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Perceptual latency priming by masked and unmasked stimuli: Evidence for an attentional interpretation

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Abstract Four experiments investigated the influence of a metacontrast-masked prime on temporal order judgments. The main results were (1) that a masked prime reduced the latency of the mask's conscious perception (perceptual latency priming), (2) that this effect was independent of whether the prime suffered strong or weak masking, (3) that it was unaffected by the degree of visual similarity between the prime and the mask, and that (4) there was no difference between congruent and incongruent primes. Finding (1) suggests that location cueing affects not only response times but also the latency of conscious perception. (2) The finding that priming was unaffected by the prime's detectability argues against a response bias interpretation of this effect. (3) Since visual similarity had no effect on the prime's efficiency, it is unlikely that sensory priming was involved. (4) The lack of a divergence between the effects of congruent and incongruent primes implies a functional difference between the judgments in the temporal order judgment task and speeded responses that have demonstrated differential effects of congruent and incongruent primes (e.g., Klotz & Neumann, 1999). These results can best be interpreted by assuming that the prime affects perceptual latency by initiating a shift of attention, as suggested by the Asynchronous Updating Model (AUM; Neumann 1978, 1982).

Perceptual latency priming by metacontrast-masked stimuli: Evidence for an attentional interpretation

Metacontrast is a version of visual backward masking in which the mask is presented laterally adjacent to the masked stimulus. Metacontrast may produce strong masking, and the masking function has typically the shape of an inverted U, with its maximum at a stimulus onset asynchrony (SOA) around 40–60 milliseconds (ms) (Bachmann, 1994; Breitmeyer, 1984; Breitmeyer & Ogmen, 2000; Enns & Di Lollo, 1997; Neumann & Müsseler, 1990). Although the discovery of metacontrast dates back to the early twentieth century (Stigler, 1910; Werner, 1935), massive research started only in the 1960s, with a focus on possible mechanisms that produce the masking (e.g., Bridgeman, 1971; Breitmeyer & Ganz, 1976; Neumann, 1978; Turvey, 1973; Weisstein, 1966). More recently, there has been a renewed interest in metacontrast, but with a different emphasis. While efforts to understand its functional basis have continued (e.g., Breitmeyer & Ogmen, 2000; Francis, 1997), most of the recent research has used metacontrast as a methodological tool.

One reason for this shift in research emphasis has been the finding that metacontrast is an efficient means for excluding a stimulus from conscious perception without obliterating its effects on processes that go on without awareness. Evidence for effects of masked stimuli (primes) has been found at various levels of information processing, such as motor preparation (e.g., Eimer & Schlaghecken, 1998; Jaskowski, van der Lubbe, Schlotterbeck, & Verleger, 2002; Leuthold & Kopp, 1998; Klotz & Neumann, 1999; Klotz & Wolff, 1995; Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), perceptual processing (e.g., Bar & Biederman, 1998) and semantic processing (e.g., Damian, 2001; Dehaene, Naccache, Le Clec'H, Koechlin, Mueller, Dehaene-Lambertz, van de Moortele, & Le Bihan, 1998). The purpose of the present research was to investigate the possible ability of a masked prime to reduce the *latency of the conscious perception* of the masking target.

There is evidence that such an effect might exist. One of the earliest demonstrations of a version of the metacontrast dissociation was a study by Fehrer and Raab (1962; see also Fehrer & Biederman, 1962; Schiller &

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Smith, 1966). These authors found that simple response time (RT) to metacontrast-masked stimuli was unaffected by masking. They interpreted this finding as indicating that a motor response could be activated without the conscious perception of the stimulus. However, their data lend themselves to an alternative explanation: The masked prime might have facilitated the perceptual processing of the masking target, which could have resulted in a shorter latency of its conscious perception (Neumann, 1982). According to this account, it was not the *masked prime* that triggered the motor response, but the *consciously perceived masking target*. There was, corresponding to this explanation, no direct specification of motor parameters by the masked prime, but a reduction of the perceptual latency of the mask, which would indirectly have led to a shorter RT.

This interpretation of Fehrer and Raab's (1962) results was first tested in a study which compared a temporal order judgment (TOJ) task and an RT task (Neumann, 1982). In the RT task, participants responded with a simple response to a ring, and in the TOJ task, they judged the temporal order of two rings. In experimental trials, one of the rings was preceded by a disk that was masked by it (a prime; Werner, 1935). Presentation of the masked disk shifted the point of subjective simultaneity (PSS) by about 40 ms in favor of the primed ring. This suggests that the latency of the conscious perception of the ring was reduced by the masked prime. However, the amount of this reduction was only about half the size of the SOA between the prime and the mask. This contrasted with the RT task, in which simple RT was facilitated by almost the full size of the SOA. Thus, the predicted effect on TOJ was obtained, but it was insufficient to explain the masked prime's effect on RT. On the one hand, these results supported Fehrer and Raab's (1962) idea that masked stimuli could directly activate a motor response. On the other hand, there was a different phenomenon, interesting in itself, namely the prime's effect on the latency of the conscious perception of the masking target.

Neumann (1982) interpreted this *perceptual latency priming* (PLP) as an attentional effect: Perceiving a visual stimulus requires attention to be directed to its location, and, according to this explanation, the prime initiated an attention shift, thereby reducing the latency of conscious perception. The findings from the original study were replicated in two later investigations (Neumann, Esselmann, & Klotz, 1993; Steglich & Neumann, 2000). However, these studies were not designed to critically test the assumption that the prime's effect was attentional. Though plausible in the context of the large body of research that has demonstrated facilitation of RT by peripheral cues that share the target's location (for reviews see, e.g., Cave & Bichot, 1999; Hopf, Luck, Girelli, Hagner, Mangun, Scheich, & Heinze, 2000; Perry & Zeki, 2000; van der Heijden, 1992), this assumption is in need of further support. The reasons are that (1) TOJs are prone to be affected by response bias, and (2) priming by a location cue could be sensory rather than attentional.

There have been several attempts to demonstrate that allocating visual attention to a location reduces perceptual latency as measured by TOJ. For example, Maylor (1985) and Gibson and Egeth (1994) have reported decreased perceptual latency as a result of peripheral cueing of a possible target location. However, they used a spatially compatible judgment mapping, which is prone to response biases. Stelmach and Herdman (1991) used either peripheral or symbolic central cues to manipulate the allocation of attention. Both methods resulted in a shift of the PSS in favor of the attended stimuli. However, Pashler (1998) and Jaskowski (1993) have argued that effects like these may also have been due to a response bias in favor of the primed, or otherwise more conspicuous (e.g., attended), stimulus (see also Spence, Shore, & Klein, 2001). When uncertain about the order of the stimuli, participants might tend to select the stimulus that was cued, or that they were asked to attend to. This response bias interpretation of a PSS shift has received some support from Jaskowski's (1993) finding that allowing "simultaneous" judgments in addition to "first" and "second" judgments (employing ternary instead of binary judgments) abolished a PSS shift that had been observed with binary judgments (though see Scharlau, 2002b; Shore, Spence, & Klein, 2001; Spence, Shore, & Klein, 2001).

Even if perceptual latency priming in TOJ experiments is not an artifact of response bias, it need not have an attentional basis. Alternatively, it is possible that the prime has a facilitatory effect on the *sensory* processing of the masking target. In previous research, the prime was always visually similar to the mask (examples are the stimuli used by Gibson & Egeth, 1994; Maylor, 1985; Neumann, Esselmann, & Klotz, 1993; Steglich & Neumann, 2000). Therefore, the prime could have preactivated detectors for these sensory features and thereby reduced sensory processing time for the mask favoring perceptual priming (for a review see Wiggs & Martin, 1998; Bar & Biederman, 1998; Haber & Hershenson, 1965; Hershenson & Haber, 1965).

To summarize, there is evidence that a prime reduces the latency of the conscious perception of the masking target, and it has been hypothesized that this facilitation is due to an attention shift initiated by the prime despite its being masked. The present experiments were intended to test the attentional account of PLP directly against the alternative explanations. The primary purpose was to look into the possibility of sensory priming. Some of the experiments also provided evidence relevant to the response bias account.

Overview

The aim of the first experiment was to reproduce perceptual latency priming under the conditions of the present series of experiments. In the other experiments, the prime's similarity to the mask was varied to decide whether PLP depends on shared features of prime and mask. If the prime produces PLP because it acts as a cue for a shift of attention, then its effect should be independent of whether or not it is visually similar to the target. By contrast, sensory priming should increase with the amount of featural overlap. Experiment 2 compared the effects of primes that were identical in shape with the mask (though smaller) with the effects of differently shaped primes (congruent vs. incongruent primes). An additional purpose of this experiment was to rule out the possibility that participants misunderstood the instructions and based their TOJ on the perceived onset of the prime rather than that of the target. In Experiment 3, we used primes whose shape differed so massively from that of the masks that they were only slightly masked. This provided both an additional test of the sensory priming hypothesis (according to which PLP should vanish with these stimuli), and a test of the response bias hypothesis (which predicts that it should increase because a response bias can only be effective if the prime is detected). As a final test of all three alternative accounts – sensory priming, response bias, and attentional cueing – the similarity of prime and masking target was varied on two different dimensions (shape and color) in Experiment 4.

Experiment 1

The first experiment was designed to demonstrate PLP by metacontrast-masked primes.

Method

Participants Seventeen student volunteers (7 males; mean age = 25.4 years) took part in the experiment. They were either paid EUR 15 or participated in fulfillment of course requirements. Two participants were excluded because they did not show up for the second part of the experiment. All participants reported normal or corrected-to-normal vision.

Sessions The experiment consisted of a TOJ session, followed by a signal detection (SD) session, which served to assess the amount of masking. The TOJ session always preceded the SD session since the SD task required informing participants about the presence of primes, of which they remained ignorant in the TOJ session.

Apparatus Stimuli were presented in dark grey (14 cd/m^2) on white background (103 cd/m^2) on a 17" color monitor. Participants responded by pressing either the left or the right key of a mouse, using their dominant hand. Viewing distance was fixed at 60 cm by a chin rest. The experiment was controlled by a computer that also served for data recording.

Stimuli In each trial, a pair of visible stimuli (targets) was presented. It consisted of a square and a diamond, both with star-like inner contours (Figure 1). This type of stimuli, originally used by Klotz (1996), has been shown to produce excellent metacontrast masking (Klotz & Neumann, 1999). The target pair was aligned either horizontally or vertically, with the stimuli located at a vertical distance of approximately 8.5° from fixation. The prime was a smaller replica of either the square or the diamond that fitted exactly into the inner contours of target. A target was always combined with a prime of identical shape. Edge length of targets was 2.3°; primes had an edge length of 1.7°.

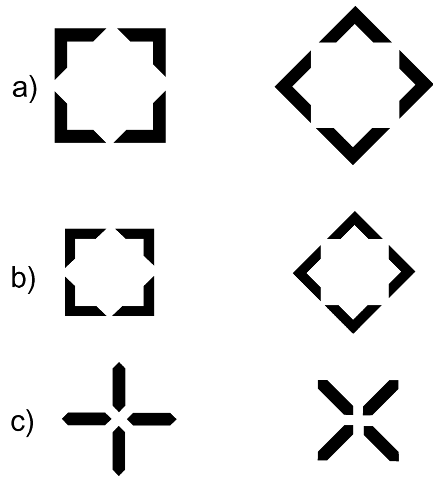

Fig. 1 Stimuli employed in the experiments. Row a) depicts the targets. In b) the congruent primes of Experiment 1 are shown. If incongruent, as in some conditions of Experiment 2, the square prime would be assigned to the diamond target and vice versa. Row c) shows the primes of Experiments 3 and 4. In Experiment 3 they were assigned as depicted; in Experiment 4, the x-prime was followed by the square target and the +-prime by the diamond in order to decrease perceptual similarity

General procedure Participants were seated in front of the monitor in a dimly lit room. Each trial started with a dynamical fixation aid. It consisted of four small dark grey squares (initial edge length 0.6°) moving quickly from the corners of the screen towards its center and shrinking in size. After 800 ms, they merged into a single square which disappeared after a random delay of 100 to 200 ms. As a fixation control, participants were instructed to observe this square and detect a variation. In a randomly selected 5% of the trials, the fixation point appeared as an empty instead of a filled square, changing into a filled square after 100 ms. Participants were instructed not to respond in these trials. However, it turned out that only some of the participants consistently followed this instruction (did not miss a single variation). According to debriefing after the experiment, mistakes occurred because participants failed to withhold their response although they had detected the empty square, that is, attended to fixation. Therefore, we decided to eliminate participants only if they had responded to more than a quarter of these catch trials.[1]

The target pair was presented immediately after the disappearance of the fixation square. In half of the trials, targets appeared to the left and right of fixation, and in the other half above and below fixation, in an unpredictable order. Assignment of the two shapes to the two locations in each trial was also randomized. Targets were presented for 32 ms with an SOA between –128 ms and +128 ms in steps of 32 ms. In half of the trials, one of the targets was preceded by a prime. The prime was presented for

[1]One might argue that this control does not sufficiently exclude eye movements, and that therefore an eye movement or express saccade account of the data is feasible. In a yet unpublished experiment with EOG recordings, we found a PLP effect of 45 ms with a priming SOA of 48 ms. When we reduced data by eliminating those trials in which a vertical eye movement occurred (vEOG amplitude of more than 40 μV; targets were presented on the vertical midline in this study), the priming effect was 46 ms. There was no difference between the two sets of data ($t[8] < 1$). Though stimulus conditions in this experiment were not strictly comparable to the experiments reported in the presented study, these data do not favor an eye movement account.

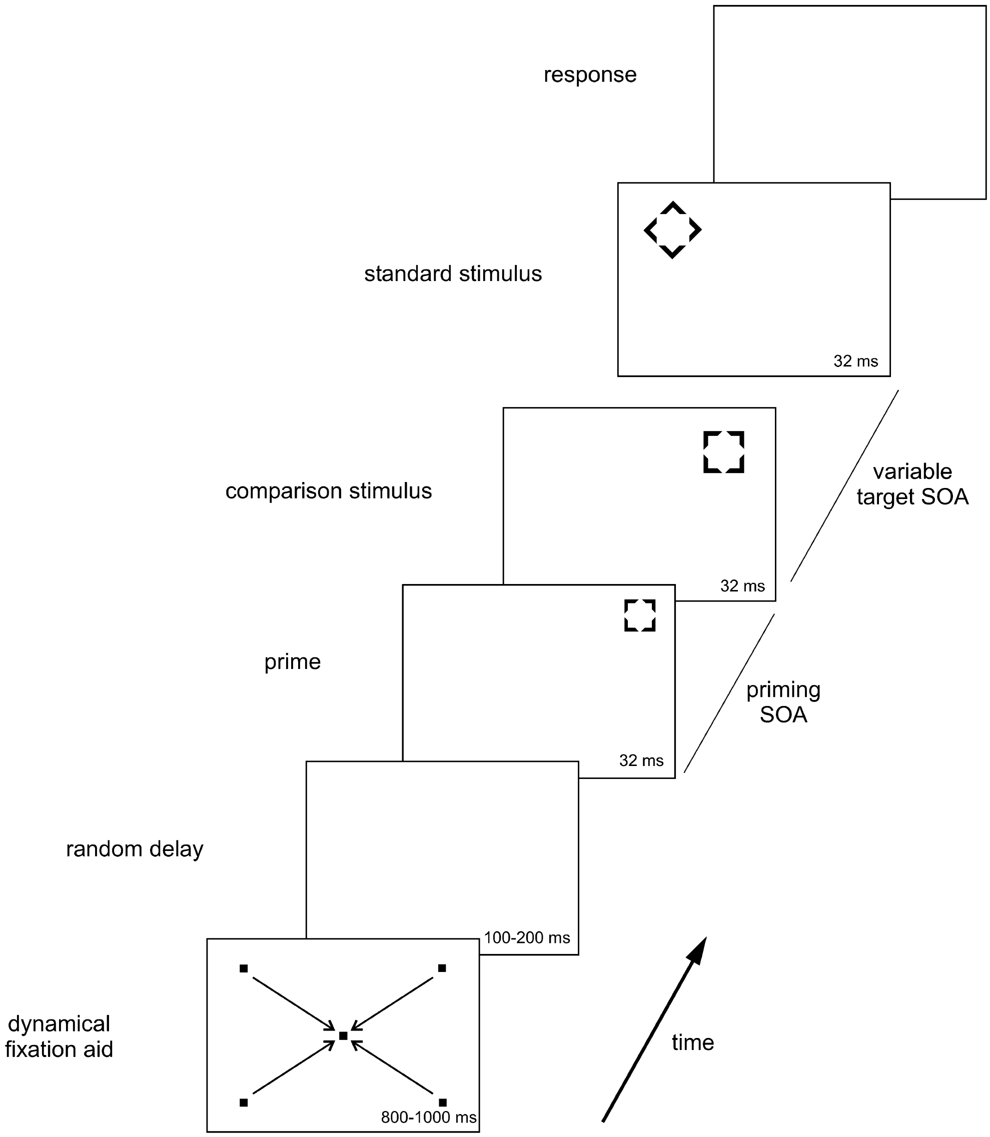

Fig. 2 Succession of events in an example trial. Each trial started with the presentation of a dynamical fixation support (first frame), followed by a random delay of 100 to 200 ms (second frame). The other frames show an example of a primed trial with the comparison preceding the standard stimulus (negative target SOA)

32 ms, and the SOA between prime and masking target was 64 ms. (For an example trial, see Figure 2.) The positions of the primed targets were balanced, and each of the two shapes was primed equally often. Thus, there were 18 conditions (9 target SOAs and prime/no prime). Each condition was presented 64 times in each session in a random order.[2]

TOJ task In the first session, participants judged the temporal order of the targets. Half of them responded with the left mouse button when they saw the square first and with the right button when the diamond was perceived first; for the other half the assignment was reversed. Thus, the defining feature of the judgment (stimulus shape) was independent of the dimension in which attention was manipulated (location), a methodology which reduces the contribution of response bias to the possible effects and was used in earlier studies (see Scharlau, 2002a; Shore, Spence, & Klein, 2001; Spence, Shore, & Klein, 2001; Steglich & Neumann, 2000). The instructions emphasized accuracy and did not require fast responding. Before data were recorded, participants had the opportunity to practice until they were sure that they had understood the instructions and were familiar with the task. No primes were presented in these trials. Feedback was given during practice if participants responded erroneously to catch trials, but no feedback was provided for temporal order judgments. During the experiment, participants could request a break whenever they wished. A session had a duration of about 75 min.

Signal detection (SD) task Except for the task, this session was identical to the first. Participants were told that in about half of the trials one of the targets would be preceded by a prime and that their task was to detect these trials, that is, to respond “yes” if one of the targets was preceded by a prime, and “no” if there was no prime. For half of the participants, the “yes” response was assigned to the left mouse button; for the other half, the assignment was reversed.

Results

TOJ task To construct psychometric functions, the primed target was defined as the comparison stimulus, and the unprimed target as the standard stimulus. In

[2]The reason why the control condition was presented with as many repetitions as the four primed conditions taken together was that an equal number of primed and unprimed trials was required for the SD task, which was designed to match the TOJ task as closely as possible.

trials without a prime, this assignment was made randomly. Negative values were arbitrarily assigned to SOAs in which the comparison stimulus preceded the standard stimulus. Figure 3 shows the relative frequencies of the response "standard first" as a function of SOA. The shape of the psychometric functions for both priming conditions is sigmoid. Inspection of the data of individual participants indicated that this was also the case at the individual level and that the individual distributions could be best approximated by logistic functions. Logit analysis (Finney, 1971) was used to estimate the point of subjective simultaneity (PSS) and the difference limen (DL, defined as the interquartile range) for each participant. If necessary, degrees of freedom were corrected by the Greenhouse-Geisser-coefficient ϵ, and alpha was adjusted accordingly (Hays, 1988).

As can be seen from Figure 3, priming had a large effect on TOJ. For primed trials, the average PSS shifted from 0 ms to +33 ms. Individual PSSs were entered into a one-way ANOVA that revealed a highly significant effect of priming ($F[1, 14] = 294.52$; $P < 0.01$). Cohen's d (Cohen, 1977) was 5.83, indicating a strong effect of priming. Figure 3 also shows similar slopes for primed and unprimed trials. This was confirmed by an ANOVA for individual DLs which showed no effect of priming ($F[1, 14] = 1.4$; $P = .2563$).

SD task To assess strength of masking, d' was calculated for each participant (Green & Swets, 1966; Velden, 1982). The average value of d' = .50 was small, but just significantly different from zero ($t[14] = 2.86$; $P < .05$), indicating strong, but not total masking.

Discussion

Experiment 1 replicated the basic findings of Neumann (1982), Neumann et al. (1993), and Steglich and Neumann (2000). A prime that was strongly masked had a massive effect on TOJ, indicating PLP in the order of magnitude of about half the SOA between the prime and the target (PLP = 33 ms; SOA = 64 ms). The quantitative relationship between the size of the masking SOA and the amount of PLP also agrees with these previous studies as well as with investigations by Aschersleben (1999a, 1999b) who employed a synchronization task to assess PLP in addition to a TOJ task. However, Experiment 1 does not yet provide evidence about the relative merits of the alternative theoretical accounts. Since primes and targets were always visually similar, attentional priming as well as sensory priming can account for the effect. Response bias can also not be completely excluded as a factor, since there was some residual discrimination of the primes, which may have biased participants to judge the primed targets "first". In a first attempt to decide between an attentional and a sensory priming interpretation, Experiment 2 employed two types of prime-target pairings that varied in visual similarity.

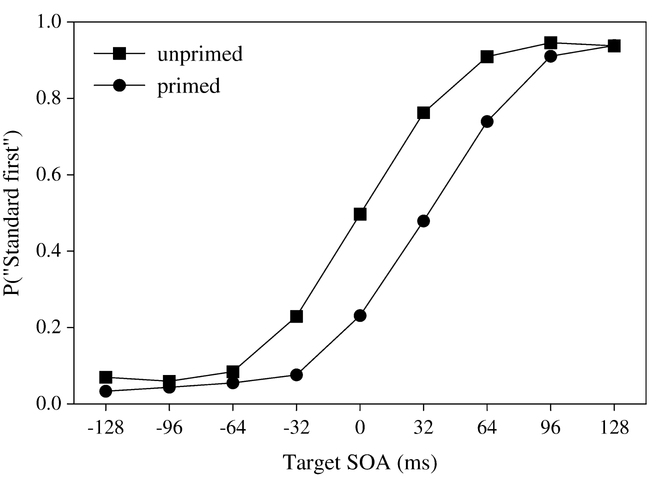

Fig. 3 Psychometric functions for the TOJ task in Experiment 1

Experiment 2

In experiments that have investigated speeded responses to primed targets, the prime's effect has been reported to depend on whether it is *congruent* or *incongruent*. In terms of the present stimuli, a congruent prime is a small square followed by a larger square, or a small diamond followed by a larger diamond, whereas incongruent stimulus pairings consist of a square followed by a diamond or vice versa. Research on the metacontrast dissociation has demonstrated that congruency is a major factor in the priming of motor responses if the two stimuli are associated with different response alternatives (e.g., Eimer, 1999; Jaskowski et al., 2002; Klotz & Neumann, 1999; Klotz & Wolff, 1995; Neumann & Klotz, 1994; Leuthold & Kopp, 1998; Schwarzbach, 2000; Vorberg et al., in press).

A comparison between congruent and incongruent stimuli can be used to test alternative predictions of the attentional and the sensory accounts of PLP. An attentional effect should be independent of the visual similarity between the prime and the target, since the prime's ability to attract attention is unlikely to be affected by the type of target that follows at a delay of 64 ms. Hence congruent and incongruent primes would be expected to entail an identical amount of priming under this hypothesis. According to the sensory hypothesis, by contrast, an incongruent prime has less featural overlap with the masking target than a congruent prime and should therefore produce less priming.

Comparing the effects of congruent and incongruent primes can also help to clarify a methodological criticism that has been raised, e.g., by Pashler (1998). He argued that participants in experiments that apparently demonstrated PLP actually based their judgment on the perceived onset of the prime, and not that of the target. This cannot be excluded for Experiment 1, in which the prime and the target were visually similar and could hence be easily confused, and where some residual detectability of primes was observed. For the present experiment, this argument leads to a clear prediction: If participants base their TOJ on the conscious perception of the prime rather than the target, then incongruent trials should be associated with a higher error rate than congruent trials, which should result in a flatter psychometric function. This follows from the fact that participants were asked to base their response on the shape of the first stimulus (e.g.: "If the square appeared first, press the left button, if the diamond appeared first, press the right button"). A response to the incongruent prime instead of the target would hence be an incorrect response, and an increase in the number of incorrect responses would produce a flatter psychometric function, that is, a larger DL.

Method

Participants Participants were 19 volunteers (13 male, mean age = 25.5 years) who served under the same conditions as in Experiment 1. Three were excluded from data analysis because they failed fixation control. A further participant was excluded because he pressed the "square first" button in all trials of the TOJ task. The remaining 15 participants reported normal or corrected-to-normal visual acuity. They were paid EUR 10 or participated in fulfillment of course requirements.

Stimuli The major difference to Experiment 1 was that half of the primes were congruent and half incongruent. To keep the number of experimental trials acceptable despite this increase in the number of conditions, only SOAs between –64 ms and +64 ms were employed. In all other respects, the stimuli were identical to Experiment 1.

Procedure Procedure in the TOJ task was as in Experiment 1. With 64 repetitions of each of the 15 conditions (5 SOAs x 3 priming conditions), this task encompassed 960 trials. In the second session, the task was adjusted to the priming conditions in this experiment. To find out whether participants could discriminate between congruent and incongruent primes, only target pairs with a prime preceding one of the targets were presented, and the task was to decide whether the prime was a diamond or a square. With 64 repetitions of each condition, this session consisted of 640 trials (congruent/incongruent priming and 5 SOAs).

Results

TOJ task Data analysis was the same as in Experiment 1. As Figure 4 shows, the psychometric functions for congruent and incongruent primes are virtually indistinguishable and differ markedly from the psychometric function for the unprimed condition. For trials without a prime, the mean PSS was located at +2 ms. The PSSs for congruent trials were at +40 ms and +42 ms, indicating massive PLP in both conditions. A one-factor ANOVA with the three-level factor priming yielded a highly significant result ($F[2, 28] = 125.26$; $P < .01$; $\epsilon = .8121$). As revealed by subsequent Scheffé tests, this effect was due to the differences between the unprimed condition and each of the primed conditions ($P < .01$), which did not differ among themselves. Cohen's d yields a very large effect (d = 3.97) for unprimed vs. primed trials.

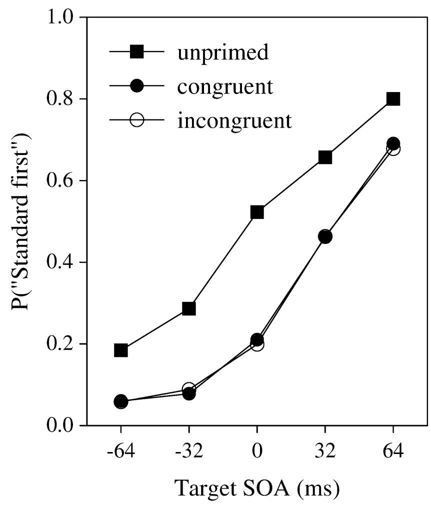

Fig. 4 Psychometric functions for the TOJ task in Experiment 2

Unlike Experiment 1, there was a significant difference between conditions with respect to the slope of the psychometric function. DL was 50 ms in trials without a prime, 37 ms in the congruent, and 38 ms in the incongruent condition ($F[2, 14] = 15.34$, $P < .01$; $\epsilon = .6949$). Scheffé tests showed differences between unprimed and each of the primed conditions ($P < .01$), whereas these did not differ among themselves. With d = .82, Cohen's d for the effect of priming was large.

SD task The discrimination task yielded chance performance. d' was .04, which is not different from zero ($t[14] = .82$; $P = .4252$).

Discussion

The finding that congruent and incongruent primes resulted in identical psychometric functions provides answers to both questions that motivated Experiment 2. First, the results from the two tasks taken together speak against the possibility that PLP is an artifact of a residual perception of, and responding to, the primes. Performance in the discrimination task indicates that participants were at chance level when asked to decide whether the prime was a square or a diamond. The TOJ task did not reveal any difference between psychometric functions for congruent and incongruent trials. As we have seen, the slope of the function for incongruent priming should have been flatter than for congruent priming if participants had erroneously responded to the prime instead of the target/mask when judging temporal order. Instead, DLs were virtually identical in these two conditions. (The reason for the larger DL in the unprimed condition is unclear; such a difference did not appear in any of the other experiments, and it is not related to the hypotheses under investigation.) Taken together, these results suggest that (a) participants could not consciously discriminate between the primes and therefore (b) did not base their responses on them.

Second, the results of Experiment 2 support the attentional account of PLP and weaken an interpretation in terms of visual feature preactivation by the prime. Apart from size, congruent primes were identical to their corresponding masking targets. By contrast, incongruent primes were visually different. One way of looking at this difference is to view it as a difference in shape. A diamond has a corner where a square has an edge and vice versa. One might also argue that the two stimuli have the same shape and differ only in orientation. In any event, stronger PLP by congruent than by incongruent primes would have constituted decisive evidence in favor of a sensory account. Its absence weakens this hypothesis. However, one might argue that a diamond and a square still share enough features to generate the same amount of sensory priming as in the congruent case. Hence, a cautious conclusion from Experiment 2 is that it failed to produce evidence in favor of the sensory priming hypothesis. It did not yet refute it. This was attempted in Experiment 3.

Experiment 3

Experiment 3 was mainly planned as a stronger test of the attentional versus sensory hypotheses than Experiment 2, but based on the same logic. In Experiment 3, the primes were small crosses with the same size and location as the primes in Experiments 1 and 2 (see Figure 2). These primes were not only visually more dissimilar to the targets than the incongruent primes in the first two experiments, but also less maskable, because metacontrast masking is known to depend critically on the coincidence or a close correspondence between the outer contours of the prime and the inner contours of the mask (e.g., Bachmann, 1994; Breitmeyer, 1984; Breitmeyer & Ogmen, 2000; Werner, 1935).

It was therefore expected that the primes used in Experiment 3 would be easily detectable. This provided an opportunity to test the response bias explanation of PLP in addition to the attentional and sensory hypotheses. A response bias can only be effective if the primed target differs in some detectable aspect from the unprimed target. The small residual detectability of the primes in Experiment 1 did not completely rule out this possibility. However, given a d' value of only .50, just different from zero sensitivity, detection of the prime must have been a rather infrequent event. In Experiment 2, participants were unable to discriminate between square-shaped and diamond-shaped primes. These results suggest that, with the congruent and incongruent primes used in these two experiments, participants could at best occasionally discriminate the presence of a prime, but not its identity. This should have been a weak basis for response bias in favor of the primed target. A response bias should be more effective if the primes are clearly visible in most trials. Hence the primes in Experiment 3 should, according to the response bias hypothesis, lead to a larger amount of PLP than in the first two experiments.

To summarize, the three hypotheses make different predictions for Experiment 3. According to the attentional explanation, the priming effects from Experiments 1 and 2 should be replicated. The sensory hypothesis predicts a reduction of PLP. If the response bias hypothesis is correct, then there should be a larger overall priming than in the first two experiments, since more primes should be detected that could be used to bias the response.

Method

Participants Instead of excluding participants from data analysis after the experiment if they had failed fixation control, participants in Experiments 3 and 4 were selected in advance. 61 student volunteers participated in a pilot session in which they performed a TOJ task of 320 trials with the standard targets, but without primes. The fixation control was as described in the Method section of Experiment 1. Of 61 participants, 16 were eliminated from the subject panel because they responded to the target in more than half of the catch trials. Sixteen participants from the remaining panel (8 female; mean age = 25.9 years) served in Experiment 3 under the same conditions as participants in the first two experiments. All reported normal or corrected-to-normal visual acuity. They received EUR 15 or participated in fulfillment of course requirements.

Stimuli Stimuli were identical to Experiment 1, except that different primes were used. The prime for a square target was a "+" cross. The prime for a diamond target was an "x" cross (see Figure 1). The crosses had the same sizes as the primes in the first two experiments, that is, the length of the crossbars was the same as the edge length of the square and diamond primes.

Apparatus and Procedure Apparatus and procedure were the same as in Experiment 1. The only change was that participants were informed that a cross might appear in addition to the targets, but that they were to ignore it and base their judgment on the onsets of the two targets.

Results

TOJ task As shown in Figure 5, the results from the first two experiments were replicated. Priming shifted the PSS from 0 ms in the control condition to +36 ms, as compared to +33 ms in Experiment 1 and an average of +41 ms in Experiment 2. A one-factor ANOVA yielded a highly significant effect ($F[1, 15] = 101.24$; $P < .01$). Effect size was again very large (d = 3.69). The DL was 38 ms in both conditions and not affected by the prime ($F[1, 14] = .01$; $P = .8964$).

SD task Detection performance was very good (d' = 2.92; $t[14] = 8.71$; $P < .01$ for a one-tailed test against zero).

Discussion

The results from Experiment 3 are clear-cut. The primes' effect was the same as in Experiments 1 and 2, although the primes had different shapes than the targets and were easily detectable. If participants had a tendency to

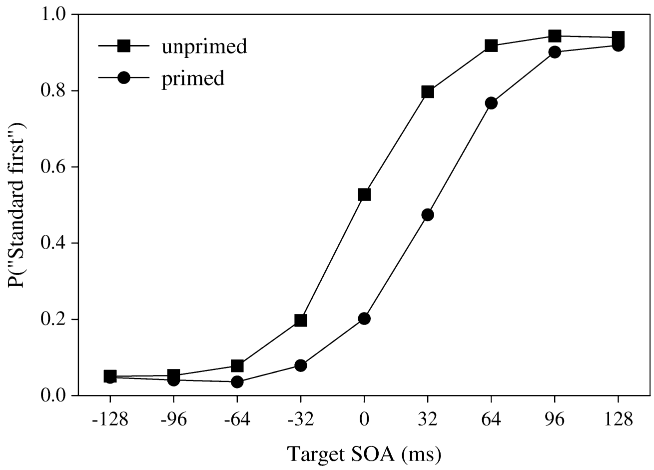

Fig. 5 Psychometric functions for the TOJ task in Experiment 3

choose the primed target if they were unsure about temporal order, such a bias should have worked more efficiently with these easily visible primes than with the barely detectable primes in the first two experiments. Yet there was no difference. One might argue that we prevented or reduced response bias by explicitly asking participants to ignore the primes. Indeed, this may well have been the case. Our data do not imply that response bias never plays a role in TOJ experiments. However, explaining the virtually identical psychometric functions from Experiments 3 and 1 in terms of response bias would require the unlikely assumption that the instruction in Experiment 3 exactly counteracted the better visibility of the primes in this experiment and thereby produced the same results as the poorly visible primes in Experiment 1 with no instruction to ignore them. Though this is rather implausible, we will return to this possibility in the discussion of Experiment 4.

The main finding from Experiment 3 was that the crosses were as effective primes as the diamond-like and square-like primes although they were visually different from the targets. This renders it highly unlikely that priming was based on the preactivation of visual features by the prime, further supporting an attentional explanation of PLP. However, two problems remain. First, it might be argued that this conclusion is weakened by the fact that similarity was varied between experiments and not within the same experiment. Second, visual similarity was only varied with respect to shape. To assess the generality of our conclusion, it is desirable to vary similarity along more than one dimension. In Experiment 4, similar and dissimilar primes were directly compared, and similarity was varied on two dimensions, shape and color.

Experiment 4

The purpose of Experiment 4 was to confirm and extend the finding that PLP was independent of prime-target visual similarity. To confirm it, we compared different levels of similarity within the same experiment. To test its generality, we varied similarity in two different ways. Shapes were either congruent squares/diamonds (same shape as target) or crosses (different shape). Colors were either identical between primes and targets or differed in a manner that, according to pilot research, minimized masking.

Method

Participants Thirteen participants (2 female, mean age = 27.9 years) from our subject panel took part in the experiment. One participant's data had to be discarded because he did not show up for the second session. A further participant performed perfectly in one condition so that no d' value could be calculated. His data were omitted for this condition. Participants received EUR 15 or earned course credits. All reported normal or corrected-to-normal visual acuity.

Stimuli The targets were the same as in the earlier experiments, with the exception that only horizontally aligned target pairs were used. Both targets in a pair had the same color (blue). In the "same shape" condition, the congruent primes from Experiments 1 and 2 were used. In the "different shape" condition, the cross-shaped primes from Experiment 3 were employed with one modification: To render the primes and the corresponding targets as dissimilar as possible, the "x" cross was assigned to the square target and the "+" cross to the diamond, so that the main orientation of edges in dissimilar prime-target pairs was different. Primes were either blue (11 cd/m^2) or red (15 cd/m^2). There were 5 SOAs, varying from –64 ms to +64 ms in 32 ms steps. As in the previous experiments, half of the 1280 trials were unprimed, 128 in each SOA. In the primed trials, each of the four kinds of primes (same/different shape combined with same/different color) was presented 32 times at each SOA.

Procedure As in Experiment 3, participants were asked to ignore the prime in their temporal order judgments. The task in the SD session was to judge whether the target pair was preceded by a prime, irrespective of which prime it was. To facilitate the task, all primes were presented repeatedly in slow motion before the start of the experiment. In all other respects, the procedure was the same as in the earlier experiments.

Results

TOJ task Data were analyzed as in the earlier experiments. As can be seen from Figure 6, all four kinds of primes produced PLP. The PSS was at –1 ms in the unprimed condition. PSSs for primed conditions were at the following temporal intervals: +38 ms for same color/same shape, +32 ms for same color/different shape, +39 ms for different color/same shape, and +38 ms for different color/different shape. A one-way ANOVA of PSSs revealed a highly significant effect of priming (F[4, 44] = 74.87, P < .01, ϵ = .5637). A subsequent Scheffé test yielded significant differences between the unprimed condition and each of the primed conditions (P < .01), whereas the primed conditions did not differ among themselves. DLs were 24 ms for the unprimed condition, 28 ms for same color/same shape, 26 ms for same color/different shape, 25 ms for different color/same shape and 27 ms for different color/same shape, with no significant differences between conditions (F[4, 40] = .67; P = .5321; ϵ = .5414).

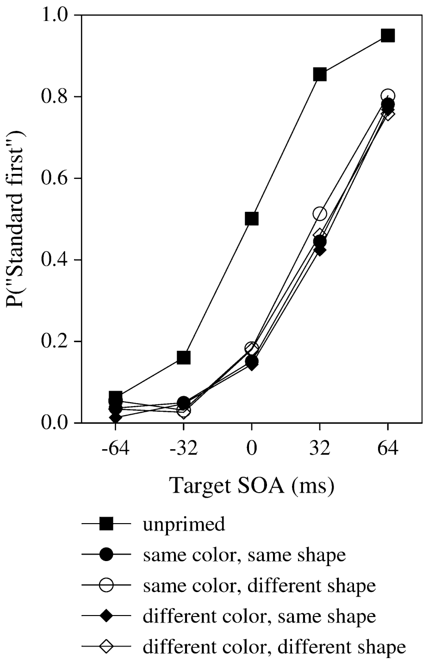

Fig. 6 Psychometric functions for the TOJ task in Experiment 4

SD task d' was .24 for same color/same shape, .61 for different color/same shape, 1.41 for same color/different shape, and 1.85 for different color/different shape. T-tests revealed that performance in all conditions differed from zero sensitivity (same color/same shape: $t[10] = 4.37$; $P < .01$; different color/same shape: $t[10] = 5.42$; $P < .01$; same color/different shape: $t[10] = 9.24$; $P < .01$; different color/different shape: $t[9] = 13.73$; $P < .01$). To assess the contributions of the dimensions to prime detectability, a two-way ANOVA was performed with the factors same/different color and same/different shape. There were significant effects of color ($F[1, 9] = 10.86$; $P < .01$) and shape ($F[1, 9] = 39.67$; $P < .01$), but no interaction ($F[1, 9] = 1.55$; $P = .24$).

Discussion

The SD data indicate that we were successful in our attempt to manipulate visibility of the primes over a wide range. Although detection performance with the color stimuli was not as good as with the dark grey crosses in Experiment 3, dissimilar primes suffered less masking than primes that had the same shape and/or color as the target. By contrast, the magnitude of PLP did not differ between same and different primes. This confirms the findings from Experiments 1 and 3 within a single experiment.

These data further support our conclusions from the earlier experiments. Neither a dissimilar shape nor a different color reduced the prime's effect, indicating that priming is attentional and not sensory. Further, the prime's detectability had no effect on priming strength, which argues against a response bias interpretation. This evidence is stronger than the evidence from the combined results from Experiments 1 and 3, because the results from Experiment 4 cannot be explained by the version of the response bias account mentioned in the discussion of Experiment 3. There, we discussed the remote possibility that response bias was relatively weak in Experiment 1 because many primes could not be detected, and that it was, by accident, exactly equally weak in Experiment 3 because the instruction asked participants to ignore the primes. This reasoning cannot explain the present results because the psychometric functions for all priming conditions were obtained under the same instruction.

General Discussion

The findings from the four experiments present a coherent picture. Visual similarity between the prime and the masking target affected strength of masking and hence signal detection performance, but it had no effect on PLP. A prime that preceded the target with an SOA of 64 ms and that was masked by it reduced the latency of its conscious perception, as measured in the TOJ task, by about 30 to 40 ms, whether it was a smaller replica of the masking target (a congruent prime; Experiments 1 and 2), a smaller replica of the target associated with the alternative response (an incongruent prime; Experiment 2), or a different shape (a cross; Experiments 3 and 4), and independently of whether it had the same color as the target or a different color (Experiment 4).

The finding that PLP was not affected by the detectability of the prime argues against an explanation in terms of response bias (Pashler, 1998), since it is difficult to see how a nondetectable prime could provoke a response bias. Further, since all manipulations of prime-target similarity failed to affect PLP, a sensory interpretation is equally unlikely. This conclusion is corroborated by electrophysiological studies of response activation by masked primes, in which no LRP onset differences were found between congruent and incongruent primes (e.g., Eimer & Schlaghecken, 1998; Klotz, Heumann, & Neumann, 2002; Leuthold & Kopp, 1998). In the study of Leuthold and Kopp (1998), there was likewise no major influence of prime-target congruity on early visual event-related potentials. This leaves the attentional account as the most plausible explanation of PLP. In accordance with this interpretation, Jaskowski, van der Lubbe, Schlotterbeck and Verleger (2002) have recently reported influences of masked primes on attention-controlled selection (the posterior contralateral negativity associated with the selection of lateralized relevant stimuli).

Presenting the prime reduces the latency of the conscious perception of the target that masks it. This implies that processing at a level that is itself not associated with awareness may affect the conscious percept of a stimulus that appears at the same location. One way to conceptualize this interaction has been suggested by Neumann

(1978, 1979, 1982, 1990b; Neumann & Müsseler, 1990). The basic idea of this model (the Asynchronous Updating Model, AUM)[3] is that visual information is analyzed and represented at two levels. The first level, termed the *spatial map*, encompasses the encoding of visual features as well as of objects, up to their classification. Processing at this level is not associated with awareness, and its content undergoes a continuous, fast updating as new information is coming in. The updating is an "overwriting" process: Earlier information is replaced by later information if it shares its location and certain critical visual features (e.g., similar contours). The output from the spatial map can feed into processes that are controlled via direct parameter specification (DPS), such as motor activation, but is not consciously perceived. (The concept of DPS will be discussed in more detail later in this section). The second level, labelled the *internal model*, comprises a coherent description of the visual environment in terms of objects, scenes and events, and it is consciously available. Updating of this internal model is comparatively slow, and it occurs selectively, as a result of directing attention to a location in the spatial map. The attention shift can be initiated by an abrupt onset or offset within the spatial map that serves as an "attention signal".

The AUM was initially developed to explain metacontrast, though it has also been applied to other visual phenomena, for example, illusions in the perception of moving stimuli (Aschersleben & Müsseler, 1999; Müsseler & Neumann, 1992; Müsseler & Aschersleben, 1998). The AUM explains metacontrast as resulting from the different updating speeds at the levels of the spatial map and of the internal representation: Upon prime presentation, the prime is entered into the spatial map and initiates an attention shift towards its location. If the mask is presented while this attention shift is being executed, it overwrites the prime in the spatial map before it has been transferred into the internal model. In this case, the observer perceives only the mask (though it may be modified by the prime due to brightness summation or other kinds of sensory integration, which may leave the prime more or less visible). Conversely, if the attention shift has been completed before the mask arrives, the observer will perceive a succession of prime and mask. Thus, metacontrast masking results from the fact that updating of the spatial map is fast, as compared to the updating of the internal representation. (Similar dual-process models of metacontrast masking have been proposed by Bachmann (1984, 1994, 1999) and, more recently, Enns and DiLollo (2000).

According to the AUM, PLP is a necessary byproduct of the processes that lead to metacontrast. If the mask is presented without a prime, then its own onset will initiate the attention shift. If it is preceded by a prime, then this shift will be initiated by the prime. It will start earlier and will therefore be completed faster, resulting in an earlier updating of the internal model. This will reduce the latency of the conscious perception of the mask. Masking does not interfere with PLP, because the prime acts as an attention signal at a stage prior to the processing level that is associated with awareness.

Further, the AUM predicts that the amount of PLP should depend on the SOA between the prime and the target. According to the model, increasing the SOA should augment the effect of the attention signal elicited by the prime, up to the point in time when the attention shift has been completed before the mask arrives. Beyond this point, a further increase of the SOA should have no effect on the size of PLP. Plotting the amount of PLP against the prime-mask SOA should therefore show an initial positive slope of less than unity and, beyond a critical SOA, a constant amount of PLP. This critical SOA is determined by the time required for the attention shift. The initial increase of the amount of PLP as a function of SOA seems to be in agreement with several studies, discussed in the Introduction, which suggest that PLP varies as a positive function of prime-target SOA (Aschersleben, 1999a; Neumann, 1982; Neumann et al., 1993; Scharlau, 2002a; 2002b; Steglich & Neumann, 2000), and it has recently been explicitly demonstrated in our laboratory (Scharlau & Neumann, 2003).

Supposing that PLP indeed is of an attentional origin, several mechanisms of attentional orienting may explain this effect. One possibility is direct parameter specification (DPS). The basic idea of the concept of DPS (Neumann, 1989, 1990a) is that response parameters can be specified by direct pathways from stimulus to response that do not require a conscious representation of the stimulus. This is possible if and when an action plan has been formed prior to the presentation of the imperative stimulus. If this is the case and if the imperative stimulus corresponds to certain criteria defined within the action plan, then the action can be executed without a conscious representation of the stimulus and without intentional control during the execution phase. This account has been used to explain the effects of masked primes on speeded responses (e.g., Ansorge, Klotz, & Neumann, 1998; Klotz & Neumann, 1999; Neumann & Klotz, 1994). PLP may be another case of DPS, where the parameters that are directly specified are the direction and the amplitude of an attention shift.

However, the prediction that attention shifts in PLP depend on the observer's intentions (the action plan) has not been tested in the present experiments. Our results are therefore also compatible with several alternative explanations, such as the attentional capture hypothesis (Jonides & Yantis, 1988; Yantis & Jonides 1984), according to which abrupt onsets capture attention in a stimulus-driven, bottom-up fashion, or the attentional control settings account that predicts that attentional capture is contingent on the observer's current attentional control settings (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). According to these authors, control settings can be

[3]The basic assumptions of this model have formerly been referred to as Weather Station Model (see Neumann, 1982; Neumann & Müsseler, 1990).

defined by either dynamic features (abrupt onset or motion) or static features such as specific colors. PLP might be a case of this top-down contingent capture. The primes may have captured attention since targets were abruptly onsetted, too, and participants were set to detect onsets in the TOJ task. The DPS account would receive support from the finding that PLP is critically dependent on a match between the prime's features and the observer's current intentions. Some support for this hypothesis has been reported by Scharlau and Ansorge (2002; see also Ansorge, Heumann, & Scharlau, (2002).

A further alternative account of our data is that PLP is due not to enhanced processing of the primed or attended stimulus, but that it is rather based on a delay in the perception of an unattended stimulus (see, e.g., Spence & Driver, 1994; Spence, Shore, & Klein, 2001). The strongest PLP effect in terms of error rate was found with positive target SOAs. With these SOAs, the prime does not indicate the location of the first target. Thus, the prime might have directed attention to a wrong location and thereby delayed the conscious perception of the first target. This might be interpreted as supporting the delayed processing account. However, the observed horizontal shift of the psychometric distribution observed in the experiments is also predicted by the AUM. Indeed, within the AUM framework, a processing delay due to the prime and PLP are two sides of the same coin: If the attention signal that is elicited by the prime directs attention to the first target's position, it will reduce its perceptual latency. If it directs attention to the alternative location, then this will delay the attention shift to the first target and thereby delay its conscious perception.

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References

Ansorge, U. (2000). *Direkte Parameterspezifikation durch Positionsinformation: Sensumotorische Effekte maskierter peripherer Hinweisreize* [Direct Parameter Specification by position information: Sensorimotor effects of masked peripheral cues]. Unpublished doctoral dissertation, University of Bielefeld, Bielefeld, Germany.

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

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

Aschersleben, G. (1999a). *Aufgabenabhängige Datierung von Ereignissen* [Task-dependent timing of events]. Aachen: Shaker Verlag.

Aschersleben, G. (1999b). Task-dependent timing of perceptual events. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events. Advances in psychology* (pp. 293–318). Amsterdam, Netherlands: North-Holland/Elsevier Science Publishers.

Aschersleben, G., & Müsseler J. (1999). Dissociations in the timing of stationary and moving stimuli. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1–12.

Bachmann, T. (1984). The process of perceptual retouch: Nonspecific afferent activation dynamics in explaining visual masking. *Perception & Psychophysics, 35*, 69–84.

Bachmann, T. (1994). *Psychophysiology of visual masking: The fine structure of conscious experience*. Commack, N.Y.: Nova Science Publishers Inc.

Bachmann, T. (1999). Twelve spatiotemporal phenomena and one explanation. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.). *Cognitive contributions to the perception of spatial and temporal events. Advances in psychology* (pp. 173–206). Amsterdam, Netherlands: North-Holland/Elsevier Science Publishers.

Bar, M., & Biederman, I. (1998). Subliminal visual priming. *Psychological Science, 9*, 464–469.

Breitmeyer, B. G. (1984). *Visual masking: An integrative approach.* Oxford, UK: Oxford University Press.

Breitmeyer, B. G., & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review, 83*, 1–36.

Breitmeyer, B. G., & Ogmen, H. (2000). Recent models and findings in visual backward masking: A comparison, review, and update. *Perception & Psychophysics, 62*, 1572–1595.

Bridgeman, B. (1971). Metacontrast and lateral inhibition. *Psychological Review, 78*, 528–539.

Cave, K. R., & Bichot, N. P (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review, 6*, 204–223.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale: New Jersey: Lawrence Erlbaum Associates.

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

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597–600.

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

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

Enns, J. T., & Di Lollo, V. (1997). Object substitution: A new form of masking in unattended visual locations. *Psychological Science, 8*, 135–139.

Enns, J. T., & Di Lollo, V. (2000). What's new in visual masking? *Trends in Cognitive Sciences, 4*, 345–352.

Fehrer, E., & Biederman, I. (1962). A comparison of reaction time and verbal report in the detection of masked stimuli. *Journal of Experimental Psychology, 64*, 126–130.

Fehrer, E., & Raab, E. (1962). Reaction time to stimuli masked by metacontrast. *Journal of Experimental Psychology, 63*, 143–147.

Finney, D. J. (1971). *Probit analysis* (3rd ed.). Cambridge: University Press.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1030–1044.

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 317–329.

Francis, G. (1997). Cortical dynamics of lateral inhibition: Metacontrast masking. *Psychological Review, 104*, 572–594.

Gibson, B. S., & Egeth, H. (1994). Inhibition and disinhibition of return: Evidence from temporal order judgments. *Perception & Psychophysics, 56*, 669–680.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. N.Y.: John Wiley.

Haber, R. N., & Hershenson, M. (1965). Effects of repeated brief exposures on the growth of a percept. *Journal of Experimental Psychology, 69*, 40–46.

Hays, W. L. (1988). *Statistics* (4th ed.). Orlando, FL: Holt, Rinehart, and Winston.

Hershenson, M., & Haber, R. N. (1965). The role of meaning in the perception of briefly exposed words. *Canadian Journal of Psychology, 19*, 42–46.

Hopf, J.-M., Luck, S. J., Girelli, M., Hagner, T., Mangun, G. R., Scheich, H., & Heinze, H.-J. (2000). Neural sources of focused attention in visual search. *Cerebral Cortex, 10*, 1233–1241.

Jaskowski, P. (1993). Selective attention and temporal-order judgment. *Perception, 22*, 681–689.

Jaskowski, P., van der Lubbe, R. H. J., Schlotterbeck, E., & Verleger, R. (2002). Traces left on visual selective attention by stimuli that are not consciously identified. *Psychological Science, 13*, 48–54.

Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. In J. B. Long, & A. D. Baddeley (Eds.), *Attention and Performance, IX* (pp. 187–203). Hillsdale, N.J., US: Erlbaum.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43*, 45–52.

Klotz, W. (1996). *Handlungssteuerung ohne bewußte Wahrnehmung: Eine experimentelle Untersuchung zur motorischen Verarbeitung visuell maskierter Reize*. [Action control without conscious perception: An experimental study of motor processing of visually masked stimuli]. Unpublished doctoral dissertation, University of Bielefeld, Bielefeld, Germany.

Klotz, W., Heumann, M., & Neumann, O. (2002). Electrophysiological activation by maked primes: Independence of prime-related and target-related activities. Manuscript submitted for publication.

Klotz, W., & Neumann, O. (1999). Motor activation without conscious discrimination in metacontrast masking. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 976–992.

Klotz, W., & Wolff, P. (1995). The effect of a masked stimulus on the response to the masking stimulus. *Psychological Research/Psychologische Forschung, 58*, 92–101.

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

Maylor, E. A. (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner, & O. S. M. Marin (Eds.), *Attention and Performance, XI* (pp. 189–204). Hillsdale, NJ, US: Erlbaum.

Müsseler, J., & Aschersleben, G. (1998). Localizing the first position of a moving stimulus: The Froehlich effect and an attention-shifting explanation. *Perception & Psychophysics, 60*, 683–695.

Müsseler, J., & Neumann, O. (1992). Apparent distance reduction with moving stimuli (Tandem Effect): Evidence for an attention-shifting model. *Psychological Research/Psychologische Forschung, 54*, 246–266.

Neumann, O. (1978). *Visuelle Aufmerksamkeit und der Mechanismus des Metakontrasts* [Visual attention and the mechanism of metacontrast]. (Report No. 6/1978). Bochum, Germany: Cognitive Psychology Unit, Department of Psychology, Ruhr-University Bochum.

Neumann, O. (1979). *Kann ein nicht bewußt repräsentierter Reiz eine Willkürbewegung auslösen? – Zur Interpretation des Fehrer-Raab-Effektes* [Is a nonconscious stimulus able to initiate a voluntary action? – On the interpretation of the Fehrer-Raab effect]. In P. Wolff, & M. Tücke (Eds.), Report on the 3rd Psychology Meeting in Osnabrück, Germany, October 1979, Psychological reports from Department 3, Osnabrück University.

Neumann, O. (1982). *Experimente zum Fehrer-Raab-Effekt und das "Wetterwart"- Modell der visuellen Maskierung* [Experiments on the Fehrer-Raab effect and the "weather station" model of visual masking]. (Report No. 24/1982). Bochum, Germany: Cognitive Psychology Unit, Department of Psychology, Ruhr-University Bochum.

Neumann, O. (1989). Kognitive Vermittlung und direkte Parameterspezifikation. Zum Problem mentaler Repräsentation in der Wahrnehmung [Cognitive mediation and direct parameter specification. On the problem of mental representation in perception]. *Sprache und Kognition, 8*, 32–49.

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

Neumann, O. (1990b). Visual attention and action. In O. Neumann, & W. Prinz (Eds.), *Relationships between perception and action: Current approaches* (pp. 227–267). Berlin, Heidelberg, New York, Tokyo: Springer.

Neumann, O., Esselmann, U., & Klotz, W. (1993). Differential effects of visual-spatial attention on response latency and temporal order judgment. *Psychological Research/Psychologische Forschung, 56*, 26–34.

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

Neumann, O., & Müsseler, J. (1990). Visuelles Fokussieren: Das Wetterwart-Modell und einige seiner Anwendungen [Visual focusing: The weather station model and some applications]. In C. Meinecke, & L. Kehrer (Eds.), *Bielefelder Beiträge zur Kognitionspsychologie* [Bielefeld contributions to cognitive psychology](pp. 77–108). Göttingen: Hogrefe.

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

Perry, R. J., & Zeki, S. (2000). The neurology of saccades and covert shifts in spatial attention: An event-related fMRI study. *Brain, 123*, 2273–2288.

Scharlau, I. (2002a). Leading, but not trailing, primes influence temporal order perception: Further evidence for an attentional account of perceptual latency priming. *Perception & Psychophysics, 64*, 1346–1360.

Scharlau, I. (2002b). *Evidence against response bias in temporal order judgment tasks with attention manipulation by masked primes*. Manuscript submitted for publication.

Scharlau, I. & Ansorge, U. (2002). Exogenous and intention-dependent control of attention shifts in dynamic displays. In: Würtz, R.P., &. Lappe, M. (Eds.), *Dynamic Perception* (pp. 89–95). St. Augustin: Infix.

Scharlau, I. & Neumann, O. (2003). Temporal parameters and time course of perceptual latency priming. *Acta psychologica* (in press).

Schiller, P. H., & Smith, M. C. (1966). Detection in metacontrast. *Journal of Experimental Psychology, 71*, 32–39.

Schwarzbach, J. (2000). *Priming of eye movements by masked stimuli*. Unpublished doctoral dissertation, University of Braunschweig, Braunschweig, Germany.

Shore, D. I., Spence, C., & Klein, R. M. (2001). Visual prior entry. *Psychological Science, 12*, 205–212.

Spence, C., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms facilitate sound localization. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 555–574.

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General, 130*, 799–832.

Steglich, C., & Neumann, O. (2000). Temporal, but not spatial, context modulates a masked prime's effect on temporal order judgment, but not on response latency. *Psychological Research/Psychologische Forschung, 63*, 36–47.

Stelmach, L. B., & Herdman, C. M. (1991). Directed attention and perception of temporal order. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 539–550.

Stigler, R. (1910). Chronophotische Studien über den Umgebungskontrast. [Chronophotic studies on surround contrast]. *Pflügers Archiv für die gesamte Physiologie, 135*, 365–435.

Turvey, M. T. (1973). On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review, 80*, 1–52.

van der Heijden, A. H. C. (1992). *Selective attention in vision*. London, New York: Routledge.

Velden, M. (1982). *Die Signalentdeckungstheorie in der Psychologie* [Signal detection theory in psychology]. Stuttgart: Kohlhammer.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (in press). Invariant time-course of priming with and without awareness. In C. Kaernbach, E. Schröger, & H. J. Müller (Eds.), *Psychophysics beyond sensation: Laws and invariants of human cognition*. Hillsdale, NJ: Erlbaum.

Weisstein, N. (1966). Backward masking and models of perceptual processing. *Journal of Experimental Psychology, 72*, 232–240.

Werner, H. (1935). Studies on contour: I. Qualitative analyses. *American Journal of Psychology, 47*, 40–64.

Wiggs, C. L., & Martin, A. (1998). Properties and mechanisms of perceptual priming. *Current Opinion in neurobiology, 8*, 227–233.

Wolff, P. (1989, April). *Einfluß des maskierten Testreizes auf die Wahlreaktion auf den Metakontrast* [Effect of the masked test stimulus on choice reaction in metacontrast] Paper presented at the 31st Congress of Experimental Psychology, Bamberg, Germany.

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