The Time-Course of Masked Negative Priming

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Abstract. Negative priming (NP) refers to the finding that reaction times and errors increase when a previously ignored prime distractor is presented as a target. In a variant of this task, the prime display is composed of only a single masked distractor that is followed by the simultaneous presentation of a target and a distractor in the probe display. In one experiment, we explore the time-course of masked NP using different variations of the prime-probe interval (short, medium, and long), and compare the results with time-course investigations of unmasked NP. We found clear evidence for a rapid-decay function of masked NP: With an increase in the prime-probe interval, masked NP decreased. This result is in line with the predictions of the temporal discrimination account and retrieval accounts of NP.

Keywords: time-course of negative priming, masked negative priming, retrieval, temporal discrimination

Negative priming (NP) refers to a slower responding to target stimuli that were presented as distractor stimuli in a previous display (for a review, see e.g., Fox, 1995). NP is typically observed in selective attention tasks that present target stimuli among distractors in two consecutive displays (the first called the prime display and the second called the probe display). Repeating the prime distractor as probe target (the ignored repetition, IR condition) produces slower reaction times (RTs) than a prime-probe sequence with unrepeated stimuli (the control, C condition). There is an ongoing debate about the processes underlying NP. On the one hand, inhibition accounts state that active suppression of the prime distractor representation produces RT costs when this representation must be activated in the probe display (Houghton & Tipper, 1994; Tipper, 1985). On the other hand, retrieval theorists (e.g., Neill & Valdes, 1992; Rothermund, Wentura, & DeHouwer, 2005) argue that automatically retrieved prime responses or do-not-respond tags interfere with target responding in the probe display. At present, there is much evidence for both explanations of NP, suggesting that both processes might contribute to NP (e.g., Rothermund et al., 2005; Tipper, 2001).

In this study, we analyze the time-course of NP in a variant of the NP design that involves presentations of a single masked distractor in the prime display followed by a probe display comprising a target and a distractor. Even though participants were not to react to the prime episode, they still showed a delayed responding to the probe target when it was previously shown as the prime stimulus. This basic finding of NP with masked-distractor-only primes was observed in several laboratories to date (e.g., Healy & Burt, 2003; Milliken, Joordens, Merikle, & Seiffert, 1998; Neill & Kahan, 1999, Expt 1a), and this has been found to be moderated by the participants' prime awareness (Frings & Wentura, 2005).

The masked single-prime variant of NP is of theoretical value for several reasons. First, NP induced by single, masked primes reveal that NP does not critically hinge upon selecting a prime target against the distractor – which is a core assumption of the original inhibition account (Tipper, 1985) that is still upheld in modern inhibition theories (cf. Houghton & Tipper, 1994). Second, to account for these effects, Milliken et al. (1998) introduced a third account of NP that emphasizes the temporal discrimination of prime and probe as a source of NP. At the core of this theory is an attention system that decides whether a response to a stimulus is already known and can be directly retrieved from memory, or whether a response to a stimulus is unknown and must be "computed" in a controlled mode of processing. It is assumed that the time to reach a decision whether a display is old (and a response is already known) or new (and a response is yet unknown) is related to a (mis)match between the prime display and the probe display: If nothing is repeated between prime and probe displays (i.e., the C condition), then the attention system rather quickly determines the probe target as "new", and a corresponding response is computed. However, if the prime distractor becomes the target in the probe display, the probe display contains both old and new information and this ambiguity is assumed to slow down the decision process. The temporal discrimination account attributes NP to this ambiguity in the IR condition. Third, several studies analyzed the influences of participants' strategies on NP, which possibly require an awareness of the IR condition or contingencies in the design, showing that NP is diminished when participants utilize the prime information as a cue for probe responding (Baylis & Driver, 1993; Christie & Klein, 2001; Frings & Wentura, 2006; Milliken & Rock, 1997). The masking of stimuli provides an adequate means to rule out such context-dependent task strategies, yielding a more direct measure of automatic processes in NP.

In this study, we attempt to analyze the time-course of masked NP with variations of the prime-probe interval.

DOI: 10.1027/1618-3169.56.5.301

In unmasked NP studies, the time interval between prime response and onset of the probe display was identified to be a key determinant of NP (cf. Hasher, Zacks, Stoltzfus, Kane, & Connelly, 1996). Accordingly, we will first summarize these findings on the time-course of unmasked NP. A comparison of the time-course of NP engendered by masked and unmasked prime displays might reveal functional differences between single masked prime episodes and ignored distractors in target-distractor prime displays.

The Time-Course of NP

Systematic research into the time-course of NP has yielded a rather inconsistent result pattern yet. Some studies failed to find evidence for a decay function of NP but others did so. Tipper, Weaver, Cameron, Brehaut, and Bastedo (1991), for example, analyzed variations in the interval between the response to the prime display and the onset of the probe display response-stimulus-interval (RSI) in identification and localization tasks and registered no decline in NP across RSIs of 1,350, 3,100, and 6,600 ms. Hasher and colleagues (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher et al., 1996) similarly obtained no clear evidence for a decay function of NP. These findings of constant NP across a broad range of prime-probe intervals were interpreted in favor of a long-lasting inhibition process that outlives prime-probe intervals of several seconds.

Other studies, however, observed NP to be dependent upon the duration of the prime-probe separation. Neill and colleagues (Neill, Valdes, Terry, & Gorfein, 1992), for instance, obtained stronger NP with an RSI of 500 ms than of 4,000 ms. Reduced NP with longer prime-probe intervals was interpreted in favor of an episodic retrieval process that is subjected to a temporal decay (Neill & Valdes, 1992; Neill & Westberry, 1987; Neill et al., 1992). According to episodic-retrieval accounts, a temporal decay of episodic retrieval should depend more on the discriminability of the prime episode from the preprime display than on the time interval between prime and probe itself. In other words, it is the ratio of the preprime-prime interval compared to the prime-probe interval that should determine the strength of NP; and indeed, congruent with this prediction Neill and colleagues observed diminished NP effects when the preprime-prime interval was shorter compared to the prime-probe interval. This influence of the preprime-prime interval was replicated by Mayr and Buchner (2006) with auditory stimuli, but other studies with visual stimuli (Conway, 1999; Hasher et al., 1996) failed to do so.

To summarize, studies on the time-course of NP yielded evidence for a temporal decay of NP at longer prime-probe intervals that is typically interpreted with a decay of episodic retrieval. In addition, there exists evidence for a more complex interaction between the preprime-prime interval and the prime-probe interval that is also taken to support episodic retrieval accounts. However, a number of studies failed to find evidence for a temporal decay of NP, and interpreted persisting NP as a consequence of an inhibition process that lasts for several seconds.

The Time-Course of Masked NP: Predictions

Concerning the time-course of masked NP, we assume that with degraded presentation conditions the prime activation might be more spurious due to the shorter prime duration and the backward masking procedure. Hence, it is expected that with a long prime-probe stimulus-onset-asynchrony (SOA) the priming influence of subliminally processed distractor displays should diminish more rapidly than the influence of optimally processed distractor displays (see Wentura & Frings, 2005, for an analogous reasoning in the context of masked semantic priming). This rapid-decay-argument is in harmony with a temporal discrimination account that predicts stronger ambiguity at a shorter SOA if the distractor activation is present in the comparison process than at a longer SOA when the distractor activation is already dissipated. In addition, a temporal decay function of NP might also be in line with retrieval accounts that expect weaker NP at longer prime-probe intervals due to a temporal decay of do-not-respond-tags (Neill & Westberry, 1987). A classic inhibition account, however, would expect persisting inhibition for a few seconds even with masked distractor presentations, and hence NP effects that are not modulated by SOA (Tipper et al., 1991). In sum, temporal moderations of masked NP are expected by temporal discrimination and episodic retrieval accounts, but not by an inhibition account of NP.

Experiment

In this experiment, we analyze for the first time the time-course of masked NP with three different prime-probe intervals (SOA of 138 ms vs. 538 ms vs. 1,038 ms). One of the advantages of masked NP is its unobtrusiveness. Thus, it is important to ensure that participants could not identify the masked distractors. Furthermore, Frings and Wentura (2005) provided conclusive evidence that prime awareness moderates masked NP effects: Aware participants strategically use the prime information for probe processing if they notice that the prime distractor is repeated as probe target above chance with a probability of $p = .50$ (with uncorrelated prime-probe displays and 12 stimuli this probability would be $p = .08$), thereby they will focus on the prime distractor instead of ignoring it and this in turn will counteract the NP effect. Hence, we used a very strict criterion for classifying participants into aware and unaware ones to obtain a direct and unobtrusive measurement of the time-course of masked NP.

In sum, an interaction between prime awareness and SOA level is hypothesized that reveals a clear influence of SOA on NP in unaware participants but a reduced influence in the case of aware participants. Such an interaction would support retrieval and temporal discrimination accounts that expect diminished masked NP with increasing prime-probe SOA, if the prime-probe contingency is not detected and utilized strategically.

Method

Participants

Sixty-seven students from Saarland University who were naïve to the purpose of the experiment participated in the experiment. Data of three participants were excluded because of too many misses (i.e., voicekey-failures in > 30% of the trials). Two additional data sets were discarded because they were outliers in respect to the average reaction time of the sample (Tukey, 1977).

Material and Apparatus

The stimuli set comprised the following high-frequency German nouns: *PALME* (palm), *PERLE* (pearl), *PULVER* (powder), *DIENER* (servant), *DOSIS* (dose rate), *DONNER* (thunder), *BOGEN* (bow), *BUCHE* (beech), *BECHER* (cup), *TELLER* (plate), *TENOR* (tenor), and *TUNNEL* (tunnel). The individual letters of the words had a size of 9 × 5 mm on the screen. Distractors in the probe display were always presented in blue color and probe targets in red color. Both words were presented in uppercase and at the center of the screen with interleaved letters. Pre- and postmasks consisted of 14 "@" symbols (cf. Milliken et al., 1998). Masks and prime distractors were presented in black at the center of the screen. Stimuli were presented on a standard 17″ CRT monitor with an 800 × 600 resolution and with a refresh rate of 80 Hz. Participants had a viewing distance of ~ 60 cm, and a voicekey-apparatus was used for latency measurement.

Design

The experimental design was a 2 (prime stimulus: repeated vs. unrepeated) × 3 (prime-probe SOA: 138 ms vs. 538 ms vs. 1,038 ms) within-subjects design. Awareness of masked stimuli (unaware vs. aware) was introduced as a quasi-experimental between-subjects factor based on participants' discrimination performance in the direct prime awareness test. NP effects were computed as the difference between distractor-to-target repetition trials and trials without repetitions.

Procedure

The participants were instructed to read aloud as fast as possible the red-colored target words that were accompanied by blue distractor words. The exact sequence of events in each trial was as follows: First, a fixation marker (+) was presented at the center of the screen until the participants pressed the enter-key. Then, the forward mask was presented for 500 ms followed by the prime distractor for 38 ms. The prime distractor was masked backwardly for 100, 500, or 1,000 ms, respectively, depending on the SOA-condition. Afterwards, the probe display appeared with interleaved target and distractor stimuli and remained on the screen until the participant responded. Participants were instructed to focus on the fixation marker and the mask, because they would indicate the presentation location of the probe stimuli. The priming phase comprised three blocks of 80 trials each. The prime-probe SOA (i.e., the duration of the backward mask) was varied blockwise, and the sequence of blocks was counterbalanced between participants. In each block, half of the trials contained distractor repetitions. In each trial, three different words were randomly chosen from the stimulus list and were assigned the roles of prime distractor, probe target, and probe distractor. IR trials were created by presenting the prime distractor once more as target stimulus. A stimulus was never repeated in a subsequent trial, and each stimulus was selected from the list without replacement. The experimenter coded the response errors of the participant online on another computer.

Subsequent to the 240 experimental trials, the participants were questioned whether they recognized anything between the masks. They were informed about the masked prime word, and then they were to work through 72 prime identification trials to obtain a direct measure of prime awareness (one block of 24 trials for each SOA condition; the block sequence matched the sequence of the SOA variation in the priming phase). In this direct identification test, each stimulus appeared six times as a prime distractor (twice in every SOA condition). In half of the trials, the prime distractor was replaced by a random number of the same length. In the direct test, the probe display did not appear; instead, a blank screen was shown and the participants had to say aloud whether a word or a number was presented between the masks. The answer was coded by the experimenter.

Results

Only correct reactions that were within 200 ms to three interquartile ranges above the third quartile of the overall RT distribution (criterion: 1,130 ms; Tukey, 1977) were considered for analysis. This data truncation resulted in the elimination of 3.9% of all trials. Individual error rates of $M = 0.7\%$ were too low for meaningful analyses.

Prime Awareness

None of the participants noticed the masked words on direct questioning; thus, all participants were unaware of the prime presentations on a subjective awareness criterion. In addition, we computed the word detection rate of each participant for each SOA level separately. In other words, we analyzed whether they showed a significant contingency between presentation (i.e., word vs. number) and response (word present vs. word absent); of course, this was a very conservative criterion for judging participants' prime awareness. Only participants who had detection rates above chance on every SOA level were classified as "aware". Nineteen participants out of 62 were considered unaware

Table 1. Mean RTs (standard deviations in parentheses) as a function of distractor repetition, SOA, and awareness

	SOA 138 (ms)		SOA 538 (ms)		SOA 1038 (ms)	
	Aware	Unaware	Aware	Unaware	Aware	Unaware
Distractor repeated	609 (70)	636 (62)	590 (81)	608 (77)	588 (75)	616 (75)
Distractor unrepeated	605 (68)	621 (73)	593 (81)	598 (75)	585 (76)	619 (74)
NP effect[a]	−3 [3]	−16* [5]	+3 [3]	−10* [5]	−2 [3]	+3 [4]

Note. Small differences in numbers are due to rounding.
*$p < .05$.
[a]Distractor-unrepeated minus distractor-repeated (standard error in square brackets).

by this criterion. At the short SOA of 138 ms, 12 of 62 participants could not judge with above chance probability whether a word or a number was shown (all $\chi^2 < 2.98$, all ps > .08). At the medium SOA of 538 ms, 14 of 62 participants did not classify above chance expectation (all $\chi^2 < 3.00$, all ps > .07). At the longest SOA of 1,038 ms, 13 of 62 participants proved unaware of the masked primes (all $\chi^2 < 3.39$, all ps > .06).

NP

RTs were submitted to a 3 (SOA: 138 ms vs. 538 ms vs. 1,038 ms) × 2 (priming condition: repeated distractor vs. unrepeated distractor) × 2 (prime awareness: aware vs. unaware) MANOVA[1] (see Table 1 for mean RTs and NP effects). A significant main effect for SOA emerged, $F(2, 59) = 8.75$, $p < .05$, $\eta^2 = .23$, indicating longer RTs at shorter SOA levels. The main effect for prime awareness was not significant, $F(1, 60) = 1.22$, $p = .27$, $\eta^2 = .02$. Importantly, the main effect for priming condition was significant, $F(1, 60) = 7.35$, $p < .01$, $\eta^2 = .11$, showing overall longer RTs when the prime distractor was repeated as the probe target (i.e., significant masked NP). Priming condition and prime awareness interacted significantly, $F(1, 60) = 4.05$, $p < .05$, $\eta^2 = .06$, as did SOA and priming condition, $F(2, 59) = 3.23$, $p < .05$, $\eta^2 = .10$. These interactions, however, were further qualified by a significant three-way interaction of SOA × Prime awareness × Priming condition, $F(2, 59) = 4.08$, $p < .05$, $\eta^2 = .12$, indicating that NP effects differed for the three SOA levels in dependence of participants' awareness. To further analyze this interaction, we conducted two separate MANOVAs for aware and unaware participants with NP effects as dependent variables. As a result, the main hypothesis for these analyses comprises a significant main effect for SOA (which would indicate different NP effects at different SOA levels) and further polynomial contrasts for the different levels of SOA (which would yield more specific information on the time-course of NP).

NP effects for unaware participants were submitted to a MANOVA with SOA as factor. There was a significant main effect for SOA, $F(2, 17) = 5.18$, $p < .05$, $\eta^2 = .38$, revealing different NP effects for the three SOA levels in this subsample of participants. To test the more specific hypothesis concerning the influence of SOA on NP, we built polynomial contrasts. The linear trend was significant, $F(1, 18) = 6.59$, $p = .02$, $\eta^2 = .27$, indicating less NP with increasing SOA. The quadratic trend was not significant, $F < 1$.

In contrast, for participants classified as aware the same analysis did not yield significant effects. Neither the main effect of SOA, $F(2, 41) = 1.23$, $p = .30$, $\eta^2 = .06$, nor the linear trend, $F(1, 42) = 0.07$, $p = .77$, $\eta^2 = .002$, nor the quadratic trend, $F(1, 42) = 2.43$, $p = .14$, $\eta^2 = .06$, were significant.

Discussion

In this study, we first obtained data on the time-course of masked NP. As expected, masked NP depended on participants' awareness and the SOA level: Aware participants did not show masked NP at any SOA level; however, when participants were unable to identify the primes above chance, masked NP depended on the prime-probe SOA with stable NP at shorter SOAs (138 and 538 ms) but no effect at a long SOA of 1,038 ms. Thus, we obtained clear evidence for a rapid-decay function in masked NP while controlling prime-induced task strategies. Before we discuss the theoretical implications of this main finding in more detail, we want to draw the reader's attention to two aspects of the data that are important to this conclusion.

First, the observation that masked NP at the middle SOA was influenced by participants' prime awareness replicated previous findings of a strategic prime processing (Frings & Wentura, 2005). Given that the distractor was repeated in half of the trials as target, the participants who were aware of the primes could make strategic use of the prime to guess

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[1] MANOVAs that are free of sphericity assumptions were used in the data analyses instead of repeated-measures ANOVAs (O'Brien & Kaiser, 1985). The statistical criterion used here was Pillai's trace.

the forthcoming probe response above chance, thereby counteracting NP. The present results suggest that this strategy might also act on top of the NP process at considerably shorter SOA levels as previously analyzed. Note that a strategic use of the prime information can reasonably explain the absence of NP in aware participants but not in unaware participants at the long SOA level. Here, we suggest that the prime episode is already too spurious to affect probe processing.

Second, two caveats of our experimental design should be taken into account in the interpretation of the results. First, the backward mask was presented continuously between prime and probe, so that SOA and mask duration were confounded. Note that a continuous presentation of the backward mask is typical to paradigms investigating NP with masked, single prime distractors (e.g., Milliken et al., 1998; Neill & Kahan, 1999); we therefore decided to implement a continuous backward masking in all SOA levels, to maintain utmost comparability to these studies. Second, one might speculate whether masked NP in our experiment is explained by a color mismatch between distractor and target that slows down RTs (e.g., Park & Kanwisher, 1994). Frings and Wentura (2005) tested this possibility, however, and they did not find any influence of a color mismatch on masked NP; in consequence, it is rather implausible that a colored feature mismatch produced our NP effects.

Finally, note that we used a very strict test for measuring participants' prime awareness to ensure an unobtrusive test of the time-course of masked NP. This led to a relatively small sample of unaware participants in the experiment that might compromise conclusions drawn from this subsample. Note, however, that our data pattern exactly replicated the previous results on masked NP at a middle SOA that are based on a larger study sample due to a less strict awareness criterion (e.g., Frings & Wentura, 2005; Healy & Burt, 2003; Neill & Kahan, 1999). Given the similarity of the findings across different studies that used different awareness checks, it seems unlikely that the result pattern can be fully explained with confounds in the awareness selection procedure.

The Time-Course of Masked NP: Results and Implications

The main finding of our experiment is a linear temporal decay of masked NP that depends on the duration of the prime-probe interval. This finding is in line with the previous observations that NP declines with increasing prime-probe intervals (e.g., Neill & Valdes, 1992; Neill & Westberry, 1987). The discrepant findings that NP was still present in studies with unmasked distractors and RSIs larger than 1,000 ms (Neill & Valdes, 1992) but was completely absent in our experiment at a comparable SOA level (1,035 ms), hint however at differences in the time-course of masked and unmasked NP. A more rapid-decay of masked NP might be due to a more spurious prime episode in masked NP that narrows the time window for processes underlying NP. Despite this difference in the time-course of unmasked and masked NP, the decay function of masked NP suggests an – at least partially – functional equivalence of masked and unmasked NP. This is an important implication because every theory on NP must now be able to explain masked NP. In the following paragraphs we will discuss how the present results combine with the current accounts of NP.

The temporal discrimination theory (Milliken et al., 1998) assumes automatic comparisons of prime and probe displays. In IR trials, this comparison is affected by an ambiguity whether the probe target is old or new, which slows down reactions (i.e., NP). With a rapidly decaying prime episode, however, the prime-induced ambiguity in the automatic comparison might be reduced at longer SOAs; hence, the system can reach a quick decision that the probe display is "new". Thus, the temporal discrimination theory would predict larger NP at shorter SOAs and diminished NP at longer SOAs. This is exactly what we observed.

The episodic retrieval theory assumes that the discrimination of the prime episode from the previous probe is crucial for the time-course of NP. When prime-probe SOA is longer than the preprime-prime interval, NP is expected to diminish. However, in our experiment we did not manipulate the preprime-prime SOA; instead, our participants started each trial with a key-press after unlimited preparation time. Provided that participants did not systematically vary in their preparation time across the different SOA levels, prime discriminability was equal for all SOA conditions, and retrieval should decrease with an increase of the prime-probe interval. Thus, our data pattern is best explained with a simple decay of the prime distractor representations (or with the decay of the do-not-respond tags encoded with the prime distractors) than with an influence of the preprime-prime interval on masked NP. Note, however, that this discussion rests on the idea that an episodic retrieval account can be applied to NP effects produced with single (masked) primes. To do this, it is assumed that a do-not-respond attribute is not only tagged to optimally processed distractors but to every event that is irrelevant to the task at hand (here, the masking displays). According to such an extended episodic retrieval account, masked primes that are unaccompanied by a target are proposed to be functionally equivalent with ignored distractors in optimally processed prime-target displays, arguing against an exclusive interpretation of single-prime NP with the temporal discrimination idea.

The proponents of an inhibition account do not expect a rapid temporal decay of NP (e.g., Tipper et al., 1991), which is at odds with the finding of the present experiment and that of others (e.g., Neill & Valdes, 1992). Furthermore, modern variants of the inhibition account (e.g., Houghton & Tipper, 1994) typically assume that it takes some time to initiate the inhibition process, that is, NP is not expected at very short SOAs (Frings & Wühr, 2007; cf. May, Kane, & Hasher, 1995). Accordingly, a modern variant of the inhibition model predicts an increase in NP at longer SOAs or a quadratic trend (i.e., no NP at very short SOAs, NP at middle SOAs and possibly a decrease at longer SOAs). However, we observed significant NP at short SOAs and a significant decrease in masked NP (i.e., a linear trend). Thus, an inhibition account of masked NP is not supported by the present data.

Taken together, three conclusions might be derived from our experiment. First, for scientific practice, we recommend an efficient masking procedure combined with a short prime-probe SOA to researchers who want to replicate masked distractor-only NP effects most effectively. Second, the decay functions from masked and unmasked NP are functionally comparable, even though the prime episode is subject to a more rapid decay with masked than with unmasked presentations. Third, the linear time-course of masked NP can be easily integrated into temporal discrimination and retrieval accounts of NP, but not into an inhibition model of masked NP.

Acknowledgments

We are grateful to Jennifer Burt, Jason Leboe, Thorsten Meiser, and an anonymous reviewer for their helpful comments on an earlier version of this article. We thank Michael Kuhlmann for collecting the data.

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Received January 28, 2008
Revision received August 25, 2008
Accepted August 28, 2008

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