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Latency facilitation in temporal-order judgments: Time course of facilitation as a function of judgment type

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Abstract

The paper is concerned with two models of early visual processing which predict that priming of a visual mask by a preceding masked stimulus speeds up conscious perception of the mask (perceptual latency priming). One model ascribes this speed-up to facilitation by visuo-spatial attention [Scharlau, I., & Neumann, O. (2003a). Perceptual latency priming by masked and unmasked stimuli: Evidence for an attentional explanation. *Psychological Research 67*, 184–197], the other attributes it to nonspecific upgrading mediated by retino-thalamic and thalamo-cortical pathways [Bachmann, T. (1994). *Psychophysiology of visual masking: The fine structure of conscious experience.* Commack, NY: Nova Science Publishers]. The models make different predictions about the time course of perceptual latency priming. Four experiments test these predictions. The results provide more support for the attentional than for the upgrading model. The experiments further demonstrate that testing latency facilitation with temporal-order judgments may induce a methodological problem resulting in fairly low estimates. A method which provides a more exhaustive measure is suggested and tested.

PsycINFO classification: 2346; 2323

Keywords: Attention; Perceptual latency; Priming; Visual masking

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1. Introduction

Metacontrast is a type of visual backward masking in which a visual stimulus is rendered invisible by a later stimulus which closely adjoins it (e.g., Breitmeyer, 1984). To give a classical example, a small disk which is followed after a short time by a surrounding ring may be phenomenally absent (Werner, 1935). Whether or to what extent the first stimulus is invisible depends on the exact temporal and spatial features of the two stimuli. In general, the metacontrast masking function is U-shaped with a minimum of visibility at intermediate onset intervals between the two stimuli, ranging from approximately 40 to 80 ms (e.g., Breitmeyer, 1984).

There have been several shifts in emphasis during the history of research on metacontrast. Most early researchers tackled the question as to how the mask influences the processing of the masked stimulus, for example whether it interrupts its processing or integrates it (for an overview, see Breitmeyer, 1984). Beginning in the late 1960s, interest began to turn to the question whether the masked information can be processed in specialised subsystems of the visuo-motor system even though it is blocked from consciousness (e.g., Fehrer & Raab, 1961). This hypothesis has indeed been corroborated by data. For example, motor responses can be 'primed' by an invisible stimulus (e.g., Leuthold & Kopp, 1998; Neumann & Klotz, 1994). Masked stimuli presented in advance of a response-relevant stimulus (masked 'primes') reduce response time and error rate if they indicate the same (choice) response as the mask, but cause an increase of both parameters if they indicate the alternative response (e.g., Ansorge, 2003, 2004; Ansorge, Heumann, & Scharlau, 2002; Ansorge, Klotz, & Neumann, 1998; Ansorge & Neumann, 2005; Breitmeyer, Ogmen, & Chen, 2004; Klotz & Neumann, 1999; Verleger, Jaśkowski, Aydemir, van der Lubbe, & Groen, 2004; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003).

However, one could also ask whether processing of the mask is influenced by whether it is preceded by a prime or not. This question has rarely been raised within masking research. An exception to that rule are two models which, as a by-product of their explanation of metacontrast masking, predict that the prime speeds up conscious perception of the mask. These two theories are the *asynchronous updating model* (AUM; Scharlau & Neumann, 2003a) and the *perceptual retouch model* (PRM; Bachmann, 1984).

The predicted acceleration of the mask's conscious perception has indeed been found in several recent studies (e.g., Neumann, Esselmann, & Klotz, 1993; Scharlau & Neumann, 2003a, 2003b; Steglich & Neumann, 2000). A primed mask and an unprimed stimulus are presented within an interval of a few milliseconds, and the observers decide in a temporal-order judgment (TOJ) which of the two stimuli comes first. The primed stimulus appears to lead the unprimed stimulus when both stimuli have a concomitant onset, and even if it trails the unprimed stimulus by a short interval. Alluding to the priming paradigm mentioned above, this effect was called *perceptual latency priming* (PLP; Scharlau & Neumann, 2003a). In addition to the evidence from temporal-order judgments of a primed and an unprimed visual stimulus, it has been demonstrated in tapping in synchrony with a primed stimulus (e.g., Aschersleben, 1999), and in choice responses to primed visual stimuli (e.g., Neumann et al., 1993).

Earlier studies further revealed some relevant features of PLP. It can be induced by visible cues as well as by invisible primes, and, as a rule, the size of PLP is independent of the prime's visibility (Scharlau, 2002; Scharlau & Neumann, 2003a). Thus, the mechanism which is responsible for PLP should be independent of whether it is triggered by conscious or nonconscious information. Further, current intentions to search for particular target features and ignore others influence to what extent a prime can accelerate the perception of the mask, that is, PLP is modified by top-down influences (Scharlau & Ansorge, 2003). Thus, the mechanism responsible for PLP must be open to top-down control.

In the following paragraphs, we will outline the two aforementioned models. More specifically, we will address the topic of the *time course* of PLP. Despite their fairly similar scopes and parallel explanations of metacontrast and PLP, the two models make clearly different predictions about the time course of PLP.

2. Models of PLP: asynchronous updating

The two models considered here—AUM and PRM—ascribe masking as well as PLP to a similar cause, a temporal asynchrony of processes in the visual system. In both models, this asynchrony concerns two central coding processes which are both triggered by the onset of a visual stimulus. The models differ, however, in the precise notion of these processes as well as in the nature of the assumed asynchrony.

In the AUM, the two asynchronous processes are *feature/object coding* and *allocation of visuo-spatial selective attention* (Neumann, 1982; Scharlau & Neumann, 2003a). Within feature coding, basic visual information is coded in spatially addressable feature maps—for instance, colour, orientation, size, and also, at least partially, as integrated object information (e.g., Rensink, 2000; Treisman, 1988). This type of coding is fast. For instance, it quickly aligns with changes in stimulation. Information coded in spatial maps can be used in sensorimotor processing, for example in order to trigger or guide prepared responses (e.g., Klotz & Neumann, 1999). Also, more recent information usually overwrites earlier information in feature coding. However, information at the level of feature coding is not consciously available (e.g., Rensink, 2000; Treisman, 1988).

Parallel to feature coding, the abrupt onset of a stimulus (or, alternatively, a change in a stimulus) initiates the second process, a shift of attention towards the location of the change within the spatial map. This second type of processing—allocation of visuo-spatial selective attention—proceeds slower than coding within the spatial maps, that is, it lags behind the information that is represented in the feature maps. Yet, it serves an important function: An object, a scene, or an event can only be perceived consciously if it has been attended to (e.g., Rensink, O'Regan, & Clark, 1997). Visuo-spatial attention is a necessary precondition for conscious perception. According to the AUM, attention allows the information to be transferred into an internal model. The contents of this model can—but need not—be perceived consciously.[1]

As reflected in the term "asynchronous updating", the main characteristic of the AUM is the asynchrony of the two main processes—fast encoding of object information and slow attentional allocation. Roughly speaking, metacontrast masking arises because during the shift of attention, the first stimulus (or prime) has been replaced by the mask on the level of the spatial map. If the information in the spatial map changes during the shift of attention, the changed or second state will be transferred into the internal model whereas the first state or the earlier information is excluded from attentional and post-attentional

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[1] Rensink's (2000) coherence theory is very similar to the AUM, except that there is no internal model. Instead, the contents of attention are equivalent to the internal model.

processing.[2] Yet, the model does not preclude sensorimotor processing of the prime: Up to the arrival of the mask's codes, the prime may be processed in the spatial map, and this nonconscious information can feed into response preparation.

More precisely, attentional allocation explains why the prime becomes more and more visible as the onset interval between prime and mask increases: The larger the onset interval, the larger is the probability that the shift of attention can be executed and completed before the mask overwrites the prime in the spatial map. Once attended-to, the prime is transferred into the internal model and, thus, escapes backward masking. The metacontrast masking function is, however, nonmonotonic and U-shaped with a maximum of masking at intermediate SOAs of 40–80 ms (Breitmeyer, 1984). In the AUM, the initial increase of masking up to SOAs of 40–80 ms is explained by a further, independent mechanism, brightness summation (Neumann, 1978; see also Reeves, 1982).

To repeat, metacontrast arises because during the slow shift of attention, the quick feature coding process has replaced the prime by the mask at the level of the spatial map. According to this explanation, the extent of metacontrast masking should be affected by attention. If attention can be directed to the prime's location on the level of the spatial map before it is overwritten by mask information, the prime can be transferred into the internal model and masking is precluded. Several recent findings are in line with this assumption. For example, valid precueing and prime pop-out reduce metacontrast (see, e.g., Enns, 2004; Tata, 2002). A related reduction in backward masking has been demonstrated by Shelley-Tremblay and Mack (1999) who used attention-grabbing stimuli such as one's own name as primes. Conversely, Neumann (1978) demonstrated that diverting attention by presenting a distractor stimulus increases masking. More precisely, masking increases within the range of longer prime-mask intervals (50–100 ms). Because the distractor, which was presented concomitantly with the prime in Neumann's study, delays the allocation of attention to the prime's location, the interval is prolonged within which the mask can replace the prime on the spatial map. (Masking within the range of 0–40 ms was not influenced by the distractor because, as Neumann reasoned, it is due to brightness summation rather than replacement of the prime by the mask on the level of the spatial map.)

For the present context, it is most notable that the asynchrony which causes metacontrast masking also has a further consequence on stimulus processing. It causes latency facilitation, that is, PLP: The prime captures attention towards its location, but is overwritten by the mask while attention is under way. This means that the mask will be attended to and transferred into the internal model. Additionally, the mask achieves a "head-start" with respect to attentional and thus consciousness-related processing: Compared to a like stimulus which is not preceded by a prime, the mask profits from that the prime has already captured attention. It can be transferred to the internal model more quickly and thus can be perceived earlier. This speeding up is latency facilitation or PLP. In terms of the cueing paradigm (e.g., Posner, 1980), the prime acts as an (invisible) cue for directing

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[2] This applies only to sequences in which the first and the second state are similar enough to be perceived as two conditions of the same, changing object, for instance as one object moving, approaching, or rotating. This precondition is usually met by metacontrast displays in which the target typically is a minimised and often rotated version of the mask (see, e.g., Jaśkowski, van der Lubbe, Schlotterbeck, & Verleger, 2002; Klotz & Neumann, 1999; Neumann & Klotz, 1994; Vorberg et al., 2003). Besides overwriting, the model also includes integration if the changes within the spatial map are very large. This second type of information integration has so far not been further investigated.

visuo-spatial selective attention towards the location of the mask. It thus allows for attentional facilitation, including latency facilitation (e.g., Stelmach & Herdman, 1991). Note that the attention-capturing function of the prime is independent of whether it is masked or not, that is, the AUM predicts PLP both for masked primes and unmasked cues.

Besides this general explanation of PLP, the AUM allows for some more specific predictions, for example about the size and time course of PLP. According to the AUM, the onset interval between the prime and the mask (priming SOA, stimulus onset asynchrony) should be the main determinant of PLP. The longer this interval, the larger is the head-start of the primed stimulus. The latency gain should further equal the size of the priming SOA for priming SOAs smaller than the duration of a shift of attention. Independent of whether the shift of attention can be *completed* within the priming SOA, if the shift has been *triggered* before the mask's onset, latency facilitation should arise. If the priming SOA exceeds this duration, the latency advantage should not increase further—the maximum gain is the duration of the shift of attention. The peak of facilitation should thus coincide with the duration of an attention shift.

In the present paper, we address the latter topic—the time course of latency facilitation as revealed by PLP. In other judgment paradigms, the maximum of attentional facilitation has been estimated to be located at about 100–200 ms, for example, in vernier discrimination tasks (Nakayama & Mackeben, 1989) and in the attentional repulsion effect (Suzuki & Cavanagh, 1997). Thus, the peak of PLP can be expected within priming SOAs of 100–200 ms, and its maximal size should approach these same values. (In the following, we will call these two measures of maximum attentional facilitation *peak location* and *maximum value* of PLP.) In addition, attention-mediated latency facilitation has been found even beyond that value. In the line-motion illusion (Hikosaka, Miyauchi, & Shimojo, 1993), some attentional facilitation was observed with SOAs of up to 1000 ms. As a measure of attention-mediated latency facilitation, PLP can thus be expected to extend up to long priming SOAs, although it might be rather small in this range.

3. Models of PLP: perceptual retouch

As the AUM, perceptual retouch was initially framed to explain visual backward masking (Bachmann, 1984, 1994). Also similar to the AUM, Bachmann explains metacontrast masking via the asynchrony of two parallel afferent processes. These processes, however, differ from those included in the AUM.

One of them is *specific encoding* of information in the visual cortex. This specific processing comprises feature coding, the encoding of conjunctions, the representation of objects, and intermodal coding. Compared to the AUM, these processes constitute a larger class of afferent processes, especially because of the inclusion of intermodal coding and object representations. Again, however, specific processing is quick. Representations are built fast, and they quickly decay. The second, and slower, process is *nonspecific activation* via retino-thalamic and thalamo-cortical pathways which modulates specific afferent processes. Generally speaking, specific processing provides the contents of experience. For a stimulus to become consciously available, the specific information has to be modulated by nonspecific activation (see, e.g., Baars, 1995; Crick, 1984; Edelman, 1989). Nonspecific processing thus provides modulatory influences which enable the contents to be upgraded into a conscious experience (Bachmann, 1994). This modulation is termed *perceptual retouch* or upgrading.

Again, the two processes differ with respect to their speed. Nonspecific activation trails specific processes by about 50–80 ms (Bachmann, 1994). This offers the possibility to explain various visuo-spatial phenomena, most importantly, metacontrast masking and PLP. For the explanation of metacontrast masking, it is important that the stronger a specific code, the larger the probability that it will be upgraded into a conscious representation. When the nonspecific signal arrives at the visual cortex, the specific codes of the prime and the mask have different strengths. In more detail: With very short priming SOAs, prime and mask are upgraded as an integrated percept because both are strong. With medium priming SOAs, the mask's codes are strong enough for upgrading while those of the prime have already decayed, and with large priming SOAs, both stimuli achieve an upgrading of their own, that is, they are retouched as separate events and therefore perceived as a sequence of two stimuli. This explains the U-shaped function of metacontrast.[3]

The PRM further predicts that the prime exerts an influence on the speed with which the mask can be processed. The prime triggers both specific processing and nonspecific activation. When the comparably slow nonspecific activation reaches the cortex, the prime's specific codes have already decayed and are unlikely to be upgraded into a conscious percept. The mask's specific codes, however, are strong and thus easily available for upgrading. They take advantage of the nonspecific activation triggered by the prime. Compared to a stimulus which is not preceded by a prime and thus has to 'wait' for the slow nonspecific activation triggered by itself, the mask's upgrading is accelerated (Bachmann, 1999).

Besides this general explanation of PLP, some more specific predictions can be drawn from the PRM. The first prediction is similar to one of the AUM: The priming SOA should influence the amount of PLP, because the interval with which the prime leads the mask determines the asynchrony of the specific codes of the mask and the nonspecific modulation elicited by the prime. More precisely, PLP should increase with the priming SOA up to the temporal lag of nonspecific activation, that is, up to 50–80 ms.

For longer SOAs, the PRM makes at present somewhat contradictory predictions. In the original version, Bachmann assumed that the nonspecific activation, once arrived, was sustained (Bachmann, 1984). Consequently, PLP should not only reach its maximum at about 50–80 ms, but stay at this level for longer SOAs. Recent results, however, suggest that nonspecific modulation is strongest after 50–150 ms but may decrease afterwards (Bachmann & Sikka, 2005). A further prediction concerns the size of PLP. For small priming SOAs, it should be somewhat smaller than the priming SOA, because nonspecific processing does not have to produce a modulation of specific processing instantly (Bachmann, 1994). As the AUM, the PRM predicts PLP to be independent of masking, that is, both masked primes and visible cues might cause latency facilitation.

4. Earlier results and overview

In an earlier study, we investigated PLP as a function of priming SOA and several other temporal parameters of the experimental procedure (Scharlau & Neumann, 2003b). As hypothesised, priming SOA determined the size of PLP. Mask duration and interstimulus

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[3] Indeed, the PRM could add to metacontrast masking as described by the AUM. In particular, perceptual retouch could be a mechanism besides brightness summation which could explain why the maximum of metacontrast masking and the maximum of PLP do not coincide. Metacontrast masking is strongest with onset asynchronies of about 50–80 ms (Breitmeyer, 1984); PLP has a later maximum.

interval between prime and mask were irrelevant, and prime duration had a numerically marginal influence. Investigation of the time course revealed that PLP was largest with an asynchrony of 80 ms and decreased with longer SOAs, that is, the peak of facilitation was located at 80 ms priming SOA. A similar time course was suggested by the data of Scharlau (2002). Here, the peak location was at 96 ms with a reduction of PLP afterwards. Both studies further revealed that PLP amounted to at most 50–60% of the priming SOA.

The early peak of PLP at about 80–96 ms priming SOA accords better with the PRM than with the AUM. Also, the small relative size of PLP (in % of the priming SOA) disagrees with the AUM. Remember that the AUM predicts that below and at its maximum, PLP should approach the size of the priming SOA. However, the reduction in the earlier study was rather large, and, suspiciously, it was the larger, the longer the priming SOA was. Thus, before reaching a conclusion we have to test whether the particular measure of PLP in these former studies may be nonexhaustive with respect to the priming effect, thereby also rendering conclusions about the peak location of PLP at least doubtful.

Finally, there was a further conspicuous finding: When the priming SOA was larger than 100 ms, the variance of PLP was high and discrimination accuracy of the TOJ markedly reduced. With these SOAs, metacontrast masking is generally rather weak, that is, the prime is well visible. Scharlau and Neumann (2003b) argued that participants may vary their strategies for coping with this situation. For instance, they might have ignored the prime in some of the trials, confused it with the mask in others and attended to it in still others. Without an opportunity to refrain from the judgment, these different strategies must have increased the noise level of the TOJ and impaired measurable facilitation. Therefore, more data are needed to decide about the different PLP models.

In the current study, we investigated the time course of PLP by means of a *ternary temporal-order judgment* (Ulrich, 1987). In addition to usual two-alternative TOJ procedures, in which the observers have to decide which of the two stimuli comes first, the ternary TOJ comprises a third judgment alternative ("unclear or simultaneous"). Two reasons justify this choice: First, variability due to uncertainty can be reduced, because the observers may use the "unclear" alternative instead of guessing. Second, an earlier study indicated that PLP estimates for the two order judgments in the ternary TOJ may differ. These two are "comparison first" judgments, that is, judgments in which the observers perceive the primed (or "comparison") stimulus as leading, and "standard first" judgments, that is, judgments in which the unprimed (or "standard") stimulus is perceived as leading. (Of course, the observers do not judge "comparison/primed stimulus first" vs. "standard/unprimed stimulus first". They judge which of the two stimuli defined by a feature difference is the first one, for example a square vs. a diamond as in the present study. This judgment is then transformed into a "comparison first" vs. "standard first" judgment.) For the "comparison first" judgments, PLP was reliably larger (Scharlau, 2004a). This is probably due to the fact that "comparison first" judgments are more frequent in trials in which the comparison actually leads the standard stimulus, so that the latter cannot interfere with attentional capture by the prime. Conversely, "standard first" judgments are more likely in trials in which the standard stimulus leads and thus may capture attention away from the prime (see Fig. 1 for an illustration of these sequences). That is, "comparison first" judgments may provide a better estimate of PLP than either "standard first" judgments or the two-alternative TOJ in which these two alternatives are complementary.

To summarise, the present experiments investigate the time course of attentional facilitation with the ternary TOJ. We want to assess the time course of PLP and especially test

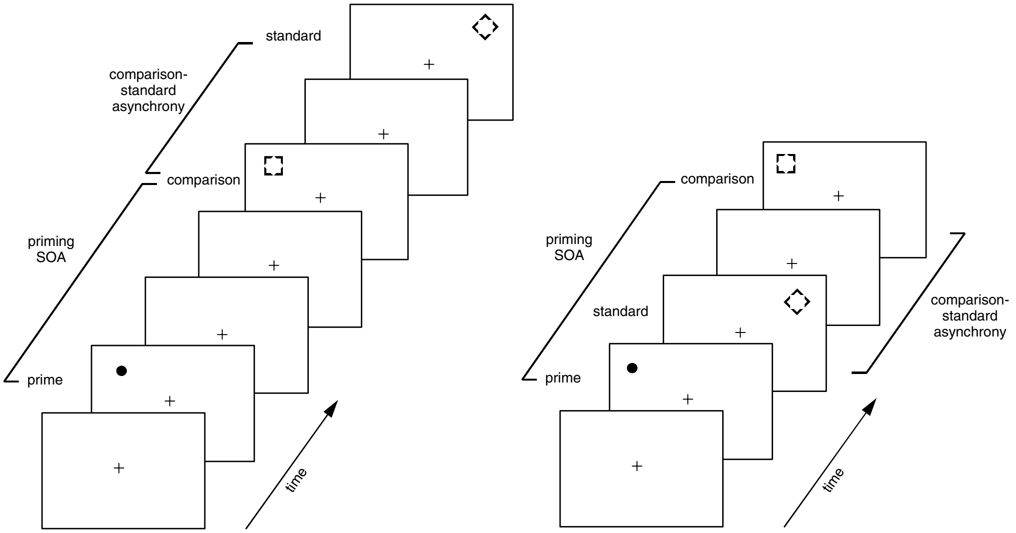

Fig. 1. Stimuli and examples of temporal sequences. Stimuli are not drawn to scale. Left panel: Comparison leads standard stimulus. Competition for attention between the locations of prime/comparison and standard is low. Thus, the prime can maximally facilitate processing of the comparison stimulus at its position. Right panel: Standard leads comparison stimulus. Competition for attention between the locations of prime/comparison and standard is high. Therefore, the prime's facilitation of processing of the comparison stimulus is diminished by attention being captured to the standard. The prime of Experiments 2–4, a dot, is presented in the figure. In Experiment 1, it was a smaller version of the comparison stimulus.

whether its peak location corresponds to the maximum of attentional facilitation—as predicted by the AUM—or to the asynchrony of perceptual retouch, that is, whether it lies at 100–200 ms or at 50–80 ms. We further investigate whether the values of facilitation equal the priming SOA, at least up to values of 100–200 ms, where the AUM expects that facilitation should approach the priming SOA. In Experiment 1, we test PLP in the range of SOAs up to the approximate duration of an attention shift (below 150 ms), and in Experiment 2 with SOAs between 170 and 510 ms at and beyond the approximate duration of an attention shift, including the time range of sustained attention. In Experiment 3, we look into the very large range of SOAs up to 1000 ms. Finally, we try to locate the peak of facilitation accurately in Experiment 4.

5. Experiment 1

5.1. Method

Participants. Twelve volunteer participants (6 female, 6 male; mean age, 24 years) took part in the experiment and received € 6.50 or course credits. All participants had normal or corrected-to-normal vision.

Apparatus. The experiment was controlled by a PC (IBM-compatible 486 CPU, run under MS DOS 6.22; timing precision was 1 ms). The experimental program was written in C and made use of the shareware Allegro/djgpp library. Stimuli were presented in dark grey (14 cd/m^2) on a light grey background (103 cd/m^2) on a 17 in. colour monitor (58.8 Hz vertical frequency, 640 × 480 pixels, Sony Triniton Multiscan G 220). Participants sat upright in a dimly lit room with the centre of the monitor at eye level. A chin rest fixed viewing distance at 60 cm. The observers responded with a serial mouse which was operated with the dominant hand.

Stimuli. The pair of comparison and standard stimulus consisted of a square and a diamond (see Fig. 1). These stimuli allow good metacontrast masking and correspond exactly to the material used in the earlier studies (e.g., Scharlau & Neumann, 2003a, 2003b). Side length of the stimuli was 2.3°, and the distance between the stimuli was 12.5°. The pair was presented horizontally either above or below the centre of the screen. The centre of the screen was marked by a fixation cross, and the participants had to fixate on this cross throughout each trial.

In half of the trials, the comparison stimulus was preceded by a prime. The prime was a smaller replica of the comparison stimulus. The interval between prime onset and comparison onset was 34, 68, 102, or 136 ms (priming SOA). The temporal intervals between the onsets of comparison and standard stimulus varied in steps of 34 ms between −136 ms and +136 ms (comparison–standard SOA). Negative numbers indicate that the comparison preceded the standard stimulus. This range of intervals reliably comprises the complete psychometric distribution (Scharlau & Neumann, 2003a). All stimuli were turned off after two refresh cycles (34 ms). (With the smallest priming SOA, this means that there was a zero interstimulus interval between prime and comparison stimulus; for all other priming SOAs, the interstimulus interval was positive.) With 16 repetitions of each of the 72 conditions (9 comparison–standard SOAs × 4 priming SOAs × 2 priming conditions), the experiment consisted of 1152 trials. Nonexperimental variables (presentation above/below fixation, right/left location of first stimulus, right/left location of prime, primed shape square/diamond, comparison–standard SOA) and experimental variables (priming SOAs, with/without prime) were presented in a random order with the method of constant stimuli.

Procedure. After each trial, the observer judged—without time pressure—whether the square had appeared first, the diamond had appeared first, or the stimuli were simultaneous. The third judgment could also be used for trials in which the observer was uncertain about what she or he saw. The instruction emphasized accuracy. The third judgment was always assigned to the centre button of the mouse. One of the two order judgments (“square first” vs. “diamond first”) was assigned to the left, the other one to the right mouse button, the assignment varying between participants. For every 40 trials, a break was initiated automatically. It was terminated by the participant. The experiment lasted 65 min on average.

Before the experimental part, the participant was trained in 36 unprimed trials with error feedback. All participants made less than 8 errors and used the “unclear/simultaneous” button maximum 4 times, which was the criterion for participation in the main experiment.

5.2. Results

Methods. The “square first” and “diamond first” judgments were converted into “comparison first” and “standard first” judgments. Both “standard first” and “comparison first” judgments allowed for constructing complete psychometric functions (see Fig. 2). From the order judgments,16 psychometric functions were calculated for each participant

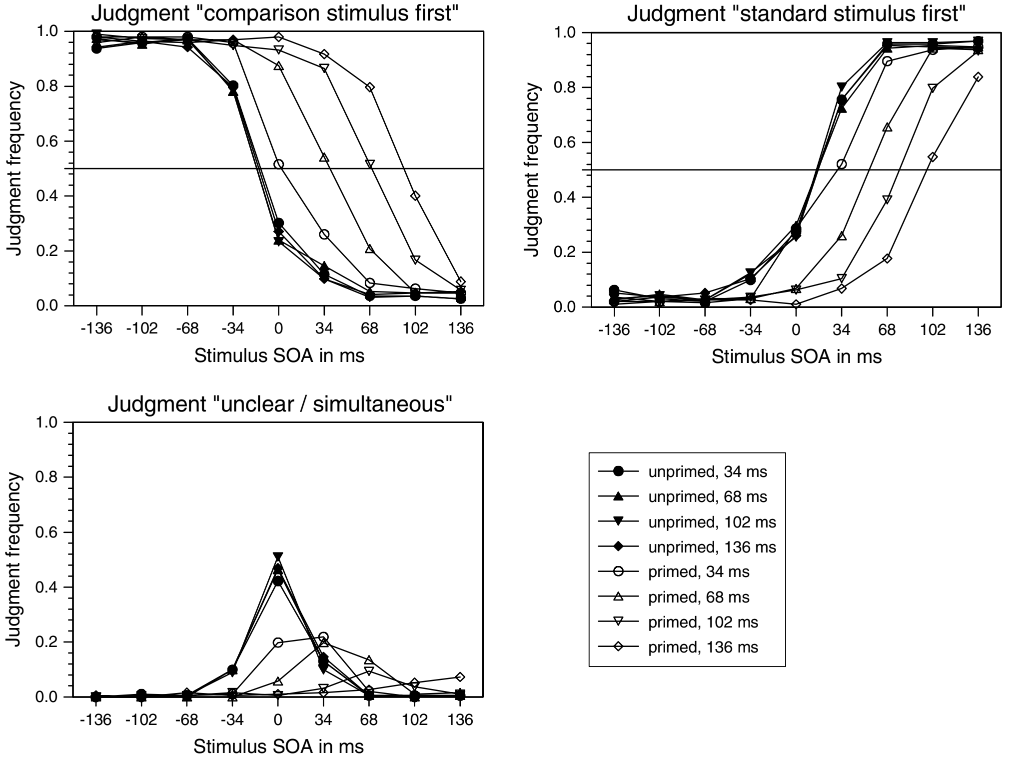

Fig. 2. Psychometric functions in Experiment 1. Top left: “Comparison first” judgments. Top right: “Standard first” judgments. Below: “Unclear/simultaneous” judgments. The intersection with the horizontal line indicates the .5 threshold. PLP is indicated by the horizontal shift of this threshold.

(judgment × without/with prime × priming SOA). Logit analysis, a parametric procedure for estimating the parameters of the psychometric function (Finney, 1971), was used to estimate the .5 threshold of the order judgment for each participant and condition (see Fig. 2; the thresholds are indicated by the horizontal line). For “comparison first” judgments, this threshold divides perceived orders into the categories “comparison first” and “not comparison first” and thus may be defined as threshold between “comparison first” and “doubt/simultaneity”. For “standard first” judgments, it analogously distinguishes between “standard first” and “not standard first”. Between these two thresholds lies the interval of uncertainty in which the “unclear/simultaneous” judgment should obtain its highest frequency (compare the two graphs in the top row of Fig. 2).

PLP was then estimated as the threshold difference between the primed and the unprimed condition for each judgment and priming SOA condition, illustrated in the rightward shift of the psychometric distributions in Fig. 2 (top row; see also Scharlau, 2004a). Points of subjective simultaneity (PSS) were derived from the two .5 thresholds (one for each judgment) by averaging. The PSS thus lies midpoint between the two thresholds from the order judgments. PLP values were submitted to a two-way repeated-measures analysis of variance (ANOVA). Since we had no clear mathematical hypotheses about the distribution of the “unclear/simultaneous” judgments, no parameters were computed from these

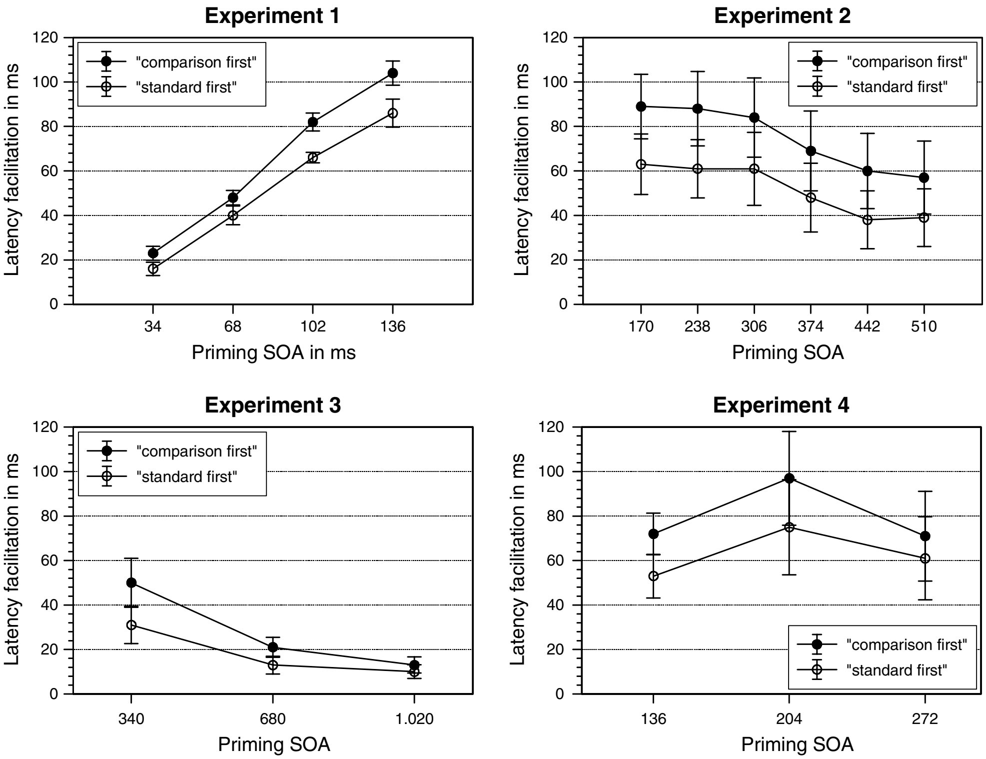

Fig. 3. PLP results. Note that the range of the *x*-axis changes. Solid symbols: "comparison first" judgments (low competition between prime and standard). Open symbols: "standard first" judgments (high competition between prime and standard). Error bars indicate standard errors of the mean.

distributions; the judgment frequencies were arcsine transformed and tested in a three-way repeated-measures ANOVA. When appropriate, degrees of freedom in the ANOVAs were corrected by the Greenhouse–Geisser-coefficient ε, and alpha was adjusted accordingly (Hays, 1988).

PLP results. Fig. 3 (upper left) depicts the PLP values, that is, the amount of latency facilitation, for each of the priming SOAs and judgment conditions. It illustrates two main findings: First, PLP increased nearly linearly with priming SOA. Second, it was larger in "comparison first" judgments than in "standard first" judgments. Both findings are supported by statistical analysis: The two-way ANOVA of PLP values revealed a main effect of priming SOA ($F[3,33] = 96.99$, $p < .001$). Bonferroni comparisons at the .05-level showed that at all priming SOAs differed from each other. Second, there was a main effect of judgment ($F[1,11] = 9.65$, $p < .05$). The interaction also reached significance ($F[3,33] = 3.43$, $p = .05$). It reflects that the difference between the two judgment conditions is 7 ms for 34 and 68 ms priming SOA, but increases to 16 ms for the two larger priming SOAs. The smaller PLP effects at the small priming SOAs possibly leave less room for differences between the judgment types.

Independent *t*-tests of the PLP values showed that all of them—ranging from 16 to 104 ms—were significantly different from zero (all ts $\geqslant 4.98$, all ps $< .001$; see Table 1 for the

Table 1
PLP values across experiments, separately for “comparison first” and “standard first” judgments

Priming SOA in ms	34	68	102	136	170	204	238	272	306	340	374	442	510	680	1020
Experiment 1, “comparison first” judgments	23	48	82	104											
Experiment 1, “standard first” judgments	16	40	66	86											
Experiment 2, “comparison first” judgments					89		88		84		69	60	57		
Experiment 2, “standard first” judgments					63		61		61		48	38	39		
Experiment 3, “comparison first” judgments										50				21	13
Experiment 3, “standard first” judgments										31				13	10
Experiment 4, “comparison first” judgments				72		97		71							
Experiment 4, “standard first” judgments				53		75		61							

PLP values). PLP amounted to 47–65% of the priming SOA for the “standard first” judgments, and to 68–80% in the “comparison first” judgments. To test whether PLP was smaller than the priming SOA, numerical differences of priming SOA and PLP were submitted to independent *t*-tests. All differed significantly from zero (all $p\text{s} \leqslant .05$, all $t\text{s} \geqslant 3.2$). That is, PLP was smaller than the priming SOA, even in that sample of the data that comprised the more favourable conditions for attentional capture by the prime.

The third judgment category. Mathematically, PLP (the amount to which the psychometric functions in primed trials are horizontally displaced from those in unprimed trials) does not necessarily covary with the use of the third judgment category (“unclear/simultaneous”). Any displacement can be achieved with any frequency of the third judgment. However, this might be different on the empirical level. The rightward shift of the psychometric functions might entirely or partly be due to an increased or decreased amount of “unclear/simultaneous” judgments. A similar argument holds for the different sizes of the shift in the different priming SOA conditions.

In order to check for such a moderating influence of the “unclear/simultaneous” judgments, we additionally analysed the use of the third category in two ways. First, we performed a three-way ANOVA of the judgments including the factors comparison–standard SOA, priming, and priming SOA (for which we selected by random one fourth of the data from conditions without a prime to match each of the levels of the variable priming SOA). Second, we performed several moderator analyses on the influence of the average frequency of “unclear/simultaneous” judgments on the relationship between priming and PSS, and between priming SOA and PLP. These two estimates—latency priming and the time course of priming—are the main effects relevant for the present study.

(1) The distribution of “unclear/simultaneous” judgments can provide information about perceived order. These judgments should be unequally distributed across comparison–standard SOAs, being scarce at long and frequent at short SOAs. Especially, the distribution should have a maximum—the comparison–standard SOA at which the participants most frequently perceive the comparison and standard stimulus as simultaneous or their order as unclear—which corresponds to the PSS. Where this assumption holds true, this

maximum should be displaced in primed trials, and it should be displaced by approximately the size of PLP. Accordingly, we might expect a three-way interaction of comparison–standard SOA, priming, and priming SOA.

This three-way interaction was indeed found ($F[24,264] = 7.4$, $p < .001$). Fig. 2 (below) shows that the expected displacement of the distributions is present. Additionally, the three-way ANOVA of the judgments revealed significant main effects of all variables (comparison–standard SOA: $F[8,88] = 26.85$, $p < .001$; priming: $F[1,11] = 10.39$, $p < .05$; priming SOA: $F[3,33] = 5.19$, $p < .01$). Two two-way interactions were significant (Priming × Comparison–standard SOA: $F[8,88] = 23.57$, $p < .001$; Priming SOA × Comparison–standard SOA: $F[24,264] = 4.74$, $p < .001$). The third two-way interaction just failed significance (Priming × Priming SOA: $F[3,33] = 3.51$, $p = .0533$). Two of the main effects provide interesting information: The main effect of priming is due to that the participants used the third category less frequently in primed than in unprimed trials (3.6% vs. 7.9%), and the main effect of priming SOA reflects the finding that the use of this category decreased with increasing priming SOA from 6.3% to 2.1%.

(2) We performed several moderator analyses (Baron & Kenny, 1986) with the average frequency of the "unclear/simultaneous" judgment as the moderator. First, we tested whether the effect of *priming* (with prime vs. without prime) as the independent variable on *PSS*, as the dependent variable, was moderated by the average frequency of "unclear/simultaneous" judgments. This had to be tested separately for each priming SOA. For the two smallest priming SOAs, the moderator was not influenced by the independent variable priming (SOA 34 ms: $\beta = -.22, p = .3$; SOA 68 ms: $\beta = -.31, p = .14$). In neither case did the moderator influence the dependent variable PSS (SOA 34 ms: $\beta = -.015$, $p = .74$; SOA 68 ms: $\beta = .02, p = .74$). For the two larger priming SOAs, the use of the third judgment category decreased in primed trials, so that an influence of the independent variable priming on the moderator was found (SOA 102 ms: $\beta = -.46$, $p < .05$; SOA 136 ms: $\beta = -.49$, $p < .05$). Again, however, the moderator did not influence the dependent variable PSS (SOA 102 ms: $\beta = -.16, p = .28$; SOA 136 ms: $\beta = -.11, p = .15$). As to be expected, the influence of the independent variable on the dependent variable was significant for all SOAs (all βs $\geqslant .73$, all ps $< .001$). This pattern remained when the influence of the moderator was controlled for (all βs $\geqslant .8$, all ps $< .001$).

We additionally checked whether the influence of *priming SOA* on *PLP* (the time course of priming) was moderated by the use of the "unclear/simultaneous" category. Again, the independent variable did not influence the moderator ($\beta = -.09$, $p = .53$). Neither did the moderator correlate with the dependent variable PLP ($\beta = -.02$, $p = .74$). The influence of priming SOA on PLP was significant ($\beta = .92$, $p < .001$) and remained significant when the moderator was controlled for ($\beta = .91$, $p < .001$). In sum, no sign of a moderating influence of the use of the third judgment category was found.

5.3. Discussion

To sum up the data pattern: Within the range of 34–136 ms, PLP increased nearly linearly with priming SOA. Although it reached values of more than 100 ms, it was reliably smaller than the priming SOA. Second, it was larger in "comparison first" judgments than in "standard first" judgments. We found no evidence that the use of the "unclear/simultaneous" category moderated the PLP effect. PLP was even visible in these judgments.

As a first conclusion from Experiment 1, "comparison first" judgments seem to provide the more exhaustive estimate of PLP than "standard first" judgments (cf. Scharlau, 2004a). "Comparison first" judgments are more frequent in trials in which the comparison precedes the standard stimulus. In these trials, prime and standard do not (or only rarely) compete for the capture of visuo-spatial attention (see Fig. 1): The prime leads the comparison which in turn leads the standard stimulus. The standard thus is late in the sequence and will not (or only rarely) capture attention away from the location indicated by the prime. In other words, "comparison first" judgments comprise a high proportion of trials with near optimal conditions for capture by the prime.

By contrast, "standard first" judgments are more frequent in trials in which the standard stimulus indeed leads the comparison. Therefore, "standard first" judgments comprise more of the trials in which the prime and the standard stimulus compete for attentional capture. If the standard stimulus in a trial captures attention away from the location indicated by the prime, no latency facilitation for the comparison stimulus can arise, and PLP as assessed in these trials is compromised. Based on this reasoning, PLP as estimated by the "comparison first" judgments is the more exhaustive measure of the priming effect, and on the basis of the AUM, PLP could be expected to approximate the size of the priming SOA. Yet, PLP did not reach the size of the priming SOA even in the "comparison first" judgments, that is, the trials with low competition. As a proportion of the priming SOA, PLP was at most 80%. We will return to the question what might account for this reduction of priming later on.

With the present procedure, a main finding from Experiment 1 is that PLP does not reach its peak before a priming SOA of 136 ms. Below this SOA, it steadily and linearly increases (remember that all PLP values differed from each other). That is, the peak location and maximum value of PLP lie at or beyond 136 ms, that is, clearly beyond the values of 80–90 ms found in the earlier studies (Scharlau, 2002; Scharlau & Neumann, 2003b).

Possibly, an advantage of the currently used ternary judgment—as compared to the two-choice judgment of the former studies—is responsible for the difference in the time course of PLP: With a ternary judgment, the observers can indicate uncertainty about the sequence. With the two-choice judgment of the earlier studies, the noise level possibly was increased because an order judgment was enforced in trials in which participants were unsure and would have rather refrained from giving an order judgment. This in turn might have compromised the sensitivity of the procedure for detecting PLP in the more extreme range of priming SOAs. (Recall that here, the prime is visible but to be disregarded in the order judgment, and it might be difficult to cope with that situation.)

In conclusion, ternary temporal-order judgments should be preferred, and in particular, "comparison first" judgments should be used to derive a more exhaustive estimate of PLP. The main reason is that with these two preconditions, a higher proportion of unequivocally judged trials with undisturbed near-optimal attentional capture by the prime will be reflected in PLP.

The analysis of the distribution of "unclear/simultaneous" judgments confirmed the PLP findings. The distribution of these judgments shifted in accord with perceived temporal order, that is, the maximum of the "unclear/simultaneous" judgments was displaced in accordance with the shift of PSS. Additionally, we found that priming decreased the use of the third judgment category. This may have arisen because the prime elicits a transient signal which is registered by the visual system and reduces the likelihood that the entire event is perceived as simultaneous. Onsets are generally difficult to mask (e.g., Breitmeyer & Ganz, 1976). Further, the "unclear/simultaneous" judgments are the less frequent, the larger the priming SOA is. This may result because it is easier to disentangle the transient signals of prime and visible stimuli if their temporal distance is large (e.g., Reeves, 1996). We will further test these possible explanations in Experiments 2–4.

6. Experiment 2

In Experiment 1, we investigated the time course of PLP below the supposed duration of an attention shift, including the smaller range of the lag of nonspecific activation. In the present experiment, we use priming SOAs of the approximate duration of an attention shift and above in the range of 170–510 ms. This is clearly beyond the lag of nonspecific activation. The original PRM predicted PLP to be sustained in this range, remaining at its maximum value (Bachmann, 1994). Recent results suggest that nonspecific modulation has its maximum 50–150 ms after prime onset and decreases again beyond this range (Bachmann & Sikka, 2005). According to the attentional explanation, a peak of facilitation is expected in between approximately 100–200 ms—the typical maximum of attentional effects (Hikosaka et al., 1993; Nakayama & Mackeben, 1989; Suzuki & Cavanagh, 1997) beyond which attentional facilitation should decline.

6.1. Method

Participants. Twelve volunteer participants (all female; mean age, 25 years) took part in the experiment and received € 11 or course credits. One participant did not return for the second session; her data from the first session were omitted from the analysis.

Apparatus did not differ from the apparatus of Experiment 1.

Stimuli did not differ from that of Experiment 1, except for the following: In Experiment 1, the prime was a similar, though smaller, version of the mask. This may occasionally have led the observers to judge the prime instead of the comparison stimulus. In order to reduce the opportunity for such confusion, we now used a dissimilar prime, a circle of 1.2° in diameter. (As a rule, similarity between prime and comparison stimulus has no influence at all on PLP, see Scharlau and Neumann, 2003a.) Six priming SOAs were used, ranging from 170 to 510 ms in steps of 68 ms. This increased the total number of trials to 1728 which were divided into two sessions of 864 trials each. The sessions were run on different days. Note also that within the range of priming SOAs used in the present experiment, masking is very weak or absent. For the sake of uniformity, we will still use the term 'prime', although 'cue' might be more appropriate. (Remember that both AUM and PRM assume that latency facilitation is independent of whether the prime is masked or not.)

Procedure was identical to that of Experiment 1.

6.2. Results

PLP results. Fig. 3 (upper right) illustrates two main findings: First, in the range between 170 and 510 ms, PLP decreased monotonically, but nonlinearly, with priming SOA. Second, it was larger as estimated by "comparison first" judgments. Both findings are supported by statistical analysis: The two-way ANOVA of PLP values revealed a main effect of priming SOA ($F[5, 50] = 7.02$, $p < .001$). Bonferroni comparisons at the .05-level showed that SOAs 170, 238, and 306 differed from SOAs 442 and 510. Second, there was a main effect of judgment ($F[1,10] = 5.94, p < .05$). The interaction failed to reach significance ($F[5,50] = 2.65, p = .09$).

PLP values ranged between 89 and 39 ms. Independent *t*-tests of the PLP values showed that all of them were significantly different from zero (all ps $\leqslant .05$, all ts $\geqslant 2.62$).

Again, mean PLP values were larger in “comparison first” than in “standard first” judgments. The difference was on average 22 ms and ranged from 16 to 26 ms.

The third judgment category. An ANOVA of the arcsine-transformed “unclear/simultaneous” judgments revealed a main effect of priming ($F[1,10] = 6.89, p < .05$) and a main effect of target SOA ($F[8,80] = 11.53, p < .001$). Priming SOA did not reach significance ($F[5,50] = 1.53, p = .23$). With one exception, all interactions were significant (Priming × Priming SOA: $F[5,50] = 3.39, p < .05$; Priming × Target SOA: $F[8,80] = 7.16, p < .05$; three-way interaction: $F[40,400] = 3.01, p < .05$). The interaction between priming SOA and target SOA just failed to reach significance ($F[40,400] = 2.26, p = .051$) (see Fig. 4).

In the moderator analysis of the possible moderating function of the frequency of the third judgment on the relationship between priming and PSS, judgment frequency was correlated with priming only for the smallest priming SOA of 170 ms ($\beta = -.47$, $p < .05$). With the priming SOA of 238 ms, the correlation just failed to reach significance ($\beta = -.42$, $p = .051$). All other correlations failed to reach significance ($-.28 \leqslant \beta \leqslant -.19$, all ps $\geqslant .21$). There was no significant correlation between judgment frequency and PSS as dependent variable ($-.25 \leqslant \beta \leqslant .02$, all ps $\geqslant .27$). As to be expected, the influence of the independent variable on the dependent variable was significant for all SOAs (all βs $\geqslant .57$, all ps $< .01$). This pattern remained when the influence of the moderator was controlled for (all βs $\geqslant .59$, all ps $< .01$).

No additional moderator analysis on the influence of priming SOA on PLP was performed. The moderator analysis requires a linear relationship between independent and dependent variable. This requirement was reasonably fulfilled in Experiment 1, but the time course of PLP is clearly nonlinear in Experiment 2.

6.3. Discussion

Experiment 2 demonstrated PLP within the range of 170–510 ms priming SOA. PLP decreased monotonically with priming SOA, and it differed from zero for all SOAs. PLP differences were only found to be significant between the smallest three and the largest two priming SOAs. That is, latency facilitation appears to be a rather sustained process with a maximum in between the largest priming SOA used in Experiment 1 (136 ms) and the smallest one used in Experiment 2 (170 ms). This—as well as the diminished but significant PLP effects at longer priming SOAs—accords well with data reported by Hikosaka et al. (1993) who found evidence for latency facilitation with SOAs up to 500 ms and possibly beyond. The results differ, however, clearly from our earlier studies in which no or only slight facilitation was found with priming SOAs of more than 100 ms (Scharlau, 2002; Scharlau & Neumann, 2003a). As explained in the discussion of Experiment 1, the fact that PLP estimates were formerly based on two-choice judgments likely increased noise levels in the former studies, which might be responsible for the different results (see also Scharlau, 2004a).

Note also that the maximum value of PLP was 85 ms in Experiment 2, that is, it was smaller than the maximum of 98 ms in Experiment 1. This reduction might be due to the fact that in the present experiment, PLP was measured beyond, but not at, the maximum of facilitation, but it is also possible that differences between the experimental samples are

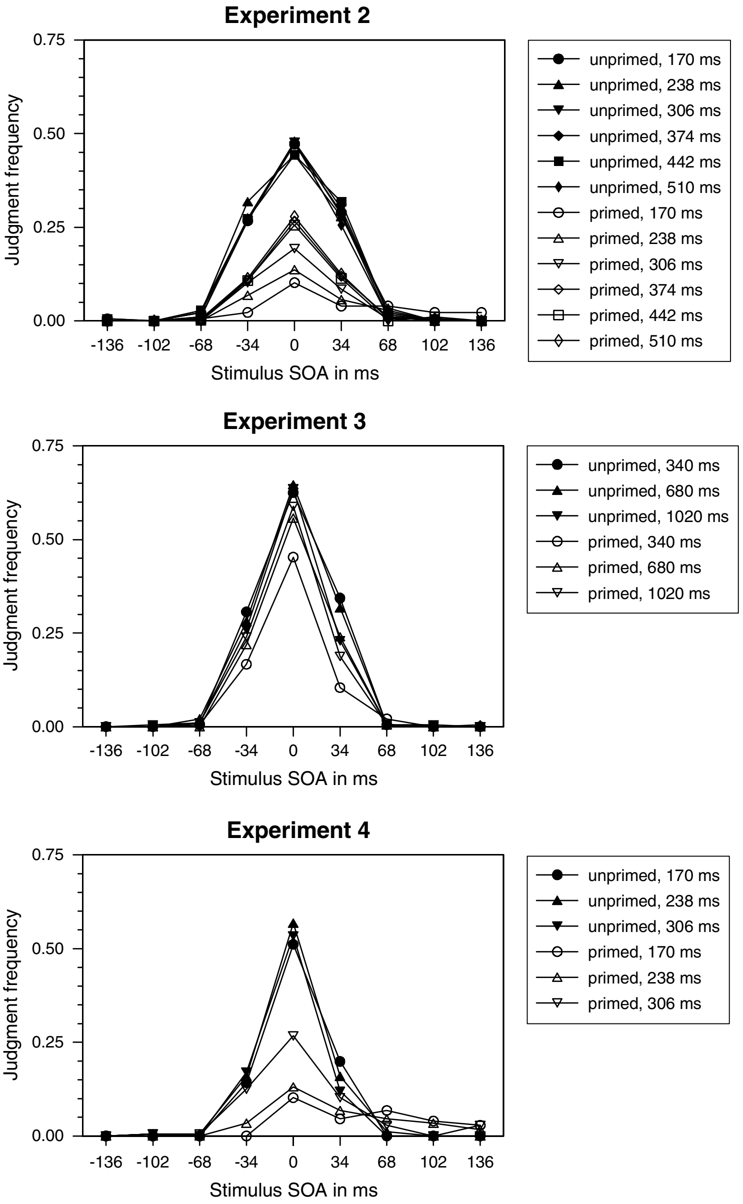

Fig. 4. “Unclear/simultaneous” judgments in Experiment 2 (top), Experiment 3 (middle) and Experiment 4 (below). Note that the *y*-axis ranges from 0 to .75.

responsible for the different sizes. We will return to this question in Section 9. Similar to Experiment 1, PLP as estimated by “standard first” judgments was smaller than PLP in the “comparison first” judgments.

Note also that, in contrast to the former experiment, it is consistent with expectations of both models for this range of SOAs that PLP is smaller than the priming SOA even in the "comparison first" judgments. In line with the attentional explanation by the AUM, if attention cannot be held at the prime's location but is instead deallocated back to fixation or distributed widely over the visual field some time after initial capture, no or reduced PLP for the primed stimulus is expected (cf. Posner & Cohen, 1984). According to the PRM, PLP should not rise above 50–80 ms, that is, the lag of nonspecific activation; and according to a recent revision of the PRM (Bachmann & Sikka, 2005), it may decline beyond 150 ms, predictions which well match the data pattern.

Experiment 2 again did not reveal the exact location of the peak of PLP because PLP decreased over the whole range of priming SOAs.

In the "unclear/simultaneous" judgments, we again found the expected three-way interaction of priming, priming SOA, and comparison–standard SOA. Fig. 4 (top), however, shows that the results differ from those of Experiment 1. Yet, they are quite systematic: Similar to Experiment 1, we again found that priming decreases the use of the third judgment category. It does so the less, the larger the priming SOA is. Different from the first experiment, the distribution of "unclear/simultaneous" judgments shows only a marginal tendency to be shifted towards the location of the PSS in primed trials. Remember, however, that finding PLP is not conditional on certain distributions of the unclear judgments. As mentioned above, the peak of the distribution of "unclear/simultaneous judgments" is usually assumed to mark the interval of uncertainty in which the point of subjective simultaneity is located. According to the findings of the present experiment, this is true for unprimed trials, but not for primed ones if—as in the present experiment—the priming SOA is large enough. Still, the likelihood of an "unclear/simultaneous" judgment in primed trials is slightly increased in the right part of the distribution where the PSS is located, too. This latter difference is very small, but it might be responsible for the three-way interaction.

7. Experiment 3

Experiment 2 revealed reliable PLP with large priming SOAs of up to 500 ms. In Experiment 3, we extend the range of priming SOAs even further. Attention-mediated latency facilitation has indeed been reported for priming SOAs as large as that, albeit with a related but different experimental paradigm (Hikosaka et al., 1993).

7.1. Method

Participants. Twelve volunteer participants (8 female, 4 male; mean age, 26 years) took part in the experiment and received € 6 or course credits. All participants had normal or corrected-to-normal vision.

Apparatus did not differ from that of Experiment 1.

Stimuli did not differ from that of Experiment 2 apart from that the three priming SOAs of 340, 680, and 1020 ms were used. The total number of trials was 864.

Procedure was identical to that of Experiment 1.

7.2. Results

PLP results. Fig. 3 (lower left) illustrates two main findings: First, PLP decreased monotonically with priming SOA. Second, it was larger as estimated by "comparison first" judgments, although the difference might be marginal for the longest priming SOA. Both findings are supported by statistical analysis: The two-way ANOVA of PLP values revealed a main effect of priming SOA ($F[2, 22] = 11.0$, $p < .05$). Bonferroni comparisons at the .05-level showed that all SOAs differed from each other. Second, there was a main effect of judgment ($F[1, 11] = 5.91$, $p < .05$), and an interaction ($F[2, 22] = 4.55$, $p < .05$).

PLP values were in the range of 10–50 ms. Independent t-tests of PLP values showed that all of them were significantly different from zero (all ps < .05, all ts $\geqslant$ 2.84).

Again, mean PLP values were larger as estimated by “comparison first” judgments. The difference was on average 10 ms and ranged from 18 to 3 ms.

The third judgment category. In the ANOVA of the “unclear/simultaneous” judgments, only the main effect of target SOA ($F[8, 88] = 40.52$, $p < .001$) and the interaction of target SOA and priming ($F[8, 88] = 4.96$, $p < .05$) reached significance. Priming ($F[1, 1] = 4.73$, $p = .052$) and priming SOA ($F[2, 22] = 1.6$, $p = .23$) failed significance, as well as all further interactions (Priming × Priming SOA: $F[2, 22] = 3.6$, $p = .07$; Priming SOA × Target SOA: $F[16, 176] = 1.59$, $p = .18$, three-way interaction: $F[16, 176] = 2.22$, $p = .06$).

In the moderator analysis of the possible moderating function of the frequency of the third judgment on the relationship between priming and PSS, judgment frequency was neither correlated with priming as the independent variable for any of the SOAs ($-.31 \leqslant \beta \leqslant 0$, all ps $\geqslant$ .15), nor was it correlated with the dependent variable, PSS ($-.32 \leqslant \beta \leqslant 0$, all ps $\geqslant$ .13). As to be expected, the influence of the independent variable on the dependent variable was significant for all SOAs (all βs $\geqslant$ .59, all ps < .05). This pattern remained the same when the influence of the moderator was controlled for (all βs $\geqslant$ .59, all ps < .05).

Again, no moderator analysis on the influence of judgment frequency on the relationship between priming SOA and PLP was performed, for the same reason as in Experiment 2.

7.3. Discussion

Experiment 3 proved PLP for SOAs as long as 1020 ms, that is, in the far sustained range of attention. Albeit small, PLP was significant and revealed the typical features of dependence on priming SOA and judgment. Also, the present results support the claim of Hikosaka et al. (1993) that latency facilitation might be present with SOAs of up to 1000 ms. PLP decreased monotonically in the range of 340–1020 ms. Again, it was smaller in “standard first” than in “comparison first” judgments.

From the findings of Experiment 3, we cannot conclude that priming influenced the distribution of “unclear/simultaneous” judgments. Priming was not significant as a main effect, and it entered only into one significant interaction (Priming × Target SOA), probably due to a small asymmetry of the primed distributions. Also, some of the main effects and interactions were close to significance, so that it would be premature to draw any definite conclusions from Experiment 3.

8. Experiment 4

One of the main goals of the present study is to estimate the maximum—peak location and maximum value—of PLP and thus decide between the AUM and the PRM as possible explanations of perceptual-latency facilitation. Although the data so far indicate a fairly late peak and thus speak in favour of the AUM, they are not decisive as to the exact location of the peak: Experiment 1 seemingly measured below the peak, Experiment 2 beyond it. So far, we can only conclude that the peak lies between 136 and 306 ms, 136 ms indicated as the lower limit by Experiment 1, and 170–306 ms marked as the upper limit by Experiment 2 (recall that no significant differences between the SOAs 170, 238, and 306 ms were found in Experiment 2). In Experiment 4, we aim at a finer estimate.

8.1. Method

Participants. Twelve volunteer participants (10 female, 2 male; mean age, 24 years) took part in the experiment and received € 6 or course credits.

Apparatus did not differ from that of Experiment 1.

Stimuli did not differ from that of Experiment 3 apart from that the three priming SOAs of 136, 204, and 272 ms were used.

Procedure was identical to that of Experiment 1.

8.2. Results

PLP results. One participant was not able to discriminate temporal order (interquartile difference of the psychometric distribution > than 400 ms). Her data were omitted from further analysis. Fig. 3 (lower right) illustrates two main findings: First, the peak of latency facilitation seems to lie at approximately 200 ms. Second, PLP as estimated by "comparison first" judgments was again larger than PLP as estimated by "standard first" judgments. However, statistical analysis does not confirm this impression. Albeit there was a main effect of judgment ($F[1, 10] = 9.14, p < .05$), neither priming SOA ($F[2, 20] = 2.47, p = .14$) nor the interaction reached significance ($F[2, 20] = 1.67, p = .23$).

PLP values ranged from 53 to 97 ms. Independent t-tests of PLP values showed that all of them were significantly different from zero (all ps < .05, all ts ⩾ 3.06).

Again, mean PLP values as estimated by "comparison first" judgments were larger than those from the "standard first" judgments. The difference was on average 16 ms and ranged from 10 to 20 ms.

Analysis of the third judgment category. The ANOVA of the arcsine-transformed "unclear/simultaneous" judgments revealed three main effects (priming: $F[1, 10] = 6.69$, $p < .05$; priming SOA: $F[2,20] = 4.18$, $p < .05$; target SOA: $F[8, 80] = 17.87$, $p < .001$). Two two-way interactions also reached significance (Priming × Target SOA: $F[8, 80] = 11.6$, $p < .001$; Priming SOA × Target SOA: $F[16, 160] = 3.88, p < .05$). The interaction of priming and priming SOA failed to reach significance ($F[2, 20] = 3.48, p = .08$), as well as the three-way interaction ($F[16, 160] = 2.22, p = .09$).

In the moderator analysis of the possible moderating function of the frequency of the third judgment on the relationship between priming and PSS, the correlation of judgment frequency with the independent variable priming just failed significance for two of the priming SOAs (136 ms: $\beta = -.39$, $p = .08$; 204 ms: $\beta = -.4$, $p = .07$; 204 ms: $\beta = -.26$, $p = .24$). Judgment frequency was correlated with PSS in one case (204 ms: $\beta = -.44$, $p < .05$) and just failed significance for the others (136 ms: $\beta = -.41, p = .06$; priming SOA 272 ms: $\beta = -.42$, $p = .052$). However, the influence of the independent variable on the dependent variable was significant for all SOAs (all βs ⩾ .59, all ps < .05). This pattern remained the same when the influence of the moderator was controlled for (all βs ⩾ .51, all ps < .05).

A further moderator analysis on the influence of the frequency of the third judgment on the relationship between priming SOA and PLP was not performed. For the reason, see Experiment 2.

8.3. Discussion

Experiment 4 aimed at more precisely localising the peak of facilitation within the range of 136–272 ms. PLP was found for each priming SOA, and it was again larger in the "comparison first" than in the "standard first" judgments. However, it did not depend on priming SOA. Experiment 4 thus failed to render any conclusive evidence with respect to its central question. Numerically, the peak of facilitation is located at 200 ms priming SOA. Statistically, however, there was no evidence for a difference between the PLP values in the SOA range of 136–272 ms. Rather than a sharp peak, we found a broad maximum. A similar lack of significant differences between different priming SOAs was found in Experiment 2. Cautiously interpreted, Experiments 2 and 4 support the conclusion that the maximum of PLP lies within the range of 136–272 ms. This range of maximal facilitation corresponds well to the maxima of attentional facilitation revealed in other accuracy measures or judgment paradigms (Hikosaka et al., 1993; Nakayama & Mackeben, 1989; Suzuki & Cavanagh, 1997). By contrast, it lies clearly beyond the maximum expected by the original PRM, and even the estimate of 50–150 ms in a recent paper on perceptual retouch (Bachmann & Sikka, 2005) deviates from the present pattern of results.

Note also that in Experiment 4 as well as in all other experiments, the time course of PLP was fairly similar for the "comparison first" and "standard first" sequences. As in Experiments 1 and 2, we did not find evidence for different peak locations in these two types of judgments—contrary to the argument made in Section 1. The low peak locations of PLP found in the earlier studies (Scharlau, 2002; Scharlau & Neumann, 2003b) thus are not due to the fact that the time course of PLP is different for these two types of judgments.

With respect to the "unclear/simultaneous" judgments, Fig. 4 (below) again shows a decisive pattern: Priming decreases the probability with which the third judgment category is used, and it does so more clearly when the priming SOA is small. Similar to Experiment 2, the primed distributions do not show a very clear peak, especially for the small priming SOAs. We did not find evidence that the "unclear/simultaneous" judgments moderated the priming effect. Different from the preceding experiments, the moderator analysis revealed a slight tendency for a strategic bias in the "unclear/simultaneous" judgments: They tended to be less frequent in primed trials, and there was a tendency towards an influence on PSS. This tendency, however, was significant only for the priming SOA of 204 ms.

9. General discussion

In the following, we will (1) discuss the use of different judgments to estimate PLP and additional findings on the time course of the "unclear/simultaneous" judgments, (2) summarise the time course of PLP, (3) compare the size of PLP across experiments, and (4) discuss the two explanations of PLP we compared in this paper. This will be followed by (5) remarks on possible further explanations of PLP. Finally (6), we will elaborate on the notion of spatial attention in the AUM.

(1) In all of the experiments reported above, we found that PLP as estimated by "comparison first" judgments was larger than PLP as estimated by "standard first"

judgments. As argued in Section 1, a likely reason for this finding is that with a "standard first" judgment there is a higher probability of competition for attention between prime and standard stimulus before the onset of the comparison stimulus. Instead of the prime, the standard stimulus might capture attention which compromises the prime's facilitating influence on the perception of the comparison stimulus. By contrast, with "comparison first" judgments, prime and standard compete less because prime and comparison stimulus lead the standard stimulus in the majority of cases. These conditions are suitable to measure an almost uninterrupted facilitation of mask perception by the preceding prime. These considerations render a methodological recommendation necessary. The standard binary TOJ, which averages across conditions with high and low competition between prime and standard stimulus, is not apt for exhaustively estimating PLP.

Note, however, that although we were apparently successful in separating two conditions with different degrees of competition and thus different degrees of latency facilitation, we seemingly did not abolish competition. Far from it, the fact that all PLP values clearly fell short of the priming SOA (see Experiment 1) indicates that at least some interference or competition remained. Whether this is specific interference with attentional capture by the standard stimulus (e.g., Neumann, 1978) or more unspecific, nonspatial filtering costs (Kahneman, Treisman, & Burkell, 1983), or whether it may be explained by the PRM's notion that nonspecific modulation, once arrived at the cortex, need not instantly upgrade the specific codes, cannot be decided on the basis of the present results.

We thus suggest that, as long as there is no means of directly measuring perceptual latency, it is advisable to assess latency facilitation separately for "comparison first" and "standard first" judgments. It may be noted in the passing that the present results also add to existing evidence that the binary TOJ is insufficient to test models of temporal perception (Ulrich, 1987). These advantages of ternary judgments may compensate for a disadvantage of the inclusion of "unclear" judgments, namely that observers may be better at discriminating when forced to decide between two alternatives in cases in which they would rather judge "unclear". That is, the perceptual system may be better than the conscious observer believes he or she is.

Interestingly, the "unclear/simultaneous" judgments showed some time course, too. It seems to consist of three stages (see Figs. 2 and 4):

(a) Up to approximately 100 ms priming SOA, the peak of these judgments shifts in accord with PLP, that is, the peak accompanies the PSS. Within this range, the frequency of the "unclear/simultaneous" judgment decreases with increasing priming SOA.

(b) Above 300 ms priming SOA, the peak is located at objective simultaneity, and any tendency to give more "unclear/simultaneous" judgments at target SOAs in which the standard leads the comparison stimulus has disappeared. Within this range, the frequency of the "unclear/simultaneous" judgments increases with increasing priming SOA.

(c) For priming SOAs between 100 and 300 ms, the distribution of "unclear judgments" shows a mixture of these two stages. The distribution may have two peaks (e.g., priming SOA 136 ms in Experiment 1), or one peak, accompanied by an asymmetry with more "unclear/simultaneous" judgments in the right than in the left part of the distribution (e.g., priming SOA 170 in Experiment 2).

In sum, the overall frequency of the "unclear/simultaneous" judgments in primed trials, mirrors the time course of PLP: It decreases up to approximately 150 ms priming SOA and increases afterwards, approaching the baseline (unprimed trials) for the longest priming SOAs. The PLP findings are further supported by the shift in the peak of the distribution of "unclear simultaneous" judgments: For priming SOAs up to 136 ms, they peak in the interval of uncertainty which accompanies the PSS. Beyond this value, the shift disappears. This lack of a shift and the apparent double peak and asymmetries in some of the intermediate SOAs (see Fig. 4) do not provide any conclusive evidence for this range of priming SOAs. Recall further that we did not find any evidence that the use of the third judgment category moderated the priming effect in Experiments 1–4 and the time course of PLP in Experiment 1.

Further, it might be premature to draw any conclusion from the findings on the "unclear/simultaneous" judgments. The third judgment category combined an "unclear" with a "simultaneous" judgment. Possibly, the criteria for ascribing "simultaneity" and those for ascribing "unclarity" may have worked in the same direction for small priming SOAs, but in different directions for longer ones. With long priming SOAs, the two targets, when they indeed appear simultaneously, produce only one onset signal and may thus appear as a single object consisting of two parts. The visual system might be able to register this single transient signal (or the absence of a second transient signal), even if, at a later stage of processing, one of the stimuli is sped up by attention. Thus, the system registers simultaneity on one level—the feature level—and asynchrony on another—the conscious or post-attentional level. Whether these two meanings of the third judgment category—"simultaneity" and "unclarity"—are, for example, responsible for the ill-defined and asymmetrical distributions of "unclear/simultaneous" judgments for the intermediate SOAs has to be clarified by disentangling the "unclear" from the "simultaneous" judgment in future experiments.

(2) PLP rises linearly with priming SOA up to at least 128 ms (Experiment 1). Between 136 and 272 ms, no marked time course was revealed in our data. Beyond 272 ms, PLP monotonically decreases, but there is still some residual facilitation with a priming SOA of approximately 1000 ms. Although it is not possible to estimate the exact peak of PLP from the data, we can conclude that it lies between 136 and 272 ms. This time course agrees with data from other attention-related paradigms, such as vernier discrimination (Nakayama & Mackeben, 1989), the attentional repulsion effect (Suzuki & Cavanagh, 1997), and illusory line motion (Hikosaka et al., 1993). The latter agreement is especially important, because illusory line motion is ascribed to the same mechanism as PLP, latency facilitation within the focus of attention, though measured on a different processing level (motion perception). There is further evidence that PLP and illusory line motion are closely related (Scharlau, 2004b), although their spatial properties seem to differ (Scharlau, 2004c).

(3) Fig. 5 collapses the data from all four experiments illustrating the time course of PLP within the range of 34–1020 ms. One feature is conspicuous: The size of PLP seems to vary considerably between experiments. For example, Experiments 1 and 4 both included a priming SOA of 136 ms, but PLP was 98 and 81 ms in Experiment 1 and only 68 and 50 ms in Experiment 2. A similar difference holds for the possible offset between Experiments 1 and 2 (although there were no identical, only neighbouring, SOAs in these two experiments). As a possible reason, the total of the experimental conditions may influence the amount to which an observer lets his or her attention be captured by a stimulus. For example, all of the primes were visible in Experiment 2 because there is no effective metacontrast

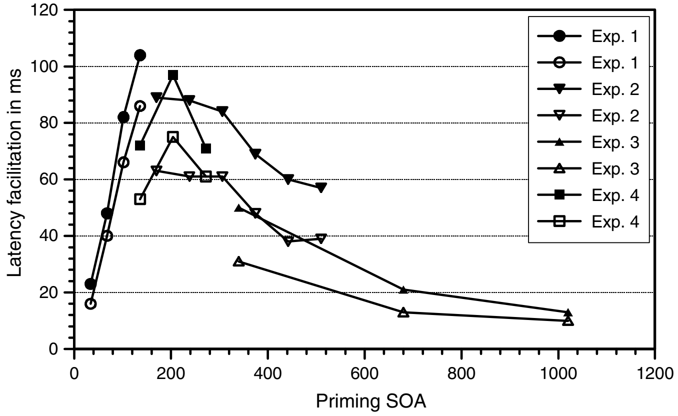

Fig. 5. PLP results collapsed across experiments. Solid symbols: "comparison first" judgments (low competition between prime and standard). Open symbols: "standard first" judgments (high competition between prime and standard).

masking at SOAs larger than 100 ms (e.g., Breitmeyer, 1984). Note that the primes were by instruction irrelevant for the task: The observers had to judge the square and the diamond and to ignore the prime if they saw it. The observers should have been able to see it in all conditions of Experiment 2, but much less frequently in Experiment 1, in which half of the priming SOAs were in the range of excellent masking. Consequently, in Experiment 2, they may have more frequently than in Experiment 1 either not directed attention towards the prime's location or, after initial capture, quickly redirected attention away from it. A similar explanation holds for the difference between Experiments 2 and 3. Due to the large priming SOAs in Experiment 3, the observers should have been able to redirect attention away from the prime's location in many of the trials. Thus, Fig. 5 might be an oversimplification with respect to the exact values of PLP.

By the same logic, it can be explained why PLP is positive in the whole range of SOAs, that is, why we observed facilitation at the primed location even for the longest priming SOA, instead of inhibition of return (IOR; Klein, 2000). IOR is often regarded as an integral part of the operation of visuo-spatial attention. This missing of IOR might have several reasons: First, IOR may be present in the data, but weaker than facilitation, so that latency facilitation is only reduced, not abolished (see Li and Lin, 2002, for similar results). Second, there is a debate as to how far and under which stimulus conditions IOR takes place in TOJs (Gibson & Egeth, 1994; Li & Lin, 2002; Maylor, 1985) or tasks with sequential stimulation at multiple locations (Birmingham & Pratt, 2005). Also, IOR is less pronounced if the cue is predictive or matches the target set (e.g., Ansorge & Heumann, 2003, 2004), conditions which are met by the present displays.

(4) As detailed in Section 1, PLP can be explained by at least two rivalling models, the AUM and the PRM. The first ascribes PLP to the facilitating influence of visuo-spatial attention, the second relates it to the temporal asynchrony of specific and nonspecific afferent processes. Taken as a whole, the data of the current investigation favour the AUM which predicts that the peak of PLP should coincide with the duration of an attention shift. By contrast, the PRM predicts an earlier peak tied to the asynchrony of specific and nonspecific afferent processes (50–80 or 150 ms). This is disproved by the pattern of results.

The present findings add to existing evidence favouring an attentional explanation of PLP. Because of the poor spatial resolution of thalamic neurons (Crick, 1984; Scheibel & Scheibel, 1970), for example, perceptual retouch is assumed to be spatially imprecise as compared to, for example, metacontrast masking. PLP, however, can show a precise spatial organisation, such as split foci (Scharlau, 2004c). Also, PLP is influenced by whether the masked prime matches the current target set (Scharlau & Ansorge, 2003). Attentional control, but not perceptual retouch, is open to top-down influences. On the other hand, the PRM offers an explanation for the robust finding that PLP is smaller than the priming SOA, even under optimal conditions for attentional capture. Perceptual retouch might not begin immediately upon the arrival of the first nonspecific signal at the cortex. The specific cortical neurons might need a large number of presynaptic impulses accumulating over time in order for the upgrading process to begin. Consequently, latency facilitation does not have to begin with the first nonspecific impulses, and thus, PLP should be less than the full priming SOA. By the same argument, one could explain why the peak location of PLP does not coincide with the maximum of metacontrast masking (Bachmann, personal communication).

Note also that we do not claim that all latency facilitation is necessarily due to visuo-spatial attention. Our argument is that latency facilitation induced by a masked prime is more likely to be caused by visuo-spatial attention than by perceptual retouch. This does not exclude the possibility that perceptual retouch—or other mechanisms—leads to latency facilitation in other situations (e.g., Bachmann, Põder, & Luiga, 2004; Rorden, Mattingley, Karnath, & Driver, 1997; Stelmach & Herdman, 1991). The PRM would also be able to explain latency facilitation when the stimuli appear at fixation, that is, when an attention shift is improbable. Data in favour of this possibility have been reported by Bachmann (1989).

(5) Are there other possible explanations of PLP? Stelmach and Herdman (1991) have proposed a *temporal-profile model* of prior entry (attention-related facilitation which includes voluntary and reflexive shifts of attention). Different from the two explanations discussed so far—which at the core put PLP down to a head-start in consciousness-related processing—, this model assumes that prior entry is due to the fact that the temporal profile of the representation of an attended stimulus is sharpened. Apart from predicting PLP, this model also assumes that attended stimuli are perceived as shorter than unattended stimuli. The latter has been disproved by Enns, Brehaut, and Shore (1999), who used peripheral cues and found a prolonging rather than a shortening (see also Downing and Treisman, 1997; but see Chen and O'Neill, 2001; Mattes and Ulrich, 1998, for different results with attention being manipulated by instruction or central cues). More important in our context, the current version of the temporal-profile model does not make any predictions about the time course of PLP.

Alternatively, the model of *object substitution* may provide an explanation of PLP. As AUM and PRM, it is a very general theory of visual masking and illusions in the perception of dynamic stimuli (Di Lollo, Enns, & Rensink, 2000). One main difference to AUM and PRM is that it relies on re-entrant processing whereas the former are feed-forward models. Masking is explained by assuming that the prime is replaced by the mask while re-entrant processing cycles are executed. Within these cycles, a hypothesis about the perceptual input which has been made up in higher processing areas is checked against the current input in lower areas. In metacontrast masking, a mismatch between hypothesis (about the prime) and current input (the mask) is detected in the first cycle. Within the next cycle, the prime is substituted by the mask on the level of the hypothesis or object information which is then again checked against the current input.

Object substitution thus can take the form that the prime initiates the establishment of an object file, but the mask may make up its final content (Lleras & Moore, 2003).[4] In this case, the prime could also pre-date the object file of the mask, that is, PLP should arise (see Kahneman, Treisman, and Gibbs, 1992, for a related case). It is yet unclear whether this explanation goes in line with the more specific features of PLP. For instance, one should assume that if both prime and mask are visible, each of them is assigned its own object file. In that case, no PLP is expected. As mentioned, we found the same size of PLP for masked as well as for visible primes (Scharlau & Neumann, 2003a). This does not agree well with the model of object substitution.

However, this is speculation. As a first step, it would be important to derive from the object-substitution model how long feedback cycles take in displays similar to those used in the present studies. On the basis of this information, one should be able to predict the time course of PLP. In V1, the influence of feedback activity is especially prominent at 80–150 ms (Lamme, 2000; Walsh & Cowey, 1998). Yet, it is unclear whether this activity coincides with hypothesis re-entrance which is the main mechanism of object substitution. Independent of object substitution, it seems a promising topic to investigate whether re-entrant processes contribute to PLP.

Besides these theoretically elaborate alternatives, other contributions to PLP-like effects are possible. For example, the processing of the prime may facilitate sensory processing of the mask (*sensory-facilitation* or *perceptual-priming explanation*). Further, it is possible that the prime induces a bias to report the stimulus at the prime's location as the first one, that is, the participants might ascribe the criterion ("being the first stimulus") to the primed stimulus (*response-bias argument*; see Pashler, 1998). Finally, the observers may confuse the onsets of prime and mask or misbind the prime's onset to the mask (*onset-confusion account*). None of these explanations is supported by earlier empirical evidence. First, PLP is independent of whether the prime resembles the mask or not (Scharlau & Neumann, 2003a). Thus, sensory facilitation or perceptual priming are not a possible explanation for PLP effects in these earlier studies. Second, response or judgment tendencies do not contribute to PLP. Scharlau (2004a) showed that the observers have no bias to ascribe the criterion ("being the first stimulus" or "being the last stimulus") to the primed stimulus. Third, observers misperceive the mask's onset although they correctly date the prime. For example, they are able to synchronize tapping correctly with the prime's onset if they are instructed to do so, whereas tapping in synchrony with the mask's onset reveals PLP (Aschersleben, 1999; see also Scharlau, 2002). Thus, temporal integration or confusion of prime and target probably do not contribute to PLP. The latency-priming hypothesis is further supported by numerous studies on the facilitating influence of instructed or cued attention on the perceived onset of a stimulus (e.g., Rorden et al., 1997; Shore, Spence, & Klein, 2001; Stelmach, Campsall, & Herdman, 1997; Stelmach & Herdman, 1991).

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[4] Note that this is only one interpretation of object substitution. The authors themselves are much less specific about the level of substitution ("replaced in consciousness", Di Lollo et al., 2000, p. 485). Further, Jiang and Chun (2001) assume that the object file initiated by the prime is substituted by a new object file for the mask. In contrast to the suggestion of Lleras and Moore (2003), these latter two explanations do not predict any temporal, PLP-related effect of the prime.

(6) The AUM ascribes PLP to visuo-spatial selective attention (Scharlau & Neumann, 2003a) which selects stimuli for prioritized processing, especially consciousness-related processing and integrated processing in which several simple features are bound into an object representation. In the light of a large body of evidence in favour of the decisive role of attention for conscious processing (e.g., LaBerge, 1997; Mack & Rock, 1998; Posner, 1994; Rensink et al., 1997; Treisman, 1988), this is a plausible assumption (but see Lamme, 2003).

Visuo-spatial attention further fulfils the criterion of being able to explain the special features of PLP mentioned in Section 1: It can be triggered by conscious as well as nonconscious information (e.g., Jaśkowski et al., 2002), and it is open to top-down control (e.g., Folk, Remington, & Johnston, 1992).

On the other hand, one might wonder why attention should be involved in a task which requires—as the TOJ in our case does—only processing of simple features (shape; e.g., Treisman, 1988). There are several possible answers to this question.

First, attentional effects for the processing of simple features have indeed been reported (e.g., Ansorge & Heumann, 2003). That is, in contrast to the assumption of feature integration theory, attention might be involved even in the processing of simple features. Second, as a judgment task, the TOJ might require conscious availability of the judged content. There is a broad consensus that consciousness presupposes attention, that is, stimuli can only be consciously perceived if they are attended to.

Let us finally point to a recent convergence in studies on visuo-spatial attention. Generally regarded, the TOJ can be conceived of as a method which assesses attentional facilitation by *order reversals*: attention increases the probability that the attended stimulus is perceived (as) earlier than a reference event, although it in fact trails the reference event. Attention thus increases the probability of order reversals. Order reversals have proven to be a useful means for investigating attention in different paradigms. For instance, Akyürek and Hommel (2005) used order reversals as a means for assessing the attentional blink.

The attentional blink occurs when people monitor a stream of stimuli presented in rapid succession for targets (cf. Raymond, Shapiro, & Arnell, 1992). The second of two targets is often missed, except for streams in which it immediately trails the first target, a phenomenon which is called lag-1 sparing. Akyürek and Hommel (2005) showed that attentional gating—opening or closing an attentional gate after targets are detected—is responsible for lag-1 sparing, and that closing the attentional gate is under endogenous control. The gate closes when enough information has accumulated to identify the target, irrespective of further distractors intervening.

Further, Bachmann et al. (2004) found order reversal for a pair of stimuli in which the first stimulus had a considerably higher contrast than the second one. Besides other explanations, an attentional bias towards the dimmer stimulus can account for their findings. Together with the present results, these findings demonstrate that temporal-order perception is a useful, so far neglected, means for investigating attentional facilitation.

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References

Akyürek, E. G., & Hommel, B. (2005). Target integration and the attentional blink. *Acta Psychologica, 119*, 305–314.

Ansorge, U. (2003). Asymmetric influences of temporally vs. nasally presented masked visual information: Evidence for collicular contributions to nonconscious priming effects. *Brain and Cognition, 51*, 317–325.

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

Ansorge, U., & Heumann, M. (2003). Top-down contingencies in peripheral cuing: The roles of color and location. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 937–948.

Ansorge, U., & Heumann, M. (2004). Peripheral cuing by abrupt-onset cues: The influence of color in S-R corresponding conditions. *Acta Psychologica, 116*, 115–143.

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

Ansorge, U., & Neumann, O. (2005). Intentions determine the effect of invisible metacontrast-masked primes: Evidence for top-down contingencies in a peripheral cueing task. *Journal of Experimental Psychology: Human Perception and Performance, 31*.

Aschersleben, G. (1999). Task-dependent timing of perceptual events. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events* (pp. 293–318). Amsterdam: Elsevier.

Baars, B. (1995). Tutorial commentary: Surprisingly small subcortical structures are needed for the state of waking consciousness, while cortical perception areas seem to provide perceptual contents of consciousness. *Consciousness & Cognition, 4*, 159–162.

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

Bachmann, T. (1989). Microgenesis as traced by the transient paired-forms paradigm. *Acta Psychologica, 70*, 3–17.

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

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

Bachmann, T., Põder, E., & Luiga, I. (2004). Illusory reversal of temporal order: The bias to report a dimmer stimulus as the first. *Vision Research, 44*, 241–246.

Bachmann, T., & Sikka, P. (2005). Perception of successive targets presented in invariant-item streams. *Acta Psychologica, 120*, 19–34.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*, 1173–1182.

Birmingham, E., & Pratt, J. (2005). Examining inhibition of return with onset and offset cues in the multiple-cuing paradigm. *Acta Psychologica, 118*, 101–121.

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., & Chen, J. (2004). Unconscious priming by color and form: Different processes and levels. *Consciousness and Cognition, 13*, 138–157.

Chen, Z., & O'Neill, P. (2001). Processing demand modulates the effects of spatial attention on the judged duration of a brief stimulus. *Perception & Psychophysics, 63*, 1129–1138.

Crick, F. (1984). Function of the thalamic reticular complex: The searchlight hypothesis. *Proceedings of the National Academy of Sciences USA, 81*, 4586–4590.

Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for consciousness among visual events: The psychophysics of reentrant visual processes. *Journal of Experimental Psychology: General, 129*, 481–507.

Downing, P., & Treisman, A. (1997). The line-motion illusion: Attention or impletion? *Journal of Experimental Psychology: Human Perception and Performance, 23*, 768–779.

Edelman, G. M. (1989). *The remembered present: A biological theory of consciousness*. New York: Basic Books.

Enns, J. T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research, 44*, 1321–1331.

Enns, J. T., Brehaut, J., & Shore, D. I. (1999). The duration of a brief event in the mind's eye. *Journal of General Psychology, 126*, 355–372.

Fehrer, E., & Raab, D. (1961). 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.

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

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

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. *Vision Research, 33*, 1219–1240.

Jaśkowski, 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.

Jiang, Y., & Chun, M. M. (2001). Asymmetric object substitution masking. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 895–918.

Kahneman, D., Treisman, A. M., & Burkell, J. (1983). The cost of visual filtering. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 510–522.

Kahneman, D., Treisman, A. M., & Gibbs, B. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24*, 175–219.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4*, 138–147.

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

LaBerge, D. (1997). Attention, awareness, and the triangular circuit. *Consciousness and Cognition, 6*, 149–181.

Lamme, V. A. F. (2000). Neural mechanisms of visual awareness: A linking proposition. *Brain and Mind, 1*, 385–406.

Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences, 7*, 12–18.

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

Li, C. R., & Lin, S. (2002). Inhibition of return in temporal order saccades. *Vision Research, 42*, 2089–2093.

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

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

Mattes, S., & Ulrich, R. (1998). Directed attention prolongs the perceived duration of a brief stimulus. *Perception & Psychophysics, 60*, 1305–1317.

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. 189–203). Hillsdale, NJ: Erlbaum.

Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision Research, 29*, 1631–1647.

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. (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., Esselmann, U., & Klotz, W. (1993). Differential effects of visual–spatial attention on response latency and temporal-order judgment. *Psychological Research, 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, MA: MIT Press.

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

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.

Posner, M. I. (1994). Attention. *Proceedings of the National Academy of Sciences USA, 91*, 7398–7403.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–556). Hillsdale, NJ, US: Erlbaum.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task—an attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 849–860.

Reeves, A. (1982). Metacontrast U-shaped functions derive from two monotonic processes. *Perception, 11*, 415–426.

Reeves, A. (1996). The visual perception of time: Temporal resolution. In W. Prinz & B. Bridgeman (Eds.), *Handbook of perception and action* (Vol. 1). *Perception* (pp. 11–24). New York: Academic Press.

Rensink, R. A. (2000). Seeing, sensing, and scrutinizing. *Vision Research, 40*, 1469–1487.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8*, 368–373.

Rorden, C., Mattingley, J. B., Karnath, H.-O., & Driver, J. (1997). Visual extinction and prior entry: Impaired perception of temporal order with intact motion perception after unilateral parietal damage. *Neuropsychologica, 35*, 421–433.

Scharlau, I. (2002). 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. (2004a). Evidence against a response bias in temporal order judgments with attention manipulation by masked primes. *Psychological Research, 68*, 224–236.

Scharlau, I. (2004b). Illusory line motion and perceptual latency priming: Two alternative measures for attentional facilitation. In R. P. Würtz & M. Lappe (Eds.), *Dynamic perception* (pp. 127–132). Berlin, Amsterdam: AKA IOS Press.

Scharlau, I. (2004c). Spatial distribution of visual attention in perceptual latency priming. *The Quarterly Journal of Experimental Psychology (A), 57*, 1411–1437.

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

Scharlau, I., & Neumann, O. (2003a). Perceptual latency priming by masked and unmasked stimuli: Evidence for an attentional explanation. *Psychological Research, 67*, 184–197.

Scharlau, I., & Neumann, O. (2003b). Temporal parameters and time course of perceptual latency priming. *Acta Psychologica, 113*, 185–203.

Scheibel, M. E., & Scheibel, A. B. (1970). Elementary processes in selected thalamic and cortical subsystems—the structural substrates. In F. O. Schmidt (Ed.), *The neurosciences. Second study program* (pp. 443–457). New York: Rockefeller University Press.

Shelley-Tremblay, J., & Mack, A. (1999). Metacontrast masking and attention. *Psychological Science, 10*, 508–515.

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

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, 63*, 36–47.

Stelmach, L., Campsall, J., & Herdman, C. M. (1997). Attentional and ocular movements. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 823–844.

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.

Suzuki, S., & Cavanagh, P. (1997). Focused attention distorts visual space. An attentional repulsion effect. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 443–463.

Tata, M. S. (2002). Attend to it now or lose it forever: Selective attention, metacontrast masking, and object substitution. *Perception & Psychophysics, 64*, 1028–1038.

Treisman, A. M. (1988). Features and objects: The Fourteenth Bartlett Memorial Lecture. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 40*, 201–237.

Ulrich, R. (1987). Threshold models of temporal order judgments evaluated by a ternary response task. *Perception & Psychophysics, 42*, 224–239.

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

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

Walsh, V., & Cowey, A. (1998). Magnetic stimulation studies of visual cognition. *Trends in Cognitive Science, 2*, 103–110.

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