same participants.

In this control condition, primes were presented for 10 ms, followed by a blank for 60 ms, and the mask for 110 ms. The mask target interval was varied ranging from 10 to 200 ms, that is, in some timing conditions the target was presented while the mask still remained on screen. As a result, the prime target SOA varied from 80 to 270 ms.

Note that the timing structures in the experimental (digit) and the control (arrow) condition differ regarding prime mask SOA, mask duration, and regarding the number of varied mask target SOAs. With the stimulus material of the experimental condition, it is not possible to vary the mask target SOA in small steps without changing the mask duration and longer lasting blanks between prime and mask are likely to result in conscious prime processing. Thus, only five mask target SOAs (50, 80, 120, 160, and 200 ms) were varied for the experimental group, but 6 mask target SOAs (10, 40, 80, 120, 160, and 200 ms) for the control group. Consequently, the more interesting longer SOA variations were similar. But experimental and control condition differed regarding prime-mask SOA (30 ms in the experimental and 70 ms in the control condition) and regarding mask duration (40 ms in the experimental and 110 ms in the control condition). However, the inhibition account does not assume that prime-mask SOA or mask duration are the determining factors, but that the prime-to-target interval determines whether the prime induced activation gets inhibited (but see Schlaghecken & Eimer, 2002). And with regard to prime target SOAs the experimental and the control condition were similar.

7.1. Method

7.1.1. Participants

Twelve volunteers (7 female, mean age 24.1) took part in three individual sessions of approximately 60 min each either in partial fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

7.1.2. Apparatus and stimuli

The same apparatus as in Experiment 1 was used. The digits 4 and 6 served as primes and targets. They were presented in Arial 44, in white on a black background. Pre- and postmasks were five characters chosen randomly out of &, %, $, ?, #, and §, presented in Arial 48. Each trial started with the presentation of a fixation cross that remained on screen for 250 ms. Then, the premask was presented for 50 ms, followed by the prime for 30 ms, and the postmask for 40 ms. The target was presented after a variable blank of either 10, 40, 80, 120, or 160 ms and remained on the screen for 200 ms. Thus, the prime target interval amounted to 80, 110, 150, 190, or 230 ms. After the response was given, 1900 ms elapsed until the next trial started. During this time interval errors were indicated by a beep tone.

For the control condition, the same primes and mask as in Experiment 1 were used. The target was a left or right-pointing arrow that surrounded the mask. Primes were presented for 1 refresh cycle of the display (i.e., 10 ms). After prime presentation a blank screen was displayed for 60 ms followed by the mask that was presented for 110 ms. After a variable mask target SOA of 10, 40, 80, 120, 160, or 200 ms, the target was presented for 110 ms. Thus, prime target SOA amounted 80, 110, 150, 190, 230, or 270 ms. After response execution a fixed time interval of 1900 ms elapsed. In this interval possible errors were indicated by a beep sound.

7.1.3. Design and procedure

In the first session, participants first completed the control condition, that is, the arrow task. They performed six blocks with 120 trials each. In every block each possible combination of prime (left, right), target (left, right), and prime target SOA (80, 110, 150, 190, 230, 270 ms) was presented five times. Then they performed four blocks of the experimental conditions. In every block each possible combination of prime (4, 6), target (4, 6), and prime target SOA (80, 110, 150, 190, 230 ms) was presented five times for a total of 100 trials per block. In the second session, participants performed 12 blocks, and in the third, they performed eight blocks. Thus, each participant performed the two-choice reaction time task for 2400 trials.

Finally, participants performed a detection task to test whether they were able to consciously perceive the arrow or the digit primes. Participants were fully informed about the precise structure of the prime and masking stimuli and were then presented with 100 trials identical to the experimental trials and with 144 trials identical to the trials of the arrow condition. Participants were to discriminate whether the presented prime was a 4 or a 6 or was a left or the right pointing arrow by pressing the same response keys as in the experiment.

7.2. Results

7.2.1. Congruency effects

RTs deviating more than 2.5 standard deviations from the individual mean RT of each factorial combination (1.64% in the control condition and 1.68% in the experimental condition) were considered outliers and

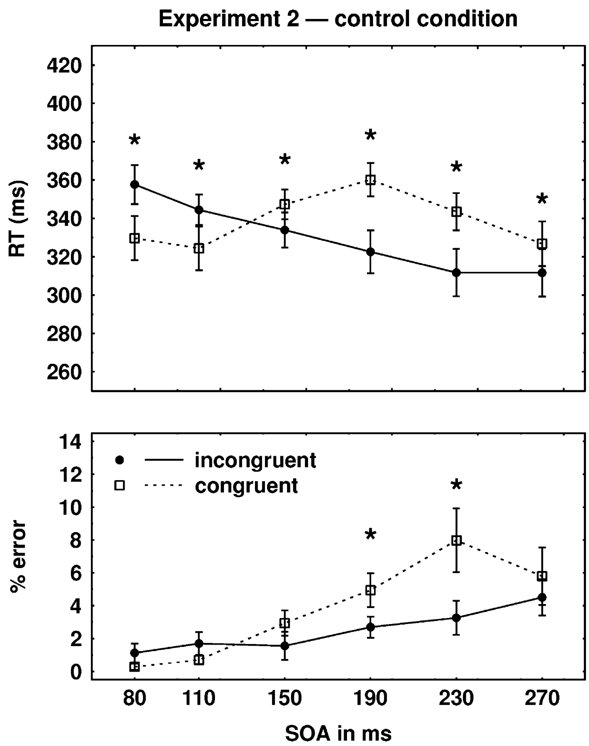

Fig. 4. Congruency effects in the control condition of Experiment 2. Mean RTs (top panel) and error rates (bottom panel) for congruent and incongruent trials depending on prime target SOA. Standard error bars are ±1 standard error of each mean.

excluded from the analysis. For the remaining trials, mean RTs for correct trials and mean percentages of error (PEs) were computed for each participant for the control and the experimental condition and each combination of the factors Congruency, SOA, and Session (see Figs. 4 and 5).

7.2.1.1. Control condition. An ANOVA on RTs with the within-subject factors Congruency and SOA revealed a significant interaction, $F(5, 55) = 22.03$, $p < .001$, $MSe = 9{,}288.4$. For short SOAs, participants responded faster in congruent than in incongruent trials. This pattern reversed starting from SOA 150 ms (see Fig. 4). Separate *t*-tests revealed PCEs for SOA 80 and SOA 110 ($t(11) = 8.71$, $p < .01$ and $t(11) = 3.56$, $p < .01$, respectively) and NCEs for all longer SOAs (SOA 150: $t(11) = 2.99$, $p < .05$; 190: $t(11) = 4.42$, $p < .001$; 230: $t(11) = 4.55$, $p < .001$; 270: $t(11) = 2.64$, $p < .05$). The main effects of Congruency, $F(1, 11) = 7.85$, $p < .05$, $MSe = 2{,}480.6$, and SOA, $F(5, 55) = 12.78$, $p < .001$, $MSe = 3{,}426.1$, were also significant. Averaged over all SOA conditions, participants responded 8 ms slower in congruent compared to incongruent trials. Averaged across congruent and incongruent trials participants tended to respond faster the longer the SOA.

The same ANOVA on error rates also showed a significant interaction between Congruency and SOA, $F(5, 55) = 4.07$, $p < .05$, $MSe = 52.9$. The error rates mimicked the RT results, as for short SOAs (80 and 110 ms) error rates were smaller for congruent compared to incongruent trials whereas this pattern was reversed for longer SOAs (150 to 270 ms). However, these differences were only significant for SOA 190 and 230 ($t(11) = 2.44$, $p < .05$, and $t(11) = 2.67$, $p < .051$, respectively). The main effects of Congruency and SOA were also significant, $F(1, 11) = 7.32$, $p < .05$, $MSe = 60.7$, and, $F(5, 55) = 8.83$, $p < .001$, $MSe = 201.3$, respectively.

7.2.1.2. Experimental condition. An ANOVA on RTs with the within-subject factors Congruency, SOA, and Session revealed a significant main effect of Congruency, $F(1, 11) = 57.15$, $p < .001$, $MSe = 23{,}641.3$, indicating that participants responded 16 ms faster in trials with congruent primes than in trials with incongruent primes. The factor Congruency interacted significantly with SOA, $F(4, 44) = 6.36$, $p < .01$, $MSe = 591.7$, reflecting that the observed congruency effect was reduced with increasing SOA, but did not reverse (for SOA 80 ms: 24 ms, 110 ms: 18 ms, 150 ms: 12 ms, 190 ms: 15 ms, 230 ms: 10 ms). In addi-

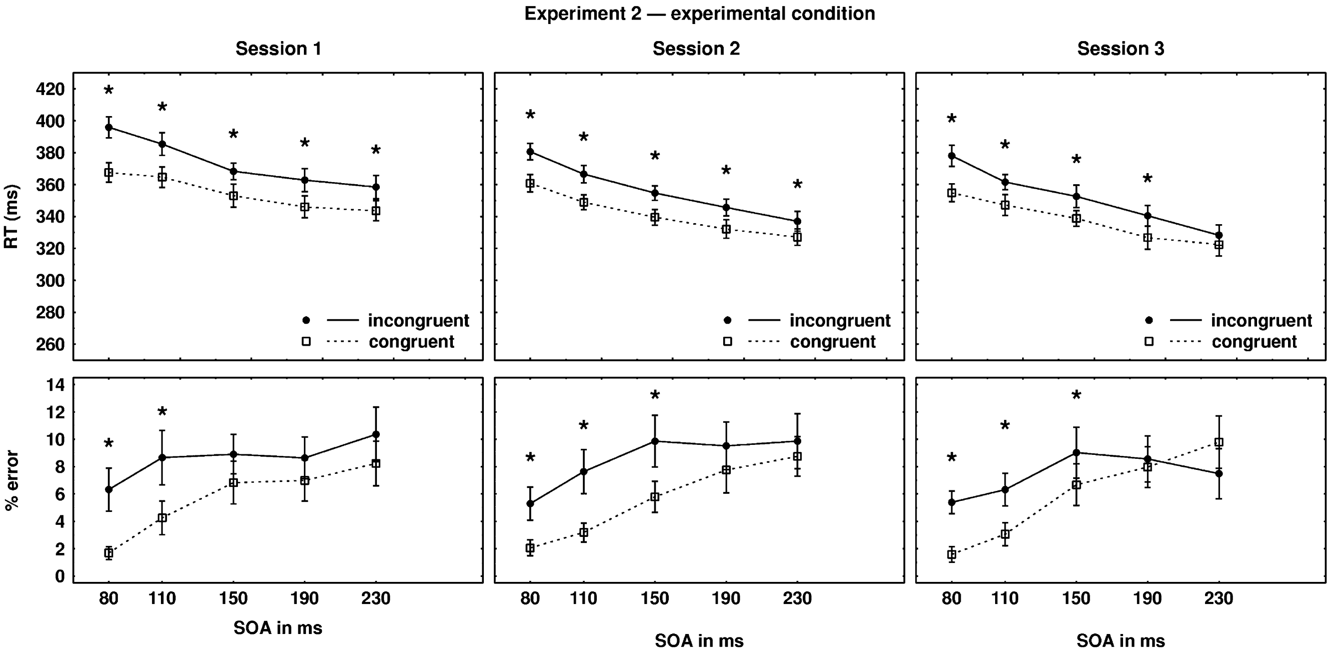

Fig. 5. Congruency effects in the experimental condition of Experiment 2 separately for the three sessions. Mean RTs (top panel) and error rates (bottom panel) for congruent and incongruent trials depending on prime target SOA. Standard error bars are ±1 standard error of each mean.

tion to that, Session and Congruency interacted, $F(2, 22) = 4.75$, $p < .05$, $MSe = 275.8$, as the congruency effect decreased with training (in Session 1 it was 19 ms, Session 2: 15 ms, Session 3: 14 ms;). The triple interaction was not significant ($p > .82$). For an overview of congruency effects across SOAs and sessions see Fig. 5. Furthermore, there was a significant main effect of SOA, $F(4, 44) = 155.25$, $p < .001$, $MSe = 34{,}572.0$. Participants responded faster with longer SOAs as mean RT with SOA of 80 ms amounted to 373 ms, with SOA 110 ms it was 363 ms, with SOA 150 ms it was 351 ms, with SOA 190 ms it was 342 ms, and with SOA 230 ms it was 335 ms. The significant main effect Session, $F(2, 22) = 20.85$, $p < .001$, $MSe = 14{,}243.7$, reflects that training resulted in faster responses as mean RT in Session 1 was 365 ms, in Session 2 it was 349 ms, and in Session 3 it was 345 ms. The interaction between SOA and Session approached significance, $F(2, 22) = 2.69$, $p < .06$, $MSe = 343.8$. RTs decreased more with longer SOAs in Session 2 and 3.

The same ANOVA on error rates revealed a main effect of Congruency, $F(1, 11) = 18.38$, $p < .001$, $MSe = 553.7$. Participants made more errors in incongruent (8.1%) than congruent (5.6%) trials. Also, Congruency interacted significantly with SOA, $F(4, 44) = 3.42$, $p < .05$, $MSe = 89.3$, as the observed congruency effect was larger with shorter SOA (for SOA 80 ms: 3.9%, 110 ms: 4.0%, 150 ms: 2.8%, 190 ms: 1.3%, 230 ms: 0.3%). The main effect SOA was also significant, $F(4, 44) = 13.60$, $p < .001$, $MSe = 680.8$. Participants made more errors with longer SOAs (3.7, 5.5, 7.8, 8.2, 9.1% for SOA 80, 110, 150, 190, and 230 ms) reflecting a speed accuracy trade-off. No other effect was significant (ps $> .17$).

7.2.1.3. Comparing control and experimental condition. For the statistical comparison between conditions, we focus on the impact of SOA and Condition on congruency effects. Main effects of the single factors are not reported. Congruency effects in terms of RT ($RT_{incongruent} - RT_{congruent}$) from the control condition were compared with congruency effects computed separately for each session as well as across all sessions of the experimental condition in separate 2 (condition: control vs. experimental) × 5 (SOA: 110, 150, 190, 230, 270 ms) repeated measures ANOVAs. Each of these ANOVAs revealed a significant Condition × SOA interaction, all $F(4, 44) > 13.50$, all $p < .001$, all $MSe > 3{,}813.7$: At SOAs 110 and 150 ms PCEs did not differ significantly between the conditions, all $t(11) < 1.83$, whereas at SOAs 190, 230, and 270 ms PCEs in the experimental condition differed significantly from NCEs in the control condition, all $t(11) > 4.67$, all $p < .001$. Analogous analyses on congruency effects in terms of error rates ($PE_{incongruent} - PE_{congruent}$) revealed significant main effects of Condition, all $F(1, 11) > 13.75$, all $p < .005$, all $MSe > 242.0$, and SOA, all $F(4, 44) > 4.37$, all $p < .005$, all $MSe > 78.8$, but no significant interactions, all $F(4, 44) < 0.83$, all $MSe < 12.7$.

7.2.1.4. Comparing congruency effects in Experiments 1 and 2. Congruency effects from Experiment 1 were compared with congruency effects computed separately for each session as well as across all sessions of the experimental condition of Experiment 2. Each of separate 2 (Exp. 1 vs. experimental condition of Exp. 2) × 4 (SOA: 110, 150, 190, 230 ms) mixed-measures ANOVAs yielded significant Experiment × SOA interactions, all $F(3, 66) > 3.16$, all $p < .05$, all $MSe > 463.6$. At SOAs 110 and 150 ms PCEs did not differ significantly between the experiments, all $t(22) < 1.04$, whereas at SOAs 190 and 230 ms PCEs in the experimental condition of Experiment 2 differed significantly from NCEs in Experiment 1, all $t(22) > 2.62$, all $p < .05$. Analogous analyses on congruency effect in terms of error rates revealed no significant Experiment × SOA interactions, all $F(3, 66) < 1.29$, all $MSe < 24.0$. Thus, congruency effects in terms of RT from Experiment 1 and from the experimental condition of Experiment 2 showed a significant discrepancy between NCEs and PCEs, respectively, at longer SOAs.

A similar comparison was conducted between congruency effects in terms of RT from Experiment 1 and the control condition of Experiment 2. A 2 (Exp. 1 vs. control condition of Exp. 2) × 5 (SOA: 110, 150, 190, 230, 270 ms) mixed-measures ANOVA also revealed a significant Experiment × SOA interaction, $F(4, 88) = 4.42$, $p < .01$, $MSe = 1{,}892.4$. At SOA 110 PCEs did not differ significantly between the experiments, $t(22) = 0.52$, whereas at SOAs 150, 190, and 230 ms congruency effects were significantly more negative in the control condition of Experiment 2 than in Experiment 1, all $t(22) > 2.70$, all $p < .05$. At SOA 270 ms, NCEs did not differ significantly between the experiments, $t(22) = 1.44$. Congruency effects in terms of error rates differed between Experiment 1 and the control condition of Experiment 2 in the same direction as congruency effects in terms of RT. The Experiment × SOA interaction approached significance, $F(4, 88) = 2.49$, $p < .073$, $MSe = 52.0$.

7.2.2. Prime visibility

Primes in the control condition were not discriminated above chance level. Discrimination rate d' was .20, .08, −.22, −.03, −.03, and −. 26 for SOA 80, 110, 150, 190, 230, and 270 ms, respectively. t-Tests indicated no significant differences from zero (all $ps > .14$), except for SOA 270 ms. Here the d' value tended to be smaller than zero, $t(11) = -2.05$, $p < .07$.

Prime visibility in the experimental condition was not subliminal in some prime target SOA conditions. The d' values were .38, .32, .46, .22, and .35 for the prime target SOAs of 80, 110, 150, 190, and 230 ms, respectively. t-Tests revealed that two of these d' measures differed significantly from zero while the others did not (SOA 80: $t(11) = 1.76$, $p < .11$, SOA 110: $t(11) = 3.05$, $p < .05$, SOA 150: $t(11) = 2.48$, $p < .05$, SOA 190: $t(11) = .96$, $p < .36$, SOA 230: $t(11) = 1.60$, $p < .14$).

7.3. Discussion

The control condition brought about the expected results: For short prime target SOAs, arrow primes induced PCEs that turned into NCEs for longer SOAs. Thus, we replicated the results of Lingnau and Vorberg (2005).

In the experimental condition, participants responded more slowly in Session 1 than in Sessions 2 or 3. Thus, training improved performance, supposedly because the S–R links were strengthened. However, training did not increase the size of the prime congruency effects. Rather, the size of the congruency effect decreased over sessions. It is hard to judge whether this is because the overall RT level is smaller or because participants acquired some ability to deal with prime interference.

Most importantly, digit primes induced PCEs at each prime target SOA. The PCEs got smaller with longer SOAs but they did not turn into NCEs. This lack of inhibition in the experimental condition contrasts with NCEs in the control condition. Thus, we can be sure that there is nothing specific to this group of participants that would prevent the occurrence of NCEs.

However, experimental and control condition differed regarding prime visibility. In the experimental condition, prime presentation was not clearly subliminal as prime detection rates were above chance for some prime target SOA levels, whereas participants were not able to discriminate primes in the control condition. One might therefore argue that no NCEs were observed in the experimental condition because the masking procedure was not sufficient. Yet, Experiment 1 revealed that NCEs are not restricted to cases with complete subliminal prime presentation. Indeed, prime detection rates in Experiment 1 where similar to prime detection rates in the experimental condition.[2] Thus, it seems unlikely that prime visibility prevented the occurrence of NCEs in the experimental condition of Experiment 2 because prime visibility was still within a range in which NCEs resulted for prime arrows in Experiment 1.

One additional issue deserves consideration: It seems possible that NCEs might have emerged for even longer SOAs if one assumes that priming effects for arrows and digits underlie different temporal dynamics due to differing processing speeds for arrows and digits. In order to rule out the possibility that we failed to obtain NCEs for digit stimuli masked with character strings merely because the implemented SOAs were too short, we reran the experimental condition of Experiment 2 with longer prime-target SOAs in Experiment 3.

8. Experiment 3

Experiment 3 was almost identical to the experimental condition of Experiment 2 except that the SOA between prime and target ranged between 100 and 500 ms. In the following, only the differences between the two experiments are described.

[2] Descriptively, prime detection rates were larger in Experiment 1 than in the experimental condition of Experiment 2. Statistically, however, the d' values did not differ, $F(1,22) < 1$.

8.1. Method

8.1.1. Participants

Twelve volunteers (4 female, mean age 22.7) took part in two individual sessions of approximately 60 min each.

8.1.2. Apparatus and stimuli

The duration of the variable blank between mask offset and target onset was varied in constant steps of 100 ms between 30 and 430 ms so that the prime target intervals amounted to 100, 200, 300, 400, and 500 ms, respectively.

8.1.3. Design and procedure

Participants received the same amount of training with the task as participants in the experimental condition of Experiment 2 by completing the same number of trials distributed evenly across two sessions (i.e., 12 blocks of 100 trials per session). The sessions were scheduled for different days.

8.2. Results

8.2.1. Congruency effects

Data were treated and analyzed as described for the experimental condition of Experiment 2. Mean RTs and mean PEs for each combination of the factors Congruency, SOA, and Session are shown in Fig. 6.

Participants' RTs were faster on congruent trials ($M = 334.5$) than on incongruent trials ($M = 340.9$ ms), $F(1, 11) = 22.81$, $p < .001$, $MSe = 2{,}443.8$. The size of the congruency effect tended to decrease with increasing SOA. This Congruency × SOA interaction approached but did not reach significance, $F(4, 44) = 2.77$, $p < .078$, $MSe = 178.0$. The triple interaction Congruency × SOA × Session also approached but did not reach significance, $F(4, 44) = 2.29$, $p < .075$, $MSe = 58.9$. Importantly, no negative congruency effects occurred at

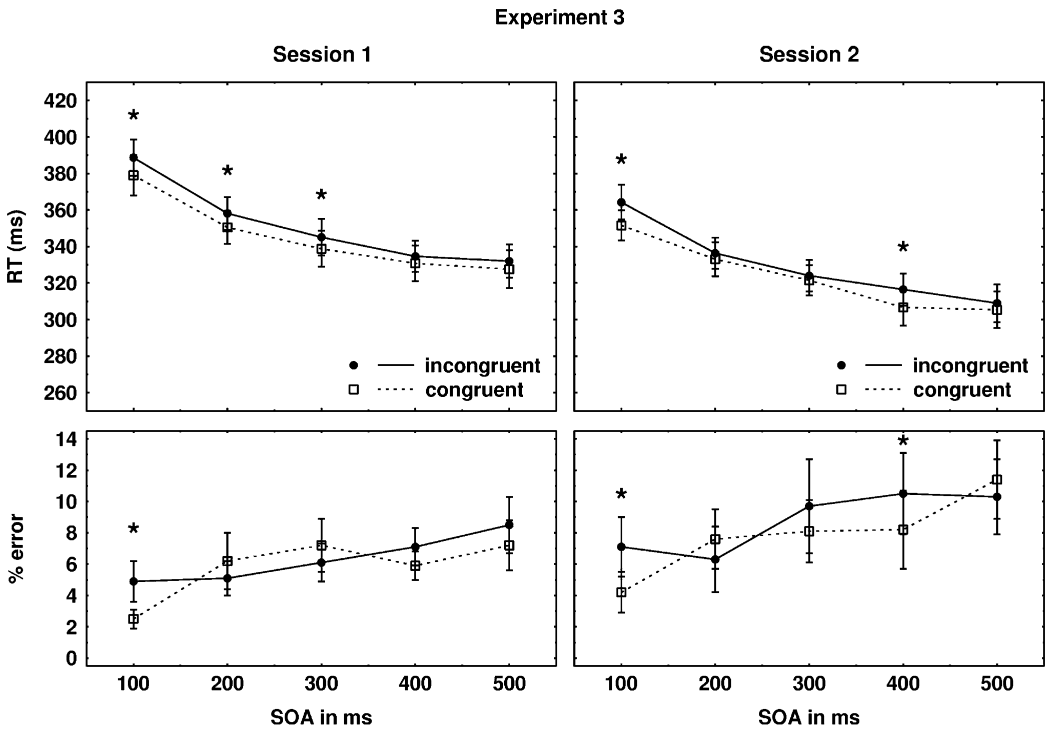

Fig. 6. Congruency effects in Experiment 3 separately for the two sessions. Mean RTs (top panel) and error rates (bottom panel) for congruent and incongruent trials depending on prime target SOA. Standard error bars are ±1 standard error of each mean.

any SOA in either session. In Session 1, the positive congruency effect amounted to 9.6, 7.6, 6.3, 3.8, and 4.4 ms at SOAs 100, 200, 300, 400, and 500 ms, respectively. It was significant at SOAs 100, 200, and 300 ms, all $t(11) > 2.71$, all $p < .05$, approached significance at SOA 500 ms, $t(11) = 1.98$, $p = .074$, and was not significant at SOA 400 ms, $t(11) = 1.24$, $p = .24$. In Session 2, the positive congruency effect amounted to 12.6, 3.3, 2.6, 9.8, and 3.6 ms at SOAs 100, 200, 300, 400, and 500 ms, respectively. It was significant at SOAs 100 and 400 ms, both $t(11) > 3.33$, both $p < .01$, approached significance at SOA 500 ms, $t(11) = 2.13$, $p = .057$, and was not significant at SOAs 200 and 300 ms, both $t(11) < 1.40$, both $p > .189$. In addition to that, there were significant main effects of Session, $F(1, 11) = 14.21$, $p < .005$, $MSe = 28{,}223.3$, and SOA, $F(4, 44) = 116.05$, $p < .001$, $MSe = 54{,}948.7$. Participants responded faster in Session 2 than in Session 1, and their response speed increased with increasing SOA. The remaining interactions were not significant, both $F < 1.06$, both $MSe < 89.1$.

An analogous analysis on participants' error rates also revealed a significant main effect of Congruency, $F(1, 11) = 5.93$, $p < .05$, $MSe = 0.003$, with participants making fewer errors on congruent trials ($M = 6.9\%$) than on incongruent trials ($M = 7.6\%$). The size and direction of the congruency effect was moderated by SOA, $F(4, 44) = 3.45$, $p < .05$, $MSe = 0.003$. Importantly, no significant NCEs occurred at any SOA in either session. In Session 1, the congruency effect amounted to 2.4, −1.0, −1.2, 1.3, and 1.3% at SOAs 100, 200, 300, 400, and 500 ms, respectively. It was significant at SOA 100, $t(11) = 2.381$, $p < .05$, approached significance at SOA 500 ms, $t(11) = 2.05$, $p = .065$, and was neither significant at SOAs 200 and 300, both $t(11) < |0.93|$, both $p > .372$, nor at SOA 400 ms, $t(11) = 1.71$, $p = .116$. In Session 2, the congruency effect amounted to 2.9, −1.3, 1.6, 2.2, and −1.1% at SOAs 100, 200, 300, 400, and 500 ms, respectively. It was significant at SOAs 100 and 400 ms, both $t(11) > 2.23$, both $p < .05$, and not significant at SOAs 200, 300, and 500 ms, all $t(11) < |1.60|$, all $p > .138$. In addition to that, there was a significant main effect of SOA, $F(4, 44) = 10.04$, $p < .001$, $MSe = 0.015$, as participants' response accuracy decreased with increasing SOA indicating a speed accuracy trade-off. No other effects were significant, all $F < 1.80$, all $MSe < 0.031$.

8.2.2. Prime visibility

Similar to the experimental condition in Experiment 2 prime visibility was not subliminal in most prime-target SOA conditions. The d' values were .39, .42, .47, .65, and .42 for SOA 100, 200, 300, 400, and 500 ms, respectively. *t*-Tests revealed that the first four of these d' measures differed significantly from zero, all $t(11) > 2.47$, $p < .05$, whereas the last did not, $t(11) = 1.37$, $p < .198$. Prime visibility did not differ between the experimental condition of Experiment 2 and the replication, $F(1, 22) = 0.49$, $p < .491$, $MSe = 0.5$.

8.3. Discussion

The results showed no significant NCEs at any of the SOAs thus confirming the original findings for the experimental condition of Experiment 2. Hence, prime activation seems to decay over time, but there is no hint of any inhibition even for long SOAs up to 500 ms.

9. Experiment 4

One might argue that activation induced by digit primes in Experiments 2 and 3 is insufficient for exceeding the inhibition threshold and bringing about NCEs although participants practiced the S–R mapping extensively. In order to address this possibility, Experiment 4 tests whether the prime-digits 4 and 6 induce NCEs when they are masked by metacontrast. If NCEs were obtained for metacontrast-masked digits this would corroborate the central role of mask induced activation in bringing about NCEs. We created the metacontrast mask for the digit primes in close analogy to the construction of a metacontrast mask for arrow stimuli by superimposing the two digits and using the negative image of the resulting configuration. Also in analogy to the typical procedure for arrow stimuli, the target digits were much larger than the prime digits in order to ensure that centred presentation of the targets did not completely block the view of the mask when mask and target presentation overlapped in time. Furthermore, the target digits were presented in dark gray to offset them against the mask in the same situation. As a result, the mask adds the features of the currently not presented prime to the scene (see Fig. 2).

Prime, mask, and target presentation mimicked the procedure of Experiment 1 and the control condition of Experiment 2. According to the inhibition account, no NCEs should result because digit primes do not induce sufficient prime-activation to trigger inhibition.

9.1. Method

9.1.1. Participants

Twelve volunteers (9 female, mean age 23.6) took part in an individual session of approximately 60 min either in partial fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

9.1.2. Apparatus and stimuli

The apparatus and stimuli were similar to Experiment 1 except for the following. The stimuli used in Experiment 4 are shown in Fig. 2. As primes the digits "4" and "6" were presented in black against white background extending 0.8×1.2 cm. As mask a black rectangle extending 1.4×1.8 cm was used. Within this rectangle the digits "4" and "6" were drawn in white superimposed on each other creating a metacontrast mask for the primes. Targets were the digits "4" and "6" presented in gray, in the same font as the primes but much larger (1.6×2.4 cm). Each trial started with a fixation cross presented for 300 ms. Primes were presented for 10 ms, followed by a blank screen for 60 ms. Then the mask was presented for 110 ms. After a variable mask target SOA of 10, 40, 80, 120, 160, or 200 ms, the target was presented for 110 ms. Thus, prime target SOA amounted to 80, 110, 150, 190, 230, or 270 ms. After response execution a fixed time interval of 1200 ms elapsed. In this interval possible errors were indicated by a beep sound.

9.1.3. Design and procedure

Participants were instructed to press a left key when the digit "4" was presented and a right key when the digit "6" was presented with the index finger of the left or right hand. The experiment consisted of six blocks comprising 120 trials each. In every block each possible combination of prime (4 or 6), target (4 or 6), and prime target SOA (80, 110, 150, 190, 230, or 270 ms) was presented five times.

After the experiment, participants performed a detection task to test whether they were able to consciously perceive the primes. Participants were fully informed about the precise structure of the prime and masking stimuli and were then presented with 144 trials identical to the experimental trials.

9.2. Results

9.2.1. Congruency effects

RTs deviating more than 2.5 standard deviations from the individual mean RT of each experimental condition (1.81%) were considered as outliers and excluded from the analysis. For the remaining trials, mean RTs for correct trials and mean percentages of error (PEs) were averaged over participants separately for each combination of the factors Congruency and SOA between mask and target (see Fig. 7).

The ANOVA on RTs revealed a significant interaction of SOA and Congruency, $F(5, 55) = 7.30$, $p < .001$, $MSe = 912.4$. For the shortest SOA a PCE was obtained that got reversed for longer SOAs. Separate t-tests confirmed a PCE of 14 ms for SOA 80, $t(11) = 3.16$, $p < .01$, and NCEs of -13 ms for SOA 190, $t(11) = -2.25$, $p < .05$, of -10 ms for SOA 230, $t(11) = -2.99$, $p < .05$, and of -12 ms for SOA 270, $t(11) = -2.22$, $p < .05$. The main effect of Congruency did not reach significance, $F(1, 11) = 2.98$, $p < .12$, $MSe = 729.1$, but the main effect of SOA did, $F(5, 55) = 20.99$, $p < .001$, $MSe = 9{,}309.0$. Mean RT decreased with longer SOAs – it amounted to 385 ms with SOA 80, 387 ms with SOA 110, 378 ms with SOA 150, 379 ms with SOA 190, 362 ms with SOA 230, and 353 ms with SOA 270.

The interaction between SOA and Congruency was not significant in an analogous ANOVA on PE, $F(5, 55) = 1.78$, $p < .17$, $MSe = 24.5$, but there was a significant main effect of Congruency, $F(1, 11) = 8.28$, $p < .05$, $MSe = 137.2$. Averaged over all SOAs, participants made more errors in congruent (5.4%) than incongruent (3.4%) trials. Separate t-test revealed that significant NCEs of -3.5% for SOA 150, $t(11) = -2.73$,

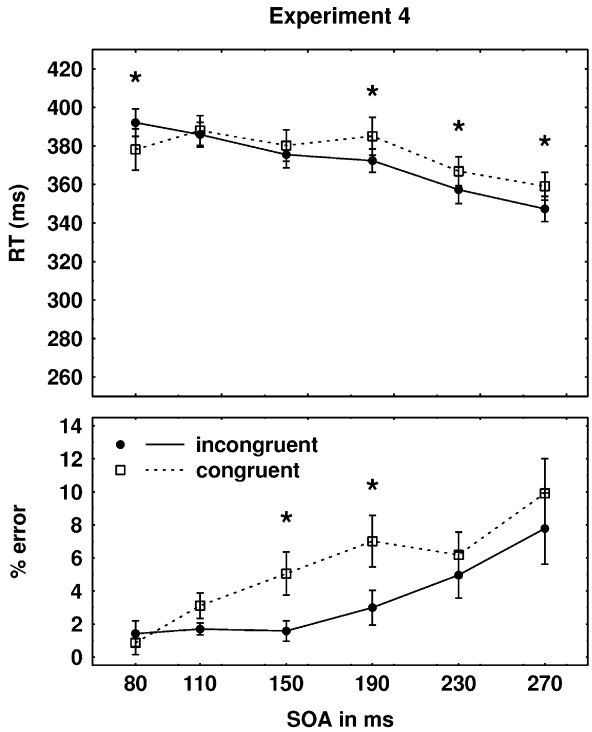

Fig. 7. Congruency effects in Experiment 4. Mean RTs (top panel) and error rates (bottom panel) for congruent and incongruent trials depending on prime target SOA. Standard error bars are ±1 standard error of each mean.

$p < .05$, and −4.0% for SOA 190, $t(11) = -3.40$, $p < .01$. Also, the main effect of SOA was significant, $F(5, 55) = 10.40$, $p < .001$, $MSe = 481.2$. Participants made more errors the longer the SOA (SOA 80: 1.1%, SOA 110: 2.4%, SOA 150: 3.3%, SOA 190: 5.0%, SOA 230: 5.6%, and SOA 270: 8.9%). Thus, again faster responses for longer SOAs went along with higher error rates, reflecting a speed accuracy trade-off.

9.2.1.1. Statistical comparisons with Experiment 2. Analogous to the between-conditions comparisons performed for Experiment 2, congruency effects in terms of RT ($RT_{incongruent} - RT_{congruent}$) from Experiment 4 were compared with congruency effects computed separately for each session as well as across all sessions of the experimental condition in Experiment 2. Each of separate 2 (Experiment 4 vs. experimental condition of Experiment 2) × 5 (SOA: 80, 110, 150, 190, 230 ms) mixed-measures ANOVAs revealed a significant main effect of Experiment, all $F(1, 22) > 20.51$, all $p < .001$, all $MSe > 8{,}932.2$, reflecting that – averaged across SOAs – the PCE in the experimental condition of Experiment 2 differed significantly from the non-significant overall NCE in Experiment 4. This main effect was not significantly moderated by SOA in the ANOVAs involving Experiment 2 data from Sessions 1 and 3 or Experiment 2 data averaged across all sessions, all $F(4, 88) < 1.81$, all $p > .135$, all $MSe < 231.7$. Only in the ANOVA involving Experiment 2 data from Session 2 was there a significant Experiment × SOA interaction, $F(4, 88) = 3.20$, $p < .05$, $MSe = 338.9$, indicating that at SOA 80 ms PCEs did not differ significantly between Experiment 4 and the experimental condition of Experiment 2, $t(11) = 1.13$, whereas for all other SOAs (110, 150, 190, 230 ms), PCEs in the experimental condition of Experiment 2 differed significantly from negative or non-significant congruency effects in Experiment 4, all $t(11) > 3.63$, $p < .005$.

Similar results were obtained in analogous analyses on congruency effects in terms of error rates ($PE_{incongruent} - PE_{congruent}$). There were significant main effects of Experiment, all $F(1, 22) > 17.6$, all $p < .001$, all $MSe > 357.9$, reflecting that PCEs in Experiment 2 differed significantly from NCEs in Experiment 4. There was no significant Experiment × SOA interaction in any of the ANOVAs, all $F(4, 88) < 2.32$, all $p > .063$, all $MSe < 43.6$.

Congruency effects in terms of RT were also compared between Experiment 4 and the control condition in Experiment 2. A 2 (Experiment 4 vs. control condition of Experiment 2) × 5 (SOA: 80, 110, 150, 190, 230, 270 ms) mixed-measures ANOVA revealed that the main effect of Experiment was not significant, $F(1, 22) = 0.93$, $MSe = 520.1$. There was, however, a significant main effect SOA, $F(5, 110) = 27.68$, $p < .001$, $MSe = 12{,}767.0$, indicating PCEs at short SOAs turning into NCEs at longer SOAs. This main effect of SOA was involved in a significant interaction with Experiment, $F(5, 110) = 7.77$, $p < .001$, $MSe = 3{,}584.5$. At SOAs 80 and 110 ms, the PCEs in the control condition of Experiment 2 were significantly larger (more positive) than the congruency effects in Experiment 4, both $t(22) > 2.57$, both $p < .05$. At SOA 150 ms the NCEs in the control condition of Experiment 2 did not differ significantly from the non-significant congruency effect in Experiment 4, $t(22) = -1.59$, $p < .126$. At SOAs 190 and 230 ms, NCEs in the control condition of Experiment 2 were significantly larger (more negative) than NCEs in Experiment 4, both $t(22) > 2.43$, both $p < .05$. Finally, at SOA 270 ms NCEs did not differ between the control condition of Experiment 2 and Experiment 4, $t(22) = -0.43$.

Analogous analyses on congruency effects in terms of error rates also revealed a significant main effect SOA, $F(5, 110) = 3.67$, $p < .05$, $MSe = 89.3$. Neither the main effect Experiment, $F(1, 22) = 0.62$, $MSe = 15.4$, nor the interaction was significant, $F(5, 110) = 1.80$, $p < .151$, $MSe = 43.7$.

9.2.2. Prime visibility

Participants' discrimination performance (d') was .05, .13, .01, .24, .02, and $-.08$ for the prime target SOA of 80, 110, 150, 190, 230, or 270 ms, respectively. t-Tests revealed that none of these d' measures differed significantly from zero (all $p > .23$), thus participants were not able to discriminate between the prime stimuli.

9.3. Discussion

The prime digits "4" and "6" trigger NCEs for prime target SOAs 190 to 270 ms in Experiment 4 but not in Experiments 2 and 3. This discrepancy seems hard to reconcile with the inhibition account. Why would digit primes evoke sufficient prime-induced activation to trigger inhibition in Experiment 4 but not in Experiments 2 and 3? Advocates of the inhibition account might speculate that the type of mask affects the amount of prime-induced activation. Specifically, metacontrast masks such as those used in Experiment 4 might result in larger priming effects than character masks such as those used in Experiments 2 and 3 because the former absorb less of the prime induced activation than the latter. Indeed there seems to be evidence that the type of mask influences the size of priming effects. Van Opstal, Reynvoet, and Verguts (2005) investigated priming effects for different mask types. Prime digits were masked by random letter strings (e.g., 'LFKCNO') in one condition and by hash signs (e.g., '#####') in another. Results showed that priming effects were larger with hash masks than with random letter masks. Therefore, van Opstal and colleagues concluded that masks containing task relevant features (i.e., letters because letters are more relevant for processing digit stimuli than are hash signs) absorb the priming effect to a larger degree (but see Kunde, et al., 2005 for an alternative explanation). According to this logic, one would expect the metacontrast mask used in Experiment 4, which consisted of superimposed prime digits, to absorb more prime activation than the task-irrelevant random character strings used in Experiments 2 and 3. Thus, priming effects should be smaller in Experiment 4 than in Experiments 2 and 3, and consequently one would expect to observe NCEs in Experiments 2 and 3 but not in Experiment 4. However, this was not the case. Instead, the reverse pattern of results was observed.

Furthermore, the following observations suggest that the strength of the S–R mappings and thus the amount of prime-induced activation was not larger but at best similar or even smaller in Experiment 4 than Experiment 2. First, the mean of participants' RT in each of the cells in the design when responding to the digit targets "4" and "6" ranged between 347 and 392 ms in Experiment 4. This range is similar to the RT ranges observed in the digit condition of Experiment 2 (322–396 ms) and in Experiment 3 (305–389 ms). Second, the PCE that was observed for the shortest prime target SOA of 80 ms in Experiment 4 amounted to 14 ms. Thus, the initial prime-induced activation observed at short SOAs was even smaller than in Experiment 2 where the PCE for the shortest SOA amounted to 28, 20, and 23 ms in Session 1, 2, and 3, respectively. Admittedly, in Experiment 3, the size of the PCE at the shortest SOA (100 ms) was 9.6 ms in Session 1 and 12.6 ms in Session 2, and thus somewhat smaller but still comparable to that in Experiment 4. However, we consider comparisons of effect sizes regarding Experiment 3 as problematic because of the extremely different SOA range.

The lack of NCEs for digit primes in Experiments 2 and 3 combined with the observation of NCEs for the same digit primes in Experiment 4 seems to be due to the different masking conditions (see Fig. 2). The mask used in the experimental condition of Experiment 2 and in Experiment 3 does not add any information that fits to the current task context. In contrast, the metacontrast mask of Experiment 4 does provide additional information corresponding to the currently not presented prime and therefore induces motor activation of the opposite response as the prime.

10. General discussion

Arguing that NCEs are restricted to particular prime and mask stimuli, Lleras and Enns (2004) as well as Verleger et al. (2004) have recently attributed NCEs to mask-induced activation. However, the inhibition account of Eimer and Schlaghecken (1998) still is in line with existing data when assuming that inhibition is restricted to subliminal prime presentation (Eimer & Schlaghecken, 2002; Klapp & Hinkley, 2002) and settings with sufficient prime-induced activation (Eimer & Schlaghecken, 2003).

In the current study, we set out to test the inhibition account by exploring whether manipulations of the amount of prime-induced activation have an impact on the occurrence of NCEs. In Experiment 1, we aimed to reduce the amount of activation induced by arrow primes by using non-arrow targets. We obtained a PCE of 16 ms for the shortest prime-target SOA of 110 ms. In Experiment 2, digits were used as primes and targets and participants extensively trained the digit-to-response mapping in order to increase prime-induced activation. In the three sessions, the resulting PCEs ranged between 20 and 28 ms for the shortest prime-target SOA of 80 ms, and between 14 and 21 ms for the prime-target SOA of 110 ms. Thus, judging from the size of the obtained PCEs, the amount of prime-induced activation appears to be similar in Experiments 1 and 2. However, NCEs at longer SOAs were observed for the arrow primes used in Experiment 1 but not for the digit primes masked with random character strings used in Experiment 2. Likewise, we did not observe any NCEs in a replication of the digit-priming condition of Experiment 2 for even longer SOAs (Experiment 3). Finally in Experiment 4, the same digit primes as in Experiments 2 and 3 were used but they were masked by metacontrast. Under these masking conditions, the digit primes induced a congruency effect of 14 ms for the shortest prime target SOA of 80 ms. Despite this small prime-induced activation, NCEs resulted for longer prime target SOAs. This pattern of result suggests that the occurrence of an NCE is independent of the amount of prime-induced activation. However, these conclusions are limited by the fact that we have no independent measure to verify the efficacy of our manipulations of prime-induced activation. We suggest the size of the PCEs obtained at short SOAs as a measure for prime strength. The observed PCEs vary in size consistently with the different experimental conditions: They are largest for prime arrows if targets are also arrows (control condition of Experiment 2), somewhat smaller for prime digits 4 and 6 when the S–R mapping is intensively trained (experimental condition of Experiment 2; Experiment 3) and again smaller for prime arrows if targets are dots (Experiment 1) or prime digits without intensive training (Experiment 4). Thus, the assumed prime strength and the observed PCEs go along together reasonably well.

Furthermore, our findings are in line with the recent observation of Lleras and Enns (2005) that prime visibility is not related to the occurrence of NCEs. In Experiment 4 and in the control condition of Experiment 2, participants could not discriminate between primes above chance level but in Experiment 1 and in the digit-priming condition of Experiment 2 as well as in Experiment 3 prime presentation was not clearly subliminal. Nevertheless, NCEs were observed for longer prime target SOAs in Experiment 1, the control condition of Experiment 2, and in Experiment 4. As prime visibility in Experiment 1 and the digit-priming condition of Experiment 2 was similar, the lack of NCEs in Experiment 2 cannot be ascribed to the fact that participants could discriminate between primes above chance.

Thus, taken together, the results of the present experiments call into question both extra assumptions of the inhibition account: First, the amount of prime-induced activation does not predict whether or not NCEs occurs. Second, the occurrence of NCEs is not influenced by prime visibility (for similar conclusions see Lleras & Enns, 2006). As mentioned in the introduction, however, these assumptions are necessary for the inhibition account to explain existing results regarding the NCE. Most importantly, if these assumptions do not hold true the inhibition account cannot explain the observation that NCEs are restricted to specific prime and mask conditions.

Taken together, our experiments did not provide any evidence in support of the inhibition account of NCEs. Neither the amount of prime-induced activation nor the visibility of primes predicted whether or not NCEs occurred. Rather, whether NCEs or PCEs were obtained for long prime target SOAs seemed to depend on the masking procedure. In our experiments, metacontrast masking always led to NCEs (Exp. 1, control condition of Exp. 2, and Exp. 4) whereas PCEs were observed for the same prime target SOAs with letter masking (Exp. 2 and Exp. 3). One may argue that metacontrast masks might affect other information processing stages than do overlapping masks, and that this is somehow the reason for the presence of NCEs with metacontrast mask and PCEs with other types of mask. Yet, this account is post hoc and would be inconsistent with existing evidence which clearly shows that NCEs can be obtained with overlapping masks as well (e.g., Eimer & Schlaghecken, 2002). A close inspection of the used prime and mask stimuli renders a different explanation likely. Metacontrast masks always add information opposite to the prime to the scene (see Fig. 2). In Experiment 1 and in the control condition of Experiment 2, primes were black arrows pointing to the left or right and the mask was a composite of both prime arrows presented white in a black frame. Thus, the mask adds information that easily can be considered as a left or right dot when participants wait for dots to prepare their response (in Experiment 1) or as a left or right pointing arrow when participants wait for arrows (control condition of Experiment 2). Similarly, masks in Experiment 4 were composites of both prime digits. Thus, the mask always adds information opposite to the presented prime to the current scene. In contrast, in the experimental condition of Experiment 2 and in Experiment 3 random character strings were used as masks, so that the masks to not contain any task relevant information. In this case, we found only PCEs.

To sum up, NCEs were observed in cases in which the masks contained task relevant features whereas only PCEs and no NCEs were observed if masks contained task-irrelevant features. Thus, the present experiments are in line with the assumption that NCEs are due to masks inducing activation opposite to the prime (Lleras & Enns, 2004; Verleger et al., 2004).

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References

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

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

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., Mueller, M., Dehaene-Lambertz, G., et al. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597–600.

Eimer, M. (1999). Facilitatory and inhibitory effects of masked prime stimuli on motor activation and behavioural performance. *Acta Psychologica, 101*, 293–313.

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.

Eimer, M., & Schlaghecken, F. (2002). Links between conscious awareness and response inhibition: Evidence from masked priming. *Psychonomic Bulletin & Review, 9*, 514–520.

Eimer, M., & Schlaghecken, F. (2003). Response faciliation and inhibition in subliminal priming. *Biological Psychology, 64*, 7–26.

Eimer, M., Schubö, A., & Schlaghecken, F. (2002). Locus of inhibition in the masked priming of response alternatives. *Journal of Motor Behavior, 34*, 3–10.

Galton, F. (1880). Visualised numerals. *Nature, 21*, 252–256.

Göbel, S., Walsh, V., & Rushworth, M. F. S. (2001). The mental number line and the human angular gyrus. *NeuroImage, 14*, 1278–1289.

Hautus, M. J. (1995). Corrections for extreme proportions and their biasing effects on estimated values of d'. *Behavior Research Methods, Instruments, and Computers, 27*, 46–51.

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

Klapp, S. T. (2005). Two versions of the negative compatibility effect: Comment on Lleras and Enns (2004). *Journal of Experimental Psychology: General, 134*, 431–435.

Klapp, S. T., & Haas, B. W. (2005). Nonconscious influence of masked stimuli on response selection is limited to concrete stimulus–response associations. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 193–209.

Klapp, S. T., & Hinkley, L. B. (2002). The negative compatibility effect: Unconscious inhibition influences reaction time and response selection. *Journal of Experimental Psychology: General, 131*, 255–269.

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

Kunde, W., Kiesel, A., & Hoffmann, J. (2005). On the masking and disclosure of unconscious eleborate processing: A reply to Van Opstal, Reynvoet, & Verguts. *Cognition, 97*, 99–105.

Lingnau, A., & Vorberg, D. (2005). The time-course of response inhibition in masked priming. *Perception and Psychophysics, 67*, 545–557.

Lleras, A., & Enns, J. T. (2004). Negative compatibility or object updating? A cautionary tale of mask-dependent priming. *Journal of Experimental Psychology: General, 133*, 475–493.

Lleras, A., & Enns, J. T. (2005). Updating a cautionary tale of masked priming: Reply to Klapp (2005). *Journal of Experimental Psychology: General, 134*, 436–440.

Lleras, A., & Enns, J. T. (2006). How much like a target can a mask be? Geometric, spatial, and temporal similarity in priming: A reply to Schlaghecken and Eimer (2006). *Journal of Experimental Psychology: General, 135*, 495–500.

Lleras, A., & Moore, C. M. (2003). When the target becomes the mask: Using apparent motion to isolate the object-level component of object substitution masking. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 106–120.

Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umilta & M. Moscovitch (Eds.), *Attention and performance XV. Conscious and nonconscious information processing* (pp. 123–150). Cambridge: MIT Press.

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.

Schlaghecken, F., & Eimer, M. (1997). The influence of subliminally presented primes on response preparation. *Sprache & Kognition, 16*, 166–175.

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

Schlaghecken, F., & Eimer, M. (2002). Motor activation with and without inhibition: Evidence for a threshold mechanism in motor control. *Perception & Psychophysics, 64*, 148–162.

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

Schlaghecken, F., & Eimer, M. (2006). Active masks and active inhibition: A comment on Lleras and Enns (2004) and on Verleger, Jaskowski, Aydemir, van der Lubbe, and Groen (2004). *Journal of Experimental Psychology: General, 135*, 484–494.

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

Van Opstal, F., Reynvoet, B., & Verguts, T. (2005). Unconscious semantic categorization and mask interactions: An elaborate response to Kunde et al. *Cognition, 97*, 89–97.

Verleger, R., Jaskowski, P., Aydemir, A., van der Lubbe, R. H. J., & 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.

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.