Accessory stimuli modulate effects of nonconscious priming

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In a recent study, it was shown that subliminal priming (SP) effects are affected by the temporal predictability of a stimulus onset. If predictability is not given, SP effects are eliminated (Naccache, Blandin, & Dehaene, 2002). In two experiments, we investigated how different levels of preparation for target processing affect SP effects. For this purpose, an accessory tone stimulus was presented at different times prior to a subliminal priming task. The results demonstrate a clear modulation of the SP effects at different foreperiod intervals. Relative to conditions without an accessory stimulus, SP effects were smaller for short foreperiod intervals of the accessory stimulus, and larger for long foreperiod intervals. The results suggest that the presentation of an accessory stimulus facilitates response activation processes because of the participants' enhanced level of preparation for stimulus processing.

Recent studies in experimental psychology have demonstrated that masked stimuli that humans remain unaware of may nevertheless affect behavior. In so-called subliminal priming tasks, it has been shown that subliminally presented stimuli are capable of activating corresponding motor responses (Ansorge, Klotz, & Neumann, 1998; Eimer, 1999; Eimer & Schlaghecken, 1998; Klotz & Neumann, 1999; Leuthold & Kopp, 1998; Schlaghecken & Eimer, 2000; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003) and even semantic categories (Abrams, Klinger, & Greenwald, 2002; Greenwald, 1992; Greenwald, Draine, & Abrams, 1996; Koechlin, Naccache, Block, & Dehaene, 1999; Naccache & Dehaene, 2001).

In subliminal priming tasks, participants are usually asked to perform a choice response after presentation of a visual target stimulus. Prior to the target stimulus, a subliminal prime is presented that either is associated with the same motor response as the target (congruent condition), is associated with the opposite motor response (incongruent condition), or does not contain any relevant response information (neutral condition). Common effects in such a task are a shortened response time (RT) in congruent prime-target conditions, relative to a neutral condition, and increased RTs in incongruent conditions (but for an exception, see Eimer, 1999; Eimer & Schlaghecken, 1998). The resulting congruency effect (i.e., the difference between RTs in the incongruent and congruent conditions) is usually interpreted as evidence for nonconscious motor activation in humans.

Although nonconscious motor activation is now a widely accepted phenomenon, researchers have recently started to specify the particular attentional characteristics of nonconscious information processing. In an important study, Naccache, Blandin, and Dehaene (2002) showed

that subliminal priming (SP) effects can be modulated by specific experimental manipulations affecting participants' attention. The authors showed that SP effects appear exclusively under conditions of temporally focused attention, disappearing under conditions in which a precise temporal focusing of attention is not possible. More specifically, in their main experimental setting, the authors implemented different conditions in which the time of target appearance was either predictable or not predictable. In the predictable condition, the temporal interval between prime and target, as well as the response stimulus interval, was constant across all trials (fixed prime and fixed target); SP effects were observed in this condition. According to the authors, the fixed temporal trial structure enabled participants to focus their attention on the predicted target appearance. The prime, which was temporally close to the target, was assumed to be within the limits of the attentional focus, which is seen as a requirement for the occurrence of SP effects.

On the other hand, SP effects were not found in conditions in which target onset was nonpredictable (fixed prime and variable target). In these conditions, the prime was presented with a fixed interval after the beginning of the trial. However, the interval between prime and target was manipulated randomly so that target onset was not predictable for participants. According to Naccache et al. (2002), the lack of SP effects in this condition was due to the participants' failure to focus their attention temporally on the time of target appearance.

On the basis of these findings, the authors proposed that an important prerequisite for the occurrence of SP effects is the exact temporal focusing of attention on the presentation of the prime-target pair. The focusing of attention to the predicted time of target appearance results

in a "temporal window" of attention that enables advantageous processing of a prime that is presented temporally close to the target. This process of successfully allocating attention to a stimulus is, of course, determined by the ability to predict the exact appearance of this stimulus. If participants do not know the timing of target appearance, as in the nonpredictable conditions, they cannot successfully deploy attention to this target. SP effects will then not occur, because stimuli will not be within the attentional focus.

The findings and conclusions of Naccache et al. (2002) add important pieces of information to the understanding of attentional mechanisms in subliminal response priming. They suggest that subliminal response priming is not a result of processes that are completely independent of attentional characteristics of information processing, but instead requires an appropriate level of attention allocation to the presented sensory information (see also Ansorge, 2004; Neumann & Klotz, 1994). However, manipulating predictable and nonpredictable target presentations, as was done by Naccache et al., implies a simplifying dichotomy: Either SP effects occur or they do not, depending on the predictability or nonpredictability of target onset.

Our study aimed to go beyond investigating the influence of a two-level manipulation of target onset predictability on performance in subliminal priming tasks. We tested whether a more fine-grained manipulation of the temporal focus of attention, rather than a predictable/nonpredictable dichotomy, would lead to a gradual influence on the size of the SP effect.

The starting point of our investigation is the assumption that the ability to precisely predict target onset results in participants' *preparation* to respond to this stimulus, which in turn affects task performance in general (Niemi & Näätänen, 1981). Indeed, in both experiments described by Naccache et al. (2002), responses were faster in predictable conditions than in nonpredictable conditions, suggesting different levels of preparation in the two conditions. This means that in predictable conditions, participants can prepare for task execution by temporally allocating attention to the expected time of target appearance and, thus, can optimize their preparation. In nonpredictable conditions, however, participants' preparation is insufficient, in that they cannot reliably allocate attention to stimulus appearance, which results in prolonged RTs and eliminated SP effects. In the present study, we will *gradually* manipulate the level of participants' preparation for target processing and test whether this will, correspondingly, lead to a *gradual* change in the size of SP effects.

A method often applied to manipulate the level of preparation is the presentation of an accessory stimulus¹ prior to the onset of an imperative stimulus (Bertelson & Tisseyre, 1969; Davis & Green, 1969; Karlin, 1966; Näätänen & Merisalo, 1977; Nickerson, Collins, & Markowitz, 1969; Teichner, 1954). It has been shown that different foreperiod intervals between the accessory and imperative stimuli lead to a gradual modulation of RTs in simple (Niemi & Näätänen, 1981) and also in choice (Bernstein, Rose, & Ashe, 1970) RT tasks. As an explanation, Niemi and Näätänen proposed that participants take

advantage of the accessory stimulus in order to prepare for the onset of the forthcoming stimulus. Since the development of preparation is assumed to be a ballistic process (Karlin, 1966) starting with the presentation of the accessory stimulus, the amount of accumulated preparation at the time of target onset differs with different foreperiod intervals. Consequently, stimulus processing proceeds under different conditions of accumulated preparation, which explains the observed gradual influence of a foreperiod manipulation on general performance in RT tasks (Bernstein et al., 1970; Niemi & Näätänen, 1981).

In the present study, we combined the effects of accessory stimuli in foreperiod manipulations with a subliminal priming task. As just described, implementing different foreperiods will result in different levels of participants' preparation to process information. Naccache et al. (2002) showed that preparation for target appearance goes along with SP effects, whereas no SP effects are observed when preparation is insufficient because of unpredictable target occurrence.² To extend their findings, our study is designed to investigate whether the size of SP effects will gradually vary with a gradual manipulation of preparation.

With the exception of Naccache et al.'s (2002) study, we do not know of other research on nonconscious information processing that has investigated the influence of temporal uncertainty, in terms of either stimulus predictability or task preparation, on SP effects. In typical subliminal priming studies, the temporal trial structure is usually fixed (Klotz & Neumann, 1999; Koechlin et al., 1999; Leuthold & Kopp, 1998; Naccache & Dehaene, 2001). That is, these studies have not manipulated the onset of an accessory stimulus that provided information about target onset, so predictability of target appearance, and thus the preparation to process this stimulus, did not change in these studies. Consequently, the influence of different degrees of attentional allocation on SP effects could not be observed in them.

EXPERIMENT 1

The purpose of Experiment 1 was to extend the findings of Naccache et al. (2002). Instead of manipulating the predictability of target appearance (predictable vs. unpredictable), we implemented a random foreperiod manipulation. More specifically, we presented an accessory tone stimulus shortly before the target stimulus in a subliminal priming task. In this task, participants were asked to manually respond to a left- or right-pointing arrow. The accessory stimulus was presented at one of six different intervals (0–1,000 msec) before the target stimulus, and its purpose was to serve as a trigger for the accumulation of task preparation.

Assuming that the development of preparation can be described in a ballistic curve starting with the presentation of the accessory stimulus (Karlin, 1966), we predicted an effect of the foreperiod manipulation on the size of the resulting SP effect. More specifically, we predicted that the size of the SP effect would increase with an increasing foreperiod interval between the accessory and target stimuli in the subliminal priming task. In other words, we

expected maximum SP effects when the accumulation of preparation reached the maximum level. According to Gottsdanker (1980), the determination of an interval allowing maximum preparation is difficult. However, with choice RT tasks involving sensory and motor requirements similar to those of the present subliminal priming task, Gottsdanker proposed that a foreperiod interval of about 250 msec is necessary to accumulate the maximum level of preparation. Consequently, we predicted that the largest SP effects would occur at a foreperiod interval of about 250 msec.

Method

Participants. Twenty undergraduate students (ages 19–40, mean 25.7 years) at Humboldt University participated. All had normal or corrected-to-normal vision and were not informed about the hypotheses of the experiment.

Apparatus. Stimuli were presented on a 17-in. color monitor that was connected to a Pentium I PC. Experiments were carried out using the Experimental Run Time System software (ERTS; Beringer, 2000).

Procedure. We used the stimulus materials of Vorberg et al. (2003). The participants were asked to respond to an arrow pointing either to the right or the left of a fixation cross. Unbeknownst to the participants, a subliminal prime stimulus was presented before the target stimulus. A trial started with the presentation of a fixation cross in the center of the screen, which remained visible for the whole trial. After an interval that was determined according to the specific foreperiod condition, a subliminal prime arrow was presented for 34 msec. After a further delay of 51 msec, the target stimulus was shown for 150 msec (see Figure 1). Thus, a constant prime (onset)–target (onset) interval of 85 msec was implemented, which resembled the “fixed prime and fixed target” condition of Naccache et al. (2002). If an RT exceeded 1,800 msec (beginning at target onset), or if the wrong response was given, the German word for *error* was presented as visual feedback for 300 msec. If the response was correct, the fixation cross was shown for a further 300 msec, after which the beginning of the next trial occurred.

The prime stimulus could be either congruent (prime and target arrows pointed in the same direction), neutral (the prime stimulus did not indicate any direction), or incongruent (the prime and target arrows indicated opposite directions).

The target arrows were black on a white background, with a white central cutout. They were positioned randomly 1.38° above or below a fixation cross located in the center of the screen. The prime stimuli were also black arrows on a white background, presented at the same position as the following target stimulus. At a viewing distance of 60 cm, the primes subtended a visual angle of 0.8° × 1.86°, the targets 1.09° × 3.47°. In order to achieve optimal metacontrast masking by the following target stimulus, which prevented conscious

identification of the prime, the outer contour of the prime coincided with the inner contour of the target’s central cutout (for reviews, see Enns & Di Lollo, 1997, 2000; Vorberg et al., 2003).

Half of the participants responded with their right hand (index finger for arrow left and middle finger for arrow right) and the other half with their left hand (index finger for arrow right and middle finger for arrow left). The participants were instructed to maintain central eye fixation and to respond as quickly and accurately as possible.

In the first and last blocks (36 trials each) of the experimental session, no accessory tone stimulus was presented. This was the *no-tone condition*, which served as the control condition. In this condition, the prime stimulus was presented 700 msec after the start of the trial (i.e., after the onset of the fixation cross).

In the conditions with an accessory tone stimulus, the trial structure was as follows: A trial started with the presentation of the fixation cross. After 700 msec, the accessory tone stimulus was presented, while the fixation cross remained on the screen. Tones could either be high or low in frequency (900 Hz vs. 350 Hz) and were presented for 150 msec. At varying intervals after the tone onset, the prime–target pair was presented. Importantly, the interval between tone onset and target onset varied randomly *within* blocks, and thus defined the foreperiod manipulation. Specifically, a target could appear either simultaneously with the accessory stimulus (a foreperiod of 0 msec) or 85, 250, 500, 650, or 1,000 msec after the tone onset. However, the interval between prime and target was constant (85 msec) across different foreperiod conditions.

It should be noted that with the foreperiod interval of 85 msec, the onset of the subliminal prime occurred simultaneously with the onset of the accessory tone. Because the tone and prime stimuli appeared simultaneously 700 msec after the trial began, the temporal structure of these trials did not differ from that of the trials with no accessory stimulus: In both trial types, the subliminal prime stimulus appeared 700 msec after the trial began. With the foreperiod interval of 0 msec, on the other hand, the accessory tone stimulus was presented with target onset. Therefore, these two foreperiod conditions, 0 and 85 msec, represent situations in which the onset of the accessory tone stimulus occurred simultaneously with different components of the visual stimulus presentation in the subliminal priming task.

Design. The participants started with a practice block of 18 trials. After completing this block, they were presented with the first no-tone block (36 trials), followed by three blocks (144 trials each) with accessory stimuli presented randomly at different foreperiods before the target. The last block was another no-tone block of 36 trials. Altogether, the experimental structure can be described by a 2 (target) × 3 (prime) × 2 (location) × 2 (tone) × 6 (foreperiod) design. Excluding practice trials, the participants performed 504 trials in total, including 72 without a tone.

Prime detection task. After finishing the RT task, prime visibility was assessed individually through subjective and objective

Figure 1. Experimental design of Experiments 1 and 2. Prime and target stimuli both appeared either above or below a centrally located fixation cross with an implemented constant prime–target interval of 85 msec.

measures. In a signal detection analysis, the participants were informed about the presence of the prime stimulus. Presented with 360 of the same trials as in the subliminal choice RT task, they were asked to indicate whether prime and target stimuli pointed in identical or opposite directions. As in the RT task, the prime detection task included a foreperiod manipulation that consisted of blocks of random foreperiods and blocks without an accessory tone stimulus. No error feedback was given. Those who responded with their right hand in the RT part of the experiment also used their right hand in the detection part. The “yes” and “no” responses were balanced across these participants, so that 5 responded “yes” with their right middle finger and “no” with their right index finger, and vice versa for the other 5 participants. The analogous procedure was used for the remaining participants, who had originally responded with their left hand. In case of uncertainty, the participants were instructed to respond intuitively.

Results

An outlier test, excluding all RTs that were two standard deviations above or below the mean RT, was conducted prior to the statistical analyses. It resulted in the elimination of 4.6% of trials from the data set. Error trials were also excluded from statistical analysis. Figure 2 shows RTs as a function of foreperiod and congruency.

RT analysis. A repeated measures ANOVA with the factors foreperiod (including no-tone condition) and congruency (congruent, neutral, and incongruent) revealed main effects of foreperiod [$F(6,114) = 13.11$, $MS_e = 403.42$, $p < .001$] and congruency [$F(2,38) = 331.99$, $MS_e = 642.83$, $p < .001$]. Most importantly, a significant interaction of both factors was observed [$F(12,228) = 10.43$, $MS_e = 172.28$, $p < .001$]. This means that different intervals between the onsets of the accessory stimulus and the target led to different RTs in congruent, neutral, and incongruent conditions. As can be seen in Figure 2, this is especially pronounced for RTs in congruent conditions [$F(6,114) = 24.35$, $MS_e = 282.57$, $p < .001$]. RTs in incongruent conditions, on the other hand, were not affected by varying foreperiod intervals ($F < 1$). These

results clearly show that the size of the SP effect was indeed modulated by the foreperiod interval.

Calculating planned contrasts allowed a differentiation of these findings. For this purpose, the size of priming effects (calculated by subtracting congruent RTs from incongruent RTs) was analyzed at different foreperiod intervals (Table 1). First, reliable SP effects were found at all foreperiod intervals. More interestingly, however, foreperiod conditions in which the interval between the accessory and target stimuli was 250 msec or more revealed substantially increased SP effects relative to the shorter foreperiod conditions (0 and 85 msec) and to the no-tone condition. More specifically, the SP effect at the 250-msec condition, for example, was 40 msec larger than in the 0-msec condition [$F(1,19) = 38.15$, $MS_e = 806.61$, $p < .001$], 44 msec larger than in the 85-msec condition [$F(1,19) = 47.24$, $MS_e = 826.99$, $p < .001$], and 20 msec larger than in the no-tone condition [$F(1,19) = 10.34$, $MS_e = 730.49$, $p < .01$]. The size of SP effects was also larger at the other long foreperiod intervals (500, 650, and 1,000 msec) than at the 0-msec interval [$F(1,19) = 30.69$, 32.26, and 31.37, all $ps < .001$].

At the same time, SP effects in the 0-msec foreperiod condition did not differ from those in the 85-msec condition ($F < 1$), but they were considerably reduced relative to the condition with no accessory stimulus [no tone: $F(1,19) = 8.98$, $MS_e = 872.29$, $p < .01$].

Error analysis. Participants had an average error rate of 4.2% (Figure 2). Error rates were analyzed with a repeated measures ANOVA including the factors foreperiod and congruency. Foreperiod significantly affected the error rates of participants [$F(6,114) = 4.28$, $MS_e = 27.87$, $p < .01$], and so did congruency [$F(2,38) = 22.29$, $MS_e = 77.14$, $p < .001$]. More errors were produced in incongruent than in congruent trials. Interestingly, a foreperiod $\times$ congruency interaction was also observed [$F(12,228) = 4.61$, $MS_e = 20.00$, $p < .001$]. Separate ANOVAs revealed

Figure 2. Response times (RTs), standard errors of the means, and percent errors in Experiment 1 as functions of foreperiod and congruency. Except for the no-tone condition, which was presented in single blocks at the beginning and end of the experiment, all foreperiod intervals were presented randomly.

Table 1
Effect Size of Subliminal Priming (SP, in Milliseconds)
in Experiments 1 and 2 As a Function of Foreperiod
(in Milliseconds), Including the No-Tone Condition

	Foreperiod						No Tone
	1,000	650	500	250	85	0	
Experiment 1	88.9	90.2	91.4	93.2	49.0	53.9	73.7
Experiment 2	73.1	84.0	80.2	90.9	68.7	71.2	68.0

Note—The SP effect was calculated by subtracting congruent trials from incongruent trials (all p s < .001).

that error rates were only affected in incongruent trials [$F(6,114) = 5.95$, $MS_e = 49.71$, $p < .001$], not in congruent trials ($F < 1$). Planned contrasts revealed that error rates in the incongruent conditions did not differ for the two short foreperiod conditions (0 and 85 msec, $F < 1$). However, in those conditions participants did commit more errors at long foreperiod intervals (250 msec and more) than at the two short ones. The highest level of errors occurred in the incongruent trials of the 250-msec foreperiod condition, which differed significantly from the error rates in the short conditions [$F(1,19) = 23.71$, $MS_e = 102.84$, $p < .001$, and $F(1,19) = 23.59$, $MS_e = 84.80$, $p < .001$, for the 0-msec and 85-msec conditions, respectively].

These findings indicate that the observed RT pattern, especially the significant interaction of foreperiod and congruency on RTs, cannot be explained by a speed-accuracy trade-off (SAT). Traditionally, an SAT has reflected a decrease in RTs with the cost of increased error rates. This is clearly not the case in our study. Even though there were more errors in incongruent conditions at long foreperiod intervals than at the 0-msec interval, RTs of incongruent trials did not differ among foreperiod conditions. More importantly, as mentioned above, the obtained interaction of foreperiod and congruency was due to an effect of the factor foreperiod on RTs in the congruent conditions (see Figure 2). However, the error rates in those conditions revealed no effect of foreperiod. Thus, an SAT cannot account for the finding of modulated SP effects due to foreperiod manipulations (for a further discussion concerning the role of the SAT, see the General Discussion section).

Prime detection task. After completing the RT part, participants performed a signal detection task to test prime visibility. No participant reported having noticed the masked primes. Objective measures of prime visibility were obtained in two steps. First, we analyzed the individual prime visibility for each participant averaged across all conditions by calculating the mean d' value. "Yes" responses in congruent trials were counted as hits, and false alarms consisted of "yes" responses in neutral trials (see also Klotz & Neumann, 1999). The overall d' value in Experiment 1 was 0.149. Subsequent statistical testing revealed that the d' value was not significantly different from zero ($\chi^2 = 0.687$, $p > .20$).

Subsequently, we performed a regression analysis, as proposed by Draine and Greenwald (1998; see also Greenwald et al., 1996; Greenwald, Klinger, & Schuh, 1995). The intercept in a regression analysis represents the value of the dependent variable if the independent variable

is at zero. Therefore, in the present analysis the intercept predicts the amount of SP effect when d' is equal to zero (e.g., under conditions of zero visibility). An intercept that is significantly different from zero indicates significant priming even under conditions of zero visibility of primes (see Greenwald et al., 1995). In Experiment 1, the intercept of the regression (23.91) was significantly greater than zero [$t(19) = 18.45$, $p < .001$], indicating that a significant SP effect was associated with zero visibility of the prime stimulus.

In order to determine whether individual differences in prime visibility substantiated differences in SP effect sizes, individual SP effects were regressed onto individual d' values (independent variable). As suggested by Draine and Greenwald (1998), we calculated a subliminal priming index for each participant: index = $100 \times (\text{mean RT for incongruent trials} - \text{mean RT for congruent trials}) / (\text{mean RT for congruent trials})$. This index was plotted in relation to individual d' values (see Figure 3). A linear regression analysis of our data revealed no significant correlation between d' and the index [$r = -.160$; $F(1,19) = 0.476$, $p = .499$]. Thus, individual prime visibility did not influence the size of SP effects.

Discussion

Experiment 1 was conducted to test whether the size of SP effects can be modulated by a gradual manipulation of participants' preparation for stimulus processing. Different levels of preparation were achieved through presenting the target stimulus at various intervals after the onset of an accessory tone stimulus.

First, we can state that independent of the foreperiod manipulation, overall RTs were generally shorter in congruent and longer in incongruent conditions than in the neutral condition. Thus, regardless of whether an accessory stimulus was present or not, and regardless of the interval with which a target followed an accessory stimulus, SP effects were observed.

The more interesting question, however, was whether different foreperiod intervals cause differences in the size of the SP effects. The most remarkable result concerning this question is expressed by an interaction between foreperiod and congruency on the participants' RTs. In line with our predictions, the foreperiod manipulation modulated the size of the SP effect. More specifically, when the accessory stimulus preceded the target stimulus by 250 msec or more, SP effects were about 75% larger than SP effects at short foreperiod intervals and more than 25% larger than SP effects in the no-tone condition. Thus, it seems that at foreperiod conditions of 250 msec and more, participants were able to build up an appropriate level of preparation for processing the upcoming target stimulus. This resulted in an increase of the SP effect at longer foreperiods (≥ 250 msec) in comparison with the shorter ones (< 250 msec). The present results are also in line with our prediction that a foreperiod of about 250 msec represents an optimal time interval for building up preparation (see also Gottsdanker, 1980) because at this interval the SP effect was largest relative to the other foreperiod conditions.

Figure 3. Individual d' values of participants in Experiment 1. d' values are plotted in relation to an index reflecting the amount of subliminal priming.

Our findings suggest an attentional modulation of the size of SP effects (Klotz & Neumann, 1999; Vorberg et al., 2003) and go beyond those of previous studies with fixed preparation intervals. Also, our results clearly extend the findings of Naccache et al. (2002), who demonstrated vanishing SP effects in conditions of unpredictable target presentation.

As a further interesting result, the size of the SP effect was reduced in conditions with short foreperiod intervals (0 and 85 msec) relative to the condition without an accessory tone stimulus (no-tone condition). At least two explanations for this result are possible: One focuses on preparational components to explain the reduced SP effects, whereas an alternative explanation highlights the influence of interference on the size of SP effects at short foreperiod intervals.

Concerning the first explanation, Karlin (1966) assumed that preparation develops in a ballistic curve starting with the onset of an accessory stimulus. Therefore, it seems plausible that at foreperiod intervals of 0 and 85 msec in Experiment 1, the actual target stimulus appeared too early for preparation to reach its peak level (Bertelson, 1967). Such a *structural limitation* would be in accordance with Soetens (1998), who obtained a reduced Simon effect when the interval between the response in trial $n-1$ and the stimulus onset in trial n was very short (50 msec) in comparison with a delayed stimulus onset (1,000 msec). Gottsdanker (1980) came to a similar conclusion: Impaired performance is not surprising at intervals less than 250 msec because participants are then not maximally prepared for task processing. Even though the mere presence of an accessory stimulus may support preparational processes, in this view the observed decrement of SP effects at short foreperiod intervals would be due to a suboptimal level of preparation at the time of target appearance. On the other hand, the SP effect at long foreperiods would reach its optimal size because of

sufficient preparation time. However, such a view may not be complete. Structural limitations of preparation may explain differences in SP effects between short and long foreperiod conditions, but they fail to explain the observed reduced size of the SP effects at short (0- and 85-msec) foreperiod conditions relative to the no-tone condition. It should be noted that in the 85-msec condition, the temporal structure of a trial was identical to the structure of trials in the no-tone condition. Thus, in these two conditions participants had a similar amount of time for developing task preparation. In our view, besides the structural limitations mentioned above, *strategic influence* evoked by the distribution of the foreperiod intervals may also have affected the development of preparation at short versus longer foreperiod intervals.

More specifically, except for the no-tone condition, which was presented in two separate blocks of trials, all variations of foreperiod intervals between the accessory and the target stimuli were randomly mixed within blocks. Thus, in these blocks the participants did not know the precise duration of the time interval between the accessory stimulus and the subsequent target stimulus. However, the frequency of stimulus presentation was equal across the different foreperiod intervals, thus creating an *aging foreperiod distribution* (Niemi & Näätänen, 1981; Schubert, 1999). It is well known that in aging foreperiod distributions, the conditional probability of target presentation increases with increasing foreperiod duration, thus affecting the degree of participants' stimulus expectations at different foreperiod intervals (Schubert, 1999). Participants can use the information conveyed by the aging foreperiod distribution in order to estimate the time of target onset and, furthermore, to strategically prepare for task processing in advance of the target stimulus presentation. Since the conditional probability is low at short foreperiods and approaches 1 at the longest foreperiod, the level of task preparation should consequently vary among dif-

ferent foreperiods, depending on the different degrees of stimulus expectation. Such strategic preparation effects, which might be accompanied by a varying degree of the precision of the target expectation at different foreperiods, could therefore have additionally affected the size of the resulting SP effect.

In summary, according to the preparation assumption, reduced priming effects at short foreperiod intervals are a combined consequence of *strategic* and *structural limitations* of the preparation process.

The second assumption that may explain the reduced size of SP effects at short foreperiod intervals does not focus on preparational effects at all. The decrement of subliminal priming in these conditions might have been caused by interference due to the simultaneous processing of the accessory stimulus and of components of the visual task. Note that the accessory stimulus appeared at prime onset in the 85-msec foreperiod interval and at target onset at the 0-msec interval, respectively. According to the interference assumption, the presentation of a sudden tone simultaneously with processing in the visual task would interfere with processes triggered by the subliminally presented prime, which might then reduce SP effects. That such a view is not trivial can be seen in studies of visual attention investigating the impact of an abrupt onset of stimulus presentation on task performance (Jonides & Yantis, 1988; Yantis, 1993; Yantis & Jonides, 1984). These studies have demonstrated that the sudden onset of a visual stimulus is associated with an automatic capture of visual attention. Hein and Schubert (2004) showed the harmful effects of such attentional capture in dual-task situations (see also Ansorge, 2004). Furthermore, recent research on attentional capture has demonstrated similar results in the auditory domain (Dalton & Lavie, 2004), confirming the assumption that task-irrelevant tones are capable of capturing attention. As a result of this attentional capture, performance in the primary task may be harmed by the presentation of the irrelevant stimulus.

In Experiment 2, we tested whether the decreased size of the SP effect in the 85- and 0-msec foreperiod conditions was due to limitations of the preparation processes or to interference between the accessory tone stimulus and processing of components of the visual task.

EXPERIMENT 2

The aim of Experiment 2 was to investigate possible explanations for the observed reduction of the SP effect at short foreperiods. For that purpose, we presented the different foreperiod conditions *in separate blocks*, rather than randomly within blocks.

A blocked presentation of different foreperiod intervals can be used to differentiate between the preparation and interference assumptions proposed in the Discussion section of Experiment 1. According to the preparation assumption, insufficient preparation for upcoming stimulus processing is responsible for the decreased SP effects at short foreperiods. The insufficient preparation is due to strategic influences on participants' preparation that are caused by the use of an aging foreperiod distribution.

Presenting each foreperiod condition in separate blocks should eliminate such strategic biases. Each block of a particular foreperiod condition would then allow participants to adapt to the time characteristics of the trial structure, so the accessory tone stimulus can be used for the precise prediction of target onset at each foreperiod. If strategic components of an aging foreperiod distribution are indeed responsible for the decreased SP effects in short foreperiod conditions, then these differences should be eliminated in Experiment 2.

According to the interference assumption, the reduced SP effects at short foreperiod conditions are due to interference when an accessory stimulus is presented while components of the visual task are simultaneously being processed. If an abrupt onset of the accessory stimulus interferes with visual task processing, and thus impairs SP effects, then one would expect that this interference would also be present at short foreperiod conditions when all foreperiod conditions are presented in separate blocks. Therefore, the interference assumption still predicts decreased SP effects in short foreperiod conditions, as was observed in Experiment 1.

Note that the use of a blocked design also allows examination of whether the main findings of Experiment 1 can be replicated with a different design. Such a replication is important because the present findings represent a new empirical phenomenon that needs further testing.

Method

Participants. Twenty-four undergraduate students of Humboldt University participated. All had normal or corrected-to-normal vision and were not informed about the hypothesis of the experiment.

Apparatus. See Experiment 1.

Procedure. This was similar to the procedure in Experiment 1, except that the factor foreperiod was realized in a blocked design. The experiment consisted of six blocks, each containing a constant accessory stimulus–target interval of either 0, 85, 250, 500, 650, or 1,000 msec and a single block without an accessory stimulus. The number of trials and the trial duration in each foreperiod condition were identical to those in Experiment 1. The order of all blocks was randomized between participants. After the experiment, a prime detection task (including the same foreperiod manipulation) consisting of 252 trials was conducted in order to investigate prime visibility.

Results

The same outlier procedure as in Experiment 1 was applied to the data of Experiment 2. This resulted in the exclusion of 4.3% of trials from the RT data analyses.

RT analysis. Results are presented in Figure 4. A repeated measures ANOVA, including foreperiod and congruency as independent factors, revealed a main effect of congruency [$F(2,46) = 506.78, MS_e = 489.74, p < .001$]. The factor foreperiod, on the other hand, was not significant [$F(6,138) = 2.01, MS_e = 1,297.73, p = .068$]. This might be due to the fact that the ITI was kept constant in our experiments. In traditional foreperiod studies, the ITI is varied randomly between trials to reinforce the importance of the accessory stimulus (e.g., Müller-Gethmann, Ulrich, & Rinkenauer, 2003).

However, there was a significant foreperiod $\times$ congruency interaction on RTs [$F(12,276) = 2.59, MS_e = 197.81, p < .01$]. Moreover, similar to Experiment 1, the

Figure 4. Response times (RTs), standard errors of the means, and percent errors in Experiment 2 as functions of foreperiod and congruency. Each foreperiod interval (including the no-tone condition) was presented in a separate block.

foreperiod manipulations affected RTs mainly in congruent conditions [$F(6,138) = 3.84$, $MS_e = 579.78$, $p < .01$], whereas RTs in incongruent conditions were not influenced by different foreperiods ($F < 1$). The observed interaction in the blocked design of Experiment 2 indicates that the modulation of SP effects by different foreperiod intervals is a replicable phenomenon that is not specific to the random-foreperiod manipulation of Experiment 1.

Planned contrasts showed that the size of the SP effects was again much larger at long than at short foreperiod intervals. This difference was especially pronounced in the foreperiod interval 250 msec, where SP effects were about 20 msec larger than with the 0-msec foreperiod [$F(1,23) = 11.61$, $MS_e = 799.56$, $p < .01$] and about 22 msec larger than in the no-tone condition [$F(1,23) = 11.34$, $MS_e = 1,103.84$, $p < .01$]. An increased SP effect relative to the 0-msec condition was also found for the 650-msec foreperiod [$F(1,23) = 5.28$, $MS_e = 751.52$, $p < .05$], with a slight tendency in the 500-msec condition [$F(1,23) = 2.32$, $MS_e = 837.91$, $p = .141$]. No significant difference was observed when comparing the size of the SP effect at the longest foreperiod interval (1,000 msec) and at the shortest (0 msec; $F < 1$). Furthermore, the size of the SP effects did not differ for the 85- and the 0-msec foreperiod intervals ($F < 1$).

In particular, the SP effects in the 85- and 0-msec foreperiod conditions *did not differ* in size relative to the effect in the no-tone condition (both F s < 1) but were considerably smaller than SP effects in long foreperiod conditions (see above). In other words, the observed interaction (foreperiod $\times$ congruency) is based solely on increased SP effects in conditions with foreperiod intervals from 250 to 650 msec. This result clearly discounts an interference hypothesis, because no impairment of subliminal priming was observed in short foreperiod conditions.

In order to back up the assumption that the size of SP effects differs at various foreperiods between Experiments 1

and 2, a repeated measures ANOVA was run including the factors foreperiod (6 levels) and congruency (2 levels), with experiment (2 levels) as an additional between-subjects factor. Whereas the main effects in the ANOVA did not vary between the experiments, the most important result was that the interaction between foreperiod and congruency [$F(5,210) = 19.37$, $MS_e = 1,207.66$, $p < .001$] appeared to be affected by experiment, resulting in a significant three-way interaction [$F(5,210) = 5.61$, $MS_e = 215.11$, $p < .001$]. A further analysis was conducted to compare SP effect sizes between Experiments 1 and 2 only for the three shortest foreperiod conditions (0, 85, and 250 msec). Here, the interaction between congruency and experiment demonstrated that SP effects were generally larger for Experiment 2 (77 msec) than for Experiment 1 (66 msec) [$F(1,42) = 5.85$, $MS_e = 374.71$, $p < .05$]. Once again, however, the interaction between foreperiod and congruency [$F(2,84) = 33.06$, $MS_e = 796.34$, $p < .001$], as well as the three-way foreperiod $\times$ congruency $\times$ experiment interaction, was again significant [$F(2,84) = 3.66$, $MS_e = 217.85$, $p < .05$].

Error analysis. Participants had a mean error rate of 3.6%. A repeated measures ANOVA including the factors congruency and foreperiod showed that the error rate was affected by congruency [$F(2,46) = 29.5$, $MS_e = 57.8$, $p < .001$]. On the other hand, the main effect of foreperiod was not significant [$F(6,138) = 2.0$, $MS_e = 13.7$, $p = .072$]. The same holds true for the interaction between foreperiod and congruency, which also failed to reach significance [$F(12,276) = 1.43$, $MS_e = 15.1$, $p = .151$]. It is interesting to note that despite the lack of a significant interaction, visual inspection suggests that most errors occurred in the incongruent 250-msec condition (see also Figure 4). Calculated contrasts revealed that error rates in this condition were significantly increased in comparison with, for instance, the 0-msec foreperiod condition [$F(1,23) = 5.41$, $MS_e = 48.28$, $p < .05$]. This finding parallels those of Experiment 1.

Prime detection task. Prime signal detection performance of participants was analyzed with the procedure described for Experiment 1. None of the participants reported having noticed the prime stimuli. The signal detection analysis performed on the data in the prime signal detection task revealed an overall d' value of 0.097, which did not differ significantly from zero ($\chi^2 = 0.254$, $p > .20$).

Furthermore, the intercept of the regression analysis (24.36) was significantly larger than zero [$t(23) = 16.70$, $p < .001$], indicating that the SP effect was significant even with zero visibility of the prime stimulus. In order to assess the relation between the size of the SP effect and the individual d' value, the index of the amount of priming was plotted in relation to individual performance in the prime detection task (see Figure 5). A linear regression analysis revealed no correlation between the individual priming index and the corresponding d' values [$r = -.095$; $F(1,23) = 0.200$, $p = .659$].

Discussion

In Experiment 2, the foreperiod manipulation was realized in a blocked design. As in Experiment 1, the SP effect in Experiment 2 was larger at foreperiods of 250 msec and more than in the shorter foreperiod conditions. In addition, the SP effect was most enhanced in the 250-msec foreperiod condition, suggesting that this interval of optimum preparation (Gottsdanker, 1980) leads to a maximum SP effect with the present experimental materials. Taken together, the present findings suggest that a manipulation of the SP effect size by administering different foreperiod intervals between an accessory stimulus and the imperative stimulus is a replicable phenomenon.

However, Experiment 2 was designed to test the preparation and interference assumptions proposed to explain the reduced SP effects at short foreperiod intervals in Experiment 1. Contrary to Experiment 1, in Experiment 2

the SP effects at short foreperiod intervals did not differ from those in the no-tone condition. This result clearly disproves the interference assumption.

In contrast, the present results are consistent with the preparation assumption. According to that assumption, the reduction of the SP effects in Experiment 1 at short foreperiods was a consequence of the aging foreperiod distribution. This specific type of foreperiod distribution causes a strategic influence on participants' stimulus expectations, which increase with increasing foreperiods, and therefore differ between the foreperiod intervals. The blocked design of Experiment 2 was used to eliminate this strategic influence of an aging foreperiod distribution, since presenting each foreperiod interval in a separate block allowed participants to adjust to the temporal structure of the specific foreperiod. In other words, participants in Experiment 2 were able to make use of the accessory tone stimulus as a temporal predictor of target onset with 100% validity within a given block. This enabled a top-down orientation of attention by precisely calibrating the time window in which the target was expected to occur (Miniussi, Wilding, Coull, & Nobre, 1999; Naccache et al., 2002). Because differences in SP effects between the short foreperiod and no-tone conditions were completely eliminated in Experiment 2, those differences can be attributed to strategic biases due to specific aging foreperiod distributions in Experiment 1, as well as to structural influences.

GENERAL DISCUSSION

In two experiments, different levels of preparation were implemented by presenting an accessory stimulus at various intervals before the target stimulus in a subliminal priming task. The results of this foreperiod manipulation were straightforward; in both experiments, we obtained a clear influence of the foreperiod condition on the resulting

Figure 5. Individual d' values of participants in Experiment 2. d' values are plotted in relation to an index reflecting the amount of subliminal priming.

size of the SP effects. In particular, we found increased SP effects when the accessory stimulus preceded target onset by 250 msec or more, relative to both a condition without an accessory stimulus and conditions with shorter foreperiods. Moreover, with an aging foreperiod distribution (Experiment 1), we even found a decrease in the size of the SP effect in short foreperiod conditions (≤ 85 msec) in comparison with a control condition without an accessory stimulus.

To our knowledge, no other study has shown a similar modulation of SP effects related to preparational or attentional manipulations. Although Naccache et al. (2002) argued that SP effects are observable under conditions of predictable but not of nonpredictable target onset, our findings suggest that the final size of SP effects depends on how well participants can prepare for the time of target appearance. A modulation of the preparation level directly influenced the final size of the SP effect in subliminal priming tasks. This finding suggests a fine-grained relation in a subliminal priming task between the temporal dynamics of the preparation processes (before target presentation) and those of the response processes triggered by the target. Since previous studies on subliminal response priming did not systematically manipulate the foreperiod between an accessory stimulus and the target stimulus, such relations have never before been observable. Whereas the results in Experiment 1 might suggest a categorical effect modulation, the results of Experiment 2 demonstrate that the pattern of modulation appears more complex (see also Table 1), indicating a gradual modulation of SP effects as a function of the accessory stimulus foreperiod. Further research using even more fine-grained foreperiod manipulations than the one in the present study may be informative about the specific type of effect modulation in subliminal priming tasks.

The present findings extend the results of a recent study by Anson (2004). That study showed that the SP effect can be modulated when another task is performed in addition to the subliminal priming task. According to Anson, the decrease of the SP effect size in such dual-task situations is caused by an imperfectly prepared action plan in the SP task resulting from the processing of a concurrent action plan. However, the findings of the present Experiment 2 rule out such an interference explanation for the observed modulation of the SP effect under short foreperiod conditions. Instead, the findings of Experiment 2 suggest that insufficient preparation, due to an insufficiently precise estimation of the time of target onset, caused the observed decrease in the SP effect in Experiment 1. Therefore, both our study and Anson's focused on different mechanisms that could potentially influence the size of the SP effect; whereas Anson showed the influence of additional cognitive processing on the size of the SP effect, our study suggests a gradual influence of temporal preparation on the processes in the subliminal priming task. Our findings, therefore, point to a close relation between the way attention modulates the processing of both target information and subliminally presented prime information. The latter conclusion shows that in order to better understand the principles and mechanisms of nonconscious information

processing in subliminal priming tasks, it is important to understand the attentional characteristics of conscious information processing going on during a subliminal priming task (Klotz & Neumann, 1999; Naccache et al., 2002).

Accessory Stimuli and Their Influence on Mechanisms in Subliminal Response Priming

Given the clear evidence about the modulatory influence of an accessory stimulus on the size of the SP effect, it is important to elaborate the possible mechanism(s) responsible for that influence. In earlier theories, the effects of an accessory stimulus were often associated with automatic stimulus-driven mechanisms. According to Posner (1978), an accessory stimulus speeds up voluntary keypress reactions, but at the cost of an increased error rate (e.g., in the form of an SAT). In case of an SAT, one would expect higher error rates when RTs were fastest—for instance, in congruent trials in the 250-msec foreperiod condition. However, in the present experiments, error rates did not differ in congruent conditions across foreperiod intervals, which excludes explanation of our results by an SAT.

Although an SAT seems not to allow an appropriate understanding of the present findings, response activation mechanisms may be responsible for the observed results. Studies using electrophysiological parameters, such as the lateralized readiness potential (LRP), have shown that foreperiod manipulations affect RTs and the stimulus-to-LRP interval, but not the LRP-to-keypress interval (for an overview, see Hackley & Valle-Inclán, 2003). These results indicate that an accessory stimulus affects early processes (i.e., premotor stages) rather than speeding up the motor stages of the response process (Hackley & Valle-Inclán, 1998, 1999; Müller-Gethmann et al., 2003; but see Sanders, 1980). A number of studies (e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Hackley & Valle-Inclán, 1999) suggest that preparation induced by an accessory stimulus in simple sensorimotor tasks especially affects response activation processes but not motor execution.

In addition, Coles et al. (1985) assumed that the presentation of an accessory stimulus would increase the level of activation in so-called response counters. The term *response counter* stems from evidence accumulation models, which assume that the presentation of a stimulus goes along with the parallel accumulation of evidence in different response counters (Logan & Gordon, 2001; Ratcliff, 1978; Ratcliff & McKoon, 1988). A response is then initiated as soon as the difference between the accumulated evidence for two opposite responses exceeds a critical threshold. In particular, Coles et al. proposed that an accessory stimulus primes all responses *nonspecifically* (Posner, Klein, Summers, & Buggie, 1973). Thus, the presentation of an accessory stimulus should increase the amount of initially accumulated response activation, irrespective of the specific response alternative, thus reducing the distance to the critical response threshold for any alternative.

In the present paradigm, the specific effects of the accessory stimulus on response activation must be considered in addition to those associated with effects of the prime stimulus on response activation. Most models of

subliminal priming assume that subliminal prime stimuli modulate the activation level of a required response (Dehaene et al., 1998; Leuthold & Kopp, 1998; Neumann & Klotz, 1994). For example, Vorberg et al. (2003) proposed an evidence accumulation mechanism similar to that of Coles et al. (1985), in which response counters collect evidence for the prime and the target. The authors assumed that subliminal prime stimuli bias the accumulators by decreasing the distance of the correct response to the threshold in congruent trials and increasing the distance in incongruent trials.

Combining the assumptions of this model with the proposed influence of an accessory stimulus provides a clue as to how the presentation of an accessory stimulus might potentially modulate SP effects. As stated before, not only the prime but also the accessory stimulus is supposed to reduce the distance to the response threshold, because both increase the initial level of evidence in the response counters. The increase of evidence, however, is nonspecific, and thus involves all response counters the same way (Coles et al., 1985). In this way, both the accessory stimulus and the prime lead to benefits in congruent trials, because both cause a reduction of the distance to the response threshold in the direction of the correct response. In incongruent trials, on the other hand, the accessory and prime stimuli both drive the accumulation rate farther away from the correct response, in the direction of the incorrect response threshold. Therefore, an accessory stimulus should speed up RTs in congruent conditions, but it should slow down RTs in incongruent conditions relative to conditions without an accessory stimulus.

This explanation is mostly consistent with the present data, suggesting a strong speed up of congruent responses when the foreperiod interval increases from 0 or 85 msec in duration to 250 msec. Nevertheless, on first glance, one finding in the present data set seems to expose difficulties for the proposed model. That is, the RT analyses in both experiments did not reveal any slowing of incongruent RTs resulting from presentation of the accessory stimulus.

How can the latter finding be reconciled with the proposed mechanism for the influence of an accessory stimulus? A first clue appears in the analysis of error rates in the incongruent conditions. As mentioned before, most errors were committed in incongruent trials under conditions of maximum preparation. Foreperiod conditions providing a maximum level of preparation should go along with the highest level of initially accumulated evidence through an accessory stimulus. The presentation of an *incongruent* prime stimulus will then drive the accumulation of response activation even farther toward the threshold of the prime-indicated response alternative, so that execution of the incorrect response is more difficult to stop than in conditions with a lower initial level of accumulated evidence (e.g., conditions of low preparation). This, in particular, should lead to an increased error rate for incongruent trials under foreperiod conditions providing maximum preparation, which is precisely what we found in the present study: The number of errors was especially increased for incongruent trials at the 250-msec foreperiod condition in both experiments. Thus, the fact that we did not find

any RT slowing with increasing foreperiod in incongruent trials can be explained by an increased error rate, which is associated with overshooting response activation in the wrong direction under conditions of optimal preparation.

It is worthwhile to stress that, whereas our findings support the idea that an accessory stimulus affects SP effects via top-down mechanisms on response activation, they are at odds with accounts assuming that the accessory stimulus has a pure bottom-up-driven influence. According to the latter assumption, the presentation of an accessory stimulus is simply associated with an improved immediate arousal (Sanders, 1980) that specifically affects response force and speed of late motor execution processes. Crucially, this influence is expected to be most effective under foreperiod conditions of less than 500 msec, conditions in which the accessory stimulus may directly affect the processing of the imperative stimulus via bottom-up mechanisms. However, according to the immediate-arousal account, we should have found the most effective influence of the accessory stimulus at rather short foreperiods. In fact, we found this influence to be most effective at rather long foreperiod intervals. Therefore, accounts like the immediate-arousal theory (e.g., Bertelson & Tisseyre, 1969; Sanders, 1980, 1983) or accounts based on theories of multisensory integration (e.g., Bernstein et al., 1970; Stein & Meredith, 1993) appear less likely to explain the present findings.

The results of the present study, however, leave open the question of whether accessory stimuli must necessarily affect the size of SP effects bidirectionally—that is, increasing the effects at long foreperiods and decreasing the effects at short ones, relative to a no-tone condition. It could be assumed that the observed modulation of the SP effect reflects simply a reduction of its size at short foreperiods, in comparison with the regular size at long foreperiods. Such an argument might be derived if the present size of the SP effect were compared with a predicted size based on the model of Vorberg et al. (2003). According to their model, the regular size of SP effects corresponds to the temporal separation between the prime and the target onset. Indeed, in both of our experiments, SP effects for the longer foreperiods (250–1,000 msec) virtually matched Vorberg et al.'s predicted value of 85 msec (see Table 1). At the same time, SP effects for shorter foreperiods (0 and 85 msec) seemed to be reduced in comparison with this predicted effect size. This is a slightly different perspective on the present data, and according to it, participants may have simply waited for the tone to occur before starting to accumulate prime or target information.³ The accessory stimulus may have opened a gate that allowed a passing of information from prime to target stimulus. With short foreperiods, this gate might not have been fully open at the time of prime onset, which might have in fact reduced the impact of the prime stimulus in affecting target processing. Although our data are partially consistent with such an account, additional assumptions would be necessary to explain our whole data pattern. In particular, it is problematic for a pure waiting explanation that the SP effect in conditions *without* an accessory stimulus (presented in separate blocks) also undershot the

predicted value of 85 msec (74 and 68 msec for Experiments 1 and 2, respectively), even though in that condition there was no need to wait for a tone stimulus at all. In addition, a pure waiting assumption cannot explain the fact that we found a difference in the SP effect sizes at short foreperiods between Experiments 1 and 2. This difference points to additional strategic influences on the preparation process that depended on the predictability of the target presentation after tone onset.

Prime Visibility

Finally, we discuss a potential influence of prime visibility on the modulation of SP effect sizes. Prime visibility was tested by calculating d' values for each participant and condition. The findings in these prime detection analyses revealed no correlation between the individual d' parameters and the corresponding sizes of the SP effects. This suggests that the size of the SP effect was not modulated by prime visibility, which is consistent with the findings of Vorberg et al. (2003). However, prime visibility may be sensitive to variations in temporally focused attention. McDonald, Teder-Sälejärvi, and Hillyard (2000), for example, argued that perceptual sensitivity (d') in luminance detection under conditions of masked target presentation can be increased by a preceding tone stimulus. In order to test for such a possibility, we conducted post hoc analyses to assess whether the foreperiod manipulation affected the visibility of the prime stimulus. The d' values were entered into a nonparametric repeated measures analysis (i.e., a Friedman test) with foreperiod as the main factor. For Experiment 1, the analysis revealed that the distribution of d' did not differ between the foreperiod conditions ($p = .551$; the d' s were 0.05, -0.01 , 0.16, -0.12 , 0.11, 0.27, and 0 for the 0-, 85-, 250-, 500-, 650-, and 1,000-msec foreperiods and for no tone, respectively).⁴ This conclusion was further confirmed by the results for Experiment 2 ($p = .952$; d' s of 0.08, 0.07, 0.03, 0.13, 0.13, 0.22, and 0.14, respectively). Thus, these findings argue against an influence of the foreperiod manipulation on prime visibility.

However, although our prime detection task was similar to standard procedures for measuring prime visibility in situations including three prime types (congruent, neutral, and incongruent; Neumann & Klotz, 1994), one could still argue that the cognitive demands in the detection task were much harder than in the RT task (Reingold & Merikle, 1988).⁵ For example, in our study the detection task required participants to compare *two* successive stimuli (arrows in the same or different directions), whereas the RT task required them simply to classify *one* stimulus (left or right). Thus, the larger cognitive demands in the prime detection versus the RT task may have obscured a possible influence of the accessory stimulus on d' values.

In order to test for such a possibility, we investigated the performance of 10 additional participants in a further prime detection task. In this task, neutral stimuli were excluded from the stimulus materials and participants were asked to simply indicate whether a prime arrow pointed to the left or the right. This simplified prime detection task was intended to yield a higher d' performance than

the standard prime detection task of Experiments 1 and 2, which is exactly what we found. Most importantly, however, d' values were still not modulated by the foreperiod manipulation ($p = .621$; 0.62, 0.66, 0.82, 0.84, 0.58, 0.81, and 0.87 for the 0-, 85-, 250-, 500-, 650-, and 1,000-msec foreperiods and for no tone, respectively).

Thus, we conclude that in the present study the observed modulation of the size of SP effects seems not to have been mediated by an influence of the accessory stimulus on prime visibility. Instead, the accessory stimulus rather directly influenced the response activation processes evoked by the presentation of the prime stimulus. Therefore, we think that the degree of prime visibility was a negligible factor in the observed modulatory influence of accessory stimuli on SP effects.

To summarize, the present results clearly demonstrate that different levels of preparation are capable of modulating the size of SP effects. This result is important because it extends the findings of Naccache et al. (2002) by showing that attention allocation to sensory information is not only a prerequisite for the occurrence of subliminal priming, and moreover by indicating that specific attentional modulations may even enlarge the size of the subliminal priming effect. Therefore, our results provide further evidence against an assumption of purely automatic and attention-independent processing of nonconscious information. Subsequent research may further elucidate the effects of accessory stimuli on nonconscious information processing by focusing, for example, on masked priming effects that are not associated with response-related "motor" stages (e.g., semantic priming).

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NOTES

1. In the foreperiod literature, the stimulus preceding the task has usually been termed the *warning signal*. These studies have quite often involved foreperiod intervals of up to several seconds. Studies that have implemented relatively short foreperiod intervals have used the term *accessory stimulus* (see also Hackley & Valle-Inclán, 1999; Welch & Warren, 1986). We are aware of the fact that warning signals and accessory stimuli can produce dissociating effects (e.g., Low, Larson, Burke, & Hackley, 1996). However, there are numerous reasons to assume that

the effects of warning signals and accessory stimuli accord with the same locus of action (Hackley & Valle-Inclán, 2003). Because the range of our foreperiod manipulation did not exceed 1,000 msec, and for reasons of simplicity when reviewing the foreperiod literature, we preferred the term *accessory stimulus* in our study.

2. Note that in their nonpredictable target condition (fixed prime and variable target), Naccache et al. (2002) manipulated target onset by using three different random SOAs (i.e., 810, 1,094, and 1,449 msec). However, although the prime stimulus in Naccache et al.'s study was always presented 710 msec after trial onset, a variable prime–target interval (100, 384, or 739 msec) was created *in addition to* the temporal manipulation of the target onset. Thus, in Naccache et al.'s nonpredictable target condition, the variable target onset was confounded with a variable prime–target interval. Therefore, their study is not informative about *gradual* preparation effects based on the foreperiod manipulation. In

contrast, the present experimental approach (see below) allows us to investigate the impact of different levels of preparation for target onsets on the size of SP effects.

3. We thank an anonymous reviewer for pointing out this alternative explanation.

4. Because of a technical problem, the assignment of d' values to the separate foreperiod conditions was only possible for 11 participants in Experiment 1: A failure in the experimental equipment resulted in the nonrecording of information identifying the specific foreperiod condition in the results files of the remaining 9 participants. Therefore, this post hoc analysis utilized the data sets of only 11 participants.

5. We thank an anonymous reviewer for mentioning this possibility.

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