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ORIGINAL ARTICLE

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Evidence against response bias in temporal order tasks with attention manipulation by masked primes

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Abstract Attending to a location shortens the perceptual latency of stimuli appearing at this location (perceptual latency priming). According to attentional explanations, perceptual latency priming relies on the speeded transfer of attended visual information into an internal model. However, doubts about the attentional origin have repeatedly been raised because efforts to minimize response bias have been insufficient in most studies. Five experiments investigated the contribution of a response bias to perceptual latency priming (judgment bias due to the two-alternative forced-choice method and due to the existence of the prime, criterion effects or second-order bias, sensorimotor priming). If any, only small response biases were found. The results thus support the attentional explanation.

Introduction

Attending to a stimulus may decrease its perceptual latency: an attended stimulus will be perceived earlier than an unattended stimulus. This *prior entry* phenomenon has been investigated since the earliest days of experimental psychology (e.g., Boring, 1929; Stone, 1926; Titchener, 1908). Attention has been manipulated by several methods: *endogenously* by instruction or centrally presented cues indicating the location to which attention is to be directed (e.g., Hikosaka, Miyauchi, & Shimojo, 1993a; Jaskowski, 1993; Stelmach & Herdman, 1991), by well-visible *peripheral location cues* (e.g., Hikosaka et al., 1993a, 1993b; Shore, Spence, & Klein, 2001), and by *masked peripheral cues* (Neumann, Esselmann, & Klotz, 1993; Scharlau, 2002; Scharlau & Neumann, in press; Steglich & Neumann, 2000).

In the latter paradigm, a stimulus location is indicated by a visual stimulus, the *prime*. A target trailing at the same location leads to visual backward masking of the prime (*metacontrast masking*). In metacontrast masking, the mask laterally adjoins the masked prime, which strongly impairs the prime's visibility with a maximum at onset intervals of about 40 to 80 ms (Bachmann, 1994; Breitmeyer, 1984; Breitmeyer & Ogmen, 2000). However, metacontrast-masked primes are not completely excluded from further processing. For example, simple responses towards the prime are not impaired by masking (Fehrer & Raab, 1962). Primes may also activate or elicit choice responses defined in current action plans (e.g., Klotz & Neumann, 1999; Neumann & Klotz, 1994). A masked prime further reduces the perceptual latency of the masking stimulus (*perceptual latency priming* or prior entry, Scharlau, 2002; Scharlau & Neumann, in press). The prime captures attention (e.g., Jonides, 1981; McCormick, 1997; Posner, 1980) and perception at the attended location is facilitated. Compared with an unprimed target, a primed target is thus perceived as appearing earlier.

Such a predating of the target's onset may, however, be due to nonattentional mechanisms. Metacontrast masking requires that prime and masking target be presented in close temporal and spatial proximity (Werner, 1935; though see Enns & DiLollo, 1997). Under these stimulus conditions, prime and target may be easily confused. For example, the observers might report the onset of the prime instead of the onset of the target, or temporally blend the two stimuli and report an inferred onset within the sequence (e.g., Scott, 1998).

A recent study demonstrated that *perceptual blending* cannot account for perceptual latency priming (Scharlau,

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2002). Observers judged either the temporal order of a prime and a target at the same location, or the temporal order of the primed target and an unprimed target at another location. The temporal sequence of prime and target was perceived correctly, i.e., the prime's perceptual latency was not influenced by the target. By contrast, the primed target's onset was predated. These findings disfavor a temporal blending account. If temporal blending or inferred onsets were responsible for the effect, the perceived onset of both the prime and the target should have been misperceived. Aschersleben (1999) found a similar misperception of the onset of the target, but not of the onset of the prime, with a synchronization method. These same findings also show that the observers do not report the onset of the prime instead of that of the target.

Besides studies with masked primes, an influence of attention on the latency of perception has been demonstrated in a number of studies that did not mask the cues so that perceptual confusion was unlikely (Gibson & Egeth, 1994; Hikosaka et al., 1993a, 1993b; Maylor, 1985; Stelmach & Herdman, 1991). However, doubts that the effect might be an artifact have been raised repeatedly: in most of the studies, efforts to minimize response bias were insufficient (Jaskowski, 1993; Pashler, 1998; Shore, Spence, & Klein, 2001; Spence, Shore, & Klein, 2001).

According to the *response bias account*, a response or judgment tendency is responsible for the changes in perceived latency. Perceptual latency priming is usually assessed with temporal order judgments of an attended and an unattended stimulus. Temporal order is difficult to discriminate because stimulus sequences are close to the limits of temporal resolution of the perceptual system. A response bias may arise in several different ways:

1. a bias according to two-alternative forced-choice methods
2. a location or first-order bias
3. a second-order bias or criterion effect
4. a sensorimotor bias

In typical temporal order judgment (TOJ) studies on perceptual latency priming, stimuli are presented in close temporal succession, and observers are instructed to judge their order. Combined with a *two-alternative forced-choice judgment* lacking the possibility to indicate uncertainty or simultaneity, observers may favor the primed stimulus independent of a genuine latency effect. Jaskowski (1993) indeed demonstrated that latency facilitation disappears if observers may indicate uncertainty in addition to a defined temporal order.

According to a *location* or *first-order bias*, observers may tend towards reporting the location of attention. If they are to indicate the side on which the first stimulus appeared, they may respond towards the attended side. This would again result in artificial perceptual latency priming effects. Recently, Shore et al. (2001) proposed an orthogonal variation of response dimensions and attentional cueing: participants judged whether a horizontal or vertical target was presented first with a right-hand or left-hand response. A location bias is unlikely. This method has also been used in research with masked primes in which perceptual latency priming was found (Neumann et al., 1993; Scharlau, 2002; Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003, in press; Steglich & Neumann, 2000).

Orthogonal variation of attentional orienting and judgment dimensions does not prevent a *second-order bias*. Observers may base their judgment on any salient stimulus quality, e.g., being primed or attended-to. They might therefore assign any criterion to the primed stimulus. Frey (1990) demonstrated that judgments may depend heavily on criteria. When observers compared the number of circles on the two sides of a visual display, he found an advantage for the attended side. This advantage was contingent on the criterion: if observers were asked to judge which side contained more circles, they judged in favor of the attended side, and if they determined which side consisted of less circles, the attended side was again favored. Frey concluded that attending to a location or stimulus increases signal saliency, and that the experimental question biases participants to assign the salient signal to a predefined category.

In addition to decision-level effects, *sensorimotor processing* of the prime may lead to artifacts. Sensorimotor effects of masked primes have been studied extensively in the reaction time paradigm: a congruent prime (indicating the same response as the target) decreases reaction time and error rate of responses to the primed target, whereas an incongruent prime increases both variables (e.g., Klotz & Neumann, 1999; Leuthold & Kopp, 1998; Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, in press). By contrast, the congruency of the primes was irrelevant for facilitation in TOJ studies. Perceptual latency priming did not depend on whether the prime indicated the same response as the target following at the location of the prime or the same response as the target at the other location (Scharlau & Neumann, in press, Experiment 2). Thus, a motor explanation for perceptual latency priming seems unlikely. However, it is possible that strong attentional capture by the masked prime left no space for a motor bias to operate. Since prior entry or perceptual latency priming should be defined as the genuine attentional effect "once the opportunities and incentives for response- and decision-level contributions to the measured PSS have been minimized" (Shore et al., 2001, p. 205; PSS is the point of subjective simultaneity), the amount of sensorimotor influences on perceptual latency priming should be measured.

Overview

In the following, I will address the response-bias argument in separate but related ways, which collect independent evidence against a bias in prior entry or perceptual latency priming. In Experiment 1, temporal perception of a pair of visual stimuli is assessed by the method of ternary TOJ.

The response-bias explanation given by Jaskowski (1993) predicts that there should be no priming effect under these conditions. Experiment 2 uses a related approach by priming both stimuli (though with different priming intervals) so that the mere presence of the prime cannot bias the judgment. According to the response-bias explanation, none of the stimuli is salient in this situation, which should decrease the response bias. By changing the criterion between blocks, Experiment 3 assesses the amount of perceptual latency priming that is due to nonattentional criterion biases. Experiment 4 applies the same logic (estimating bias effects) to sensorimotor response priming. In Experiment 5, scaling and reproduction of perceived intervals are used as dependent variables. These methods are not prone to criterion effects. If perceptual latency priming can be found in scaling or reproduction responses, this will be another proof of its attentional origin.

Experiment 1

In the early history of psychophysics and experimental psychology, the question how many and which categories of judgment observers should use in psychophysical experiments designed to estimate thresholds was a hotly debated issue (see, e.g., Boring, 1920; Fernberger, 1930; Guilford, 1954; Woodworth & Schlosberg, 1961). By and large, agreement on a two-alternative judgment consisting of a "greater/more" and a "smaller/less" category was reached. Providing observers with a third category ("equal" or "doubtful") was rejected for several reasons (for overviews see Guilford, 1954; Woodworth & Schlosberg, 1961). The "equal" judgment falls into the interval of uncertainty where judgments are unstable and thus difficult to treat. Use of this category depends on attitude, and participants forced to guess in situations in which they would be likely to respond "equal/doubtful" perform considerably better than chance.

However, reasons for using a *ternary temporal order judgment* including an "equal/doubtful" category in temporal perception research have recently been collected (Jaskowski, 1993; Ulrich, 1987). Jaskowski argues that, especially in the domain of prior entry, binary TOJs are prone to response bias. When two stimuli are physically simultaneous and attention is not manipulated, both judgments are equally likely (see, e.g., Fig. 4). By contrast, the judgment "unprimed stimulus first" is less frequent if one stimulus location is primed. This can be clearly observed in the range of short temporal intervals or target SOAs (stimulus onset asynchrony). At longer SOAs, the psychometric functions converge. Thus, the shift of PSS is due to those temporal conditions in which perception of temporal order is most difficult. If participants have no information about temporal order but nevertheless have to choose, they will judge in favor of any stimulus that is marked by some property—e.g., being the attended-to stimulus. This elicits a shift of psychometric functions and PSS, but does not reflect perceived temporal order (second-order bias).

According to Jaskowski (1993), the shift of psychometric distributions should vanish if participants are allowed a judgment category indicating absence of perceived order. In his study, participants first reacted as fast as possible to a stimulus at an attended location (primary task) and then judged the temporal order, either with a two-alternative or a three-alternative response (secondary task). The primary task was employed to ensure effective attentional allocation. Prior entry was found exclusively if participants used two judgment categories but was absent in the three-alternative condition. Although Jaskowski presents his argument with respect to tasks with instructed attentional focus, it is applicable to attentional capture by peripheral cues.

Experiment 1 tests whether the ternary TOJ is a useful means of eliminating a second-order bias. Jaskowski's explanation (1993) is based on the precondition that participants are not, or only partially, able to discriminate temporal order. In these cases they will guess based on other cues. In order to test this hypothesis, Experiment 1 includes a restrictive and a nonrestrictive instruction for the use of the "equal" category. By this means, judgment difficulty can be estimated. If perception of temporal order was difficult, more "equal" judgments should be found under nonrestrictive instruction, in which doubt could be expressed by this category. With restrictive instruction, the "equal" category was limited to perceived simultaneity.

Method

Participants

Ten voluntary participants (6 female; mean age 26.1 years) took part in the experiment and received € 9 or course credits. All participants reported that they had normal or corrected-to-normal visual ability.

General design

The experiment consisted of two TOJ sessions that differed in the instruction given to the participants (restrictive vs. nonrestrictive use of the "equal" alternative). The order of the sessions was randomly assigned to the participants.

Apparatus

Stimuli were presented dark gray (14 cd/m^2) on a light gray background (103 cd/m^2) on a 17-in color monitor (vertical frequency 60 Hz, resolution 640 × 480 pixels). Participants sat upright in front of the monitor in a dimly lit room, with their line of gaze straight ahead. They responded via the buttons of a serial mouse, which was operated with two fingers of the dominant hand. The viewing distance was fixed at 60 cm by a chin rest.

Stimuli

In each trial, a pair of visual stimuli was presented, a square and a diamond with star-shaped inner contours, which allow good

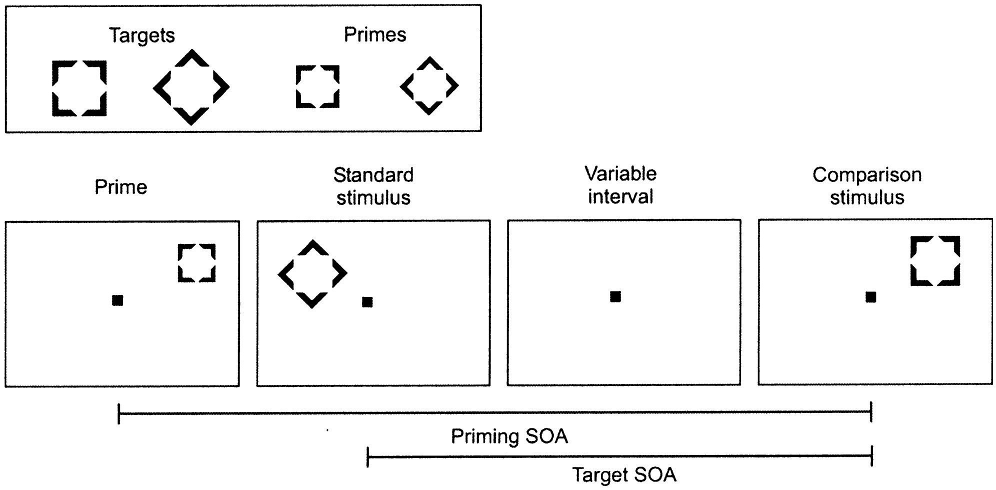

Fig. 1 Stimulus shapes (*upper box*) and succession of events in a sample trial of Experiment 1. Stimuli are not drawn to scale

metacontrast masking (see Fig. 1, Klotz & Neumann, 1999). The pair appeared horizontally above or below the center of the screen. The side length of the targets was 2.3°, and the distance between the stimuli was 12.5°. One of the two stimuli was preceded by a smaller version of itself (a prime) in half of the trials; the side length of this prime was 1.7°.

All stimuli were presented for 32 ms. The priming SOA (stimulus onset asynchrony between the prime and the primed target) was 64 ms. If primed, a target was preceded by a prime of identical shape. The temporal intervals between the targets were −128 to +128 ms in steps of 32 ms (target SOA). Negative numbers indicated that the primed target (according to psychophysical terminology, the *comparison stimulus*) preceded the unprimed target (the *standard stimulus*), and positive numbers indicated that the unprimed stimulus appeared first. In trials without a prime, positive and negative numbers were assigned randomly while realizing all other variables (vertical position of the pair, position of the shapes, position of the first stimulus) equally often (see Fig. 1 for a sample trial). The positions of the primed targets were balanced, and each of the two shapes was primed equally often.

Participants were instructed to fixate the center of the screen throughout each trial. The center was marked by a square. In a randomly selected 5% of the trials, the central square was presented as a contour drawing instead of a solid black figure for the initial 100 ms. In these cases, participants were not to respond to the subsequent trial. All participants suppressed judgments for at least 75% and most of them for all of these fixation modifications. According to debriefing after the experiment, mistakes occurred because they sometimes were not able to suppress the response, although they had detected the fixation change.

Procedure

Participants judged the temporal order of two visual stimuli presented at short temporal intervals. Half of the participants responded with the left mouse button when they saw the square first, and with the right one if the diamond was perceived first; for the other half the assignment was reversed. The middle button was assigned to the "equal" category. In the condition with restrictive instruction, participants were instructed to use this category only if they had undoubtedly perceived simultaneity. In the other condition, they could indicate perceived simultaneity as well as uncertainty with this button. In both conditions, the instruction emphasized accuracy. Before the experiment, participants had the opportunity to practice the task until they were familiar with it. In these training trials, no primes were presented.

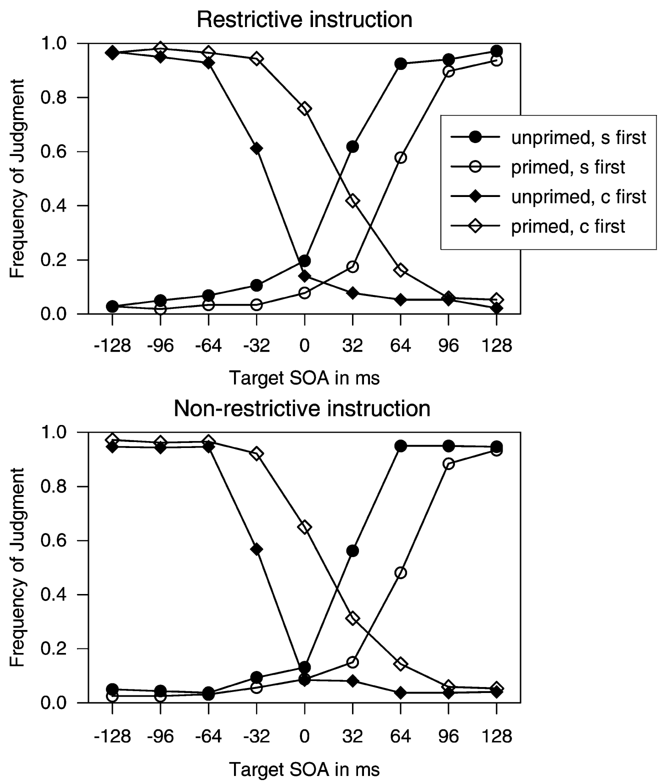

Fig. 2 Results of the two order judgments in Experiment 1. Judgment frequency is given on the y-axis, target SOAs on the x-axis. In the *upper part*, data for restrictive instruction are shown and in the *lower part*, data for the nonrestrictive instruction. *Diamonds* mark judgments in which the comparison stimulus was perceived first; *circles* represent judgments in which the standard stimulus was perceived first

Results

The primed target was defined as comparison, and the unprimed target as standard stimulus. For each target SOA and priming condition, the frequency of three judgments ("comparison first", "standard first", and "equal") was calculated. Psychometric distributions for the two order judgments can be seen in Fig. 2. Thresholds and performance measures (difference limen [DL], the interquartile range) were estimated from the distributions of "comparison first" and "standard first" judgments by means of logit-analysis (Finney, 1971). For "comparison first" judgments, this threshold divides perceived orders into the categories "comparison first" and "not comparison first" and thus may be defined as the 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 with maxima for the "equal" judgment. By this means, 4 thresholds per participant and experimental part were computed (2 judgments × 2 priming conditions). If appropriate, degrees of freedom were corrected by the Greenhouse-Geisser-coefficient ϵ, and alpha was adjusted accordingly (Hays, 1988).

For each part of the experiment, a two-way ANOVA (judgment × priming) of thresholds was computed. Figure 2 indicates a shift of threshold for both parts and both judgments. In the first part (restrictive instruction), there was a highly significant main effect of priming on thresholds ($F[1, 9] = 149.92$, $p < .0001$) as well as a main effect of judgment ($F[1, 9] = 14.3$, $p < .01$), and a marginally significant interaction ($F[1, 9] = 7.84$, $p < .05$). The main effect of judgment reflects the difference between the "comparison first" threshold and the "standard first" threshold. These two thresholds differ because they are separated by the interval of uncertainty. The interaction results from the fact that the threshold shift was larger for "comparison first" than "standard first" judgments (50 ms vs. 38 ms).

A two-way ANOVA of DL revealed a significant main effect of judgment ($F[1, 9] = 21.44$, $p < .01$). This is due to the fact that DL is negative for "comparison first" judgments, and positive for "standard first" judgments. There was no main effect of priming and no interaction (both $F < 1$). Mean DL was −28 and +28 ms indicating high acuity.

In the second part (nonrestrictive instruction), the results are similar. In the threshold data, a main effect of judgment as well as priming was found (judgment: $F[1, 9] = 36.33$, $p < .001$; priming: $F[1, 9] = 157.74$, $p < .001$). The interaction failed to reach significance ($F[1, 9] = 3.96$, $p = .07$). DL was again −28 and +28 ms. Only the main effect of judgment was significant ($F[1, 9] = 26.41$, $p < .001$; all other $F < 1$).

In order to determine the PSS and attentional influences on it, threshold estimates must be combined, e.g., averaged (Woodworth & Schlosberg, 1961). The PSS lies midpoint between the two thresholds of the order judgments. The average PSS in unprimed conditions was close to objective simultaneity (−2 ms). If one of the targets was primed, it amounted to +42 ms with restrictive, and to +39 ms with nonrestrictive instruction. Thus, perceptual latency priming was 44 and 41 ms.

To statistically test the "equal" judgments, arcsine-transformed frequencies were entered into a three-way ANOVA comprising three factors—instruction, priming, and target SOA (for the distributions, see Fig. 3). There were significant main effects of priming and target SOA (priming: $F[1, 9] = 15.15$, $p < .05$; target SOA: $F[8, 72] = 36.55$, $p < .0001$) as well as a highly significant interaction of these factors ($F[8, 72] = 34.41$, $p < .0001$). The main effect of instruction, and the interaction of instruction and target SOA approached significance whereas both other interactions did not reach significance (instruction: $F[1, 9] = 3.99$, $p = .08$; instruction × target SOA: $F[8, 72] = 2.81$, $p = .06$; instruction × priming: $F < 1$; instruction × priming × target SOA: $F[8, 72] = 1.79$, $p = .16$; see Fig. 3).

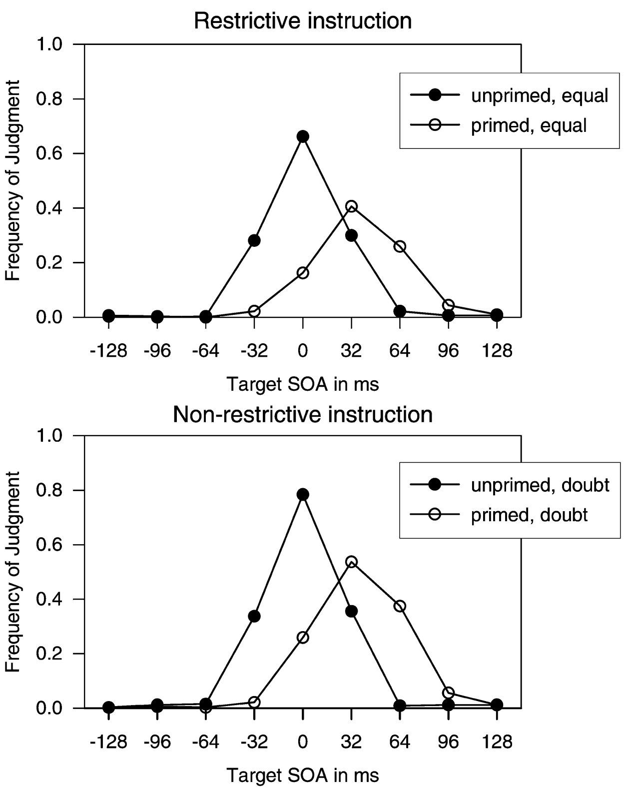

Fig. 3 Results of Experiment 1, "equal judgment", restrictive instruction in the *upper part*, and nonrestrictive instruction in the *lower part*

Discussion

The main result of the experiment was that there was a clear priming effect although participants were allowed to use an "equal" judgment indicating perceived simultaneity or, additionally, uncertainty. With 41 ms, this effect is of the size expected from earlier studies (Scharlau, 2002; Scharlau & Neumann, in press). As in the earlier studies, priming one of the targets influenced thresholds, but not discrimination performance. The finding of a priming effect with ternary TOJ is in clear disaccord with both the predictions and the data from the study of Jaskowski (1993).

The main effect of instruction on the distribution of "equal" judgments just failed to reach significance. This was also found for the interaction of instruction and target SOA. Judgment frequency does not vary much under restrictive and nonrestrictive use of the "equal" category although participants judged "equal" more often under nonrestrictive instruction. This finding shows that they complied with the instruction. That the difference is small may be interpreted as evidence against one of Jaskowski's basic assumptions, which is that at short SOAs temporal discrimination is impossible or difficult. If this had been the case, the "equal" alternative should have been used much more often with nonrestrictive instruction, as in this condition this alternative could be used when participants were uncertain about temporal order.

The difference between Jaskowski's (1993) study and Experiment 1 which causes the shift to appear or disappear may be due to the fact that participants in Jaskowski's study had to perform a double task, responding as fast as possible to the stimulus at the attended location and thereafter judging temporal order. This may have impaired temporal perception. Further, temporal conditions of attentional control are different. Priming elicits a stable allocation of attention, whereas attending due to instruction, as Jaskowski used it, is more unstable. This hypothesis finds support in a recent study by Shore et al. (2001) where prior entry with endogenous cueing (centrally presented arrows) was influenced by a change in criterion, whereas only a small influence was found with exogenous cueing. With the symbolic cues, an attentional effect was found only when observers reported the first stimulus, but not when they reported the second stimulus. With exogenous cues, the average PSS shift was reduced, but not extinguished. However, there was no "equal" category in this study. Also, Stelmach and Herdman (1991) found the same effects of endogenous cueing with binary and ternary TOJs. They further demonstrated attentional facilitation if participants adjusted an interval in which simultaneity was perceived or asynchrony minimized while attending to the left, the right or to the center of the display. With this method, it is not easy to see how a response bias might influence TOJs (see also Rorden, Mattingley, Karnath, & Driver, 1997).

Research on exogenous and endogenous orienting of attention (Posner, 1980; Posner & Cohen, 1984) supports this argument. Endogenous or volitional orienting of attention is initiated by symbolic cues or by instruction. Exogenous capture of attention is caused by peripheral stimulation (see, e.g., Eriksen & Hoffman, 1972; Jonides, 1981; Posner, 1980; Yantis & Jonides, 1984). These types of orienting seem to be functionally different. Most importantly, the time to focus attention in response to a symbolic cue or instruction is highly variable. As Müller and Rabbitt (1989) demonstrated, costs and benefits of central cues reach their peak at cueing SOAs between 200 and 400 ms. Attention shifts caused by peripheral cues are faster and carried out with less effort than attentional orienting in response to central cues (Jonides, 1981; see also Cheal & Lyon, 1991; Lambert, Naikar, McLachlan, & Aitken, 1999; Müller & Rabbitt, 1989).

However, exogenous capture need not be automatic or reflexive (Jonides & Yantis, 1988). In the present experiments, observers were set for onsets, and abruptly onsetting stimuli agreed with the observer's intentions. Indeed, evidence for intention-dependent control of attention by masked primes has been revealed in a number of studies. For example, masked primes elicited perceptual latency priming if they matched the target set, but not if they resembled distractor elements (Scharlau & Ansorge, 2003).

Experiment 1 yielded one unexpected finding: under restrictive instruction, priming effects were larger for "comparison first" than "standard first" judgments. This result cannot be explained on the basis of the attentional explanation. The prime's influence on attention may be larger if it is the first event in the display than if it is preceded by the unprimed stimulus. Further research is needed to test whether this finding is robust and to reveal its functional basis.

Experiment 2

Experiment 1 revealed evidence against a response bias. Experiment 2 was designed to strengthen this evidence by another line of argument. According to, e.g., Jaskowski (1993) and Pashler (1998), a possible response bias consists in choosing an attended stimulus as the first target although no temporal order was perceived. In Experiment 2, both targets are primed, either with similar or with different priming SOA. The larger the priming SOA, the more time is available for executing a shift of attention, and the larger perceptual latency priming should be. Thus, the target with the larger priming SOA should show the larger perceptual latency priming and consequently a net effect of priming. This relationship holds as long as the priming SOA is smaller than the time needed for attentional orienting (see Scharlau & Neumann, 2003). On the other hand, if a bias is induced

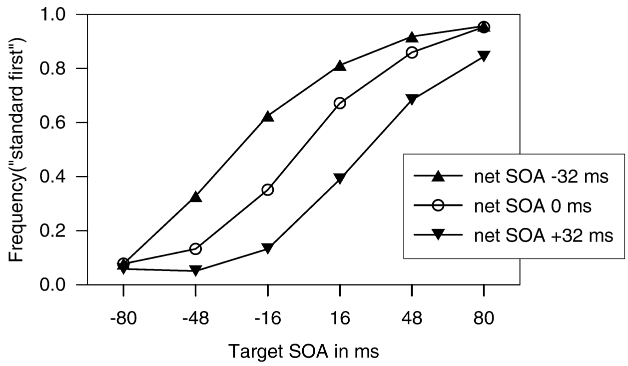

Fig. 4 Psychometric functions of Experiment 2, depicting the frequency of the judgment "standard stimulus first" for the target SOAs

by the mere existence of a (salient) primed and an unprimed location, an influence of the prime is unlikely in Experiment 2 or should at least be reduced.

Method

Participants

Eight voluntary participants (6 female; mean age 26.3 years) took part in the experiment and received € 4.50 or course credits. All participants had normal or corrected-to-normal visual ability.

Apparatus

The apparatus did not differ from Experiment 1.

Stimuli

The stimuli of Experiment 1 were used. Both targets were primed. Experiment 2 differs from Experiment 1 in the target SOAs used (−80 to +80 ms in steps of 32 ms) and the net priming SOA. For the standard stimulus, the priming SOA was fixed at 64 ms. The priming SOA of the comparison stimulus was 32, 64, or 96 ms, resulting in a net priming SOA of −32, 0, and +32 ms. With 32 repetitions of each of the 18 conditions (3 net priming × 6 target SOAs), the experiment consisted of 576 trials and lasted about 40 min. Target pairs were presented using the method of constant stimuli.

Procedure

The procedure did not differ from Experiment 1 except that there was no fixation control and no third judgment alternative.

Results

The target primed with variable intervals was defined as the comparison stimulus and the target primed with the same 64 ms every trial the standard stimulus. From the judgments, the frequency of the judgment "standard stimulus first" was computed for each target SOA and participant. PSS and DL were estimated from the psychometric distributions by logit analysis (Finney, 1971).

Figure 4 indicates a priming effect. In the baseline condition (both stimuli primed with equal SOA), there was no perceptual latency priming. PSS was −2 ms. If the comparison priming SOA was larger than the standard, psychometric functions shifted towards the right (PSS +30 ms), and if it was smaller, there was a shift in the opposite direction (PSS −25 ms). Mean perceptual latency priming was thus 27 ms.

Individual PSS and DL were entered into a one-level ANOVA. There was a large effect of priming SOA on PSS ($F[2, 14] = 139.32$, $p < .0001$). Priming did not influence discrimination performance (DL: $F < 1$). Mean DL was 33 ms.

Discussion

In Experiment 2, the mere presence of the prime could not bias the judgment. Both targets were primed and thus equally salient. However, they were primed with different priming SOAs. A priming effect was found, and it depended on the priming SOA, i.e., the relative time available for the allocation of attention.

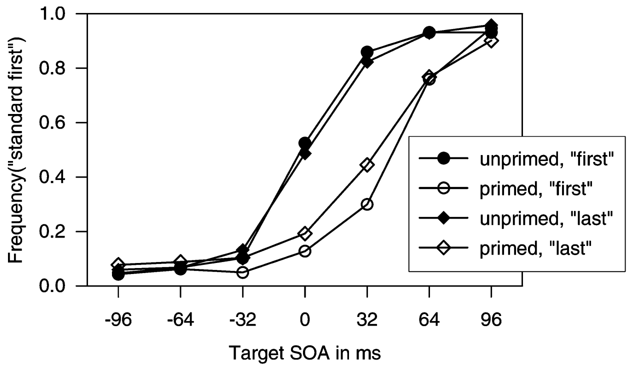

Fig. 5 Psychometric functions of Experiment 3, depicting the frequency of the judgment "standard stimulus first" for the target SOAs

Experiment 3

Experiment 3 directly tests whether the PSS shift caused by a masked prime is due to a criterion effect or second-order response bias. Do participants assign the instructed criterion to the primed stimulus, independent of the content of the criterion? Spence et al. (2001) recently demonstrated that criterion effects have only a small influence if attention is captured by peripheral cues. However, criterion effects have not yet been assessed with masked information, and, due to their invisibility, masked primes may be less subject to conscious control. In Experiment 2, participants judged which of two stimuli was the last or the first one. If a second-order bias accounts for perceptual latency priming, the primed stimulus should be favored independent of the judgment criterion, so that it will be judged as the first one if the criterion is "first" and as the last one if the criterion is "last". The amount of response bias in perceptual latency priming can be computed by subtracting the perceptual latency shifts in the "first" and "last" condition.

The attentional explanation, by contrast, predicts that the influence of a prime on the perceived onset of a target is due to shifting attention. The prime speeds up the primed target's perception. A primed stimulus will thus have an advantage in being judged the first stimulus and an equally large disadvantage in being judged the last stimulus.

Method

Participants

Twelve voluntary participants (8 female; mean age 24.0 years) took part in the experiment and received € 5 or course credits. All participants had normal or corrected-to-normal visual ability. Due to computer malfunction, one set of data was lost.

General design

The experiment consisted of two sessions administered in random order. In one of them, participants judged which stimulus was the last one, and in the other, they judged which stimulus was the first one.

Apparatus

The apparatus did not differ from Experiments 1 and 2.

Stimuli

The stimuli did not differ from Experiment 2 except that only one target was primed. Target SOAs were −96 ms to +96 ms in steps of 32 ms. There were 14 conditions (2 priming conditions × 7 target SOAs). Each part of the experiment consisted of 448 trials and lasted about 30 min. Target pairs were again presented using the method of constant stimuli.

Procedure

The procedure did not differ from Experiment 2 with the exception that in one session, participants judged which stimulus was presented first, and in the other, they judged which stimulus was presented last.

Results

Data were treated as in Experiment 2. Figure 5 depicts the psychometric distributions. A clear horizontal shift can be seen. There is no influence of criterion. A primed stimulus was perceived as the first one more often and as the last one less often than an unprimed stimulus.

A two-way ANOVA of PSS revealed a large effect of priming on PSS ($F[1, 10] = 65.42$, $p < .001$). Neither judgment criterion ($F[1, 10] = 1.63$, $p = .23$) nor the interaction ($F < 1$) reached significance. The average PSS of unprimed trials was +1 ms for both judgments. In primed trials, PSS amounted to +40 ms with "first" judgments and +35 ms with "last" judgments. Mean perceptual latency priming was thus 38 ms. As proposed by Shore et al. (2001), perceptual latency priming should be defined as the facilitation effect that is independent of the observers' criterion, i.e., the average effect of the two instructions (36.5 ms). The response bias is calculated as half the difference between the two PSS, which would be 2.5 ms in the present case.

Discrimination performance was influenced by priming (although only marginally significantly), by judgment criterion, and also by the interaction of these factors (priming: $F[1, 10] = 4.78$, $p = .05$; judgment criterion: $F[1, 10] = 5.63$, $p < .05$; interaction: $F[1, 10] = 11.42$, $p < .01$). Performance was slightly better without than with the prime (28 vs. 37 ms), and also slightly better with "first" than with "last" judgments (28 vs. 37 ms). Performance was comparatively low with "last" judgments in the primed trials (46 ms).

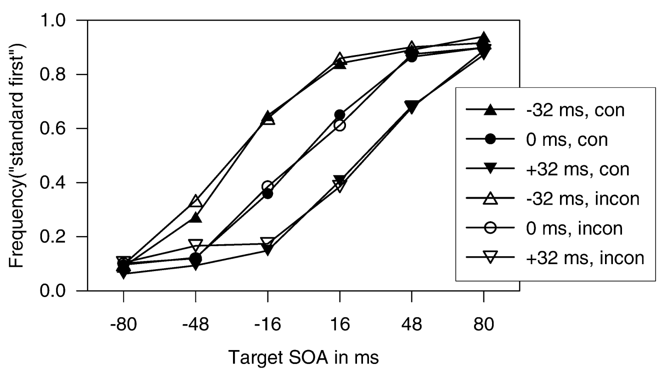

Fig. 6 Psychometric functions of Experiment 4, depicting the frequency of the judgment "standard stimulus first" for the target SOAs. Conditions with congruent primes are marked by *filled symbols* and conditions with incongruent primes are marked by *open symbols*

Discussion

Experiment 3 revealed a large perceptual latency priming effect accompanied by a minor response bias effect. Priming the comparison stimulus shifted the PSS by 36.5 ms. The response bias contribution was very small (2.5 ms). Most importantly, the shift was in the direction expected by the attentional explanation of prior entry. Priming one of the targets did marginally influence discrimination performance with larger DL, i.e., decreased performance, in primed/"last" trials. This has been very occasionally found in our laboratory (see Scharlau & Neumann, in press, Experiment 2). However, DL does not typically vary with priming.

Experiment 4

Experiment 4 combines the rationale of Experiment 2 with a logic used by Scharlau and Neumann (in press). In these latter studies, we investigated if perceptual latency priming was influenced by imperative features of the prime, i.e., its response-congruency with the primed target. However, we found no dependence on the shape of the prime even though participants reported the shape of the first stimulus. The PSS shift was 40 ms for a prime of the same shape, and 42 ms for primes of the alternative shape, with no significant difference between these conditions. This was interpreted as evidence against a motor response bias or sensorimotor priming. Such an explanation would hold that the prime itself elicits a motor response via direct parameter specification (Neumann, 1990). However, this refutation may be premature.

Possibly, a strong location-specific attentional bias interferes with the direct specification of a response and the latter cannot therefore be discovered as long as only one location is primed. Thus, Experiment 4 primes both stimuli and additionally varies response congruency between the prime and the primed target.

Method

Participants

Twelve participants (8 female; mean age 25.9 years) served in Experiment 4. All reported normal or corrected-to-normal visual acuity. They received € 6 or course credits.

Apparatus

The apparatus was the same as in the previous experiments.

Stimuli

The stimuli were identical to the previous experiments, except that the congruency of the prime was varied. The prime preceding the standard target was always congruent, i.e., of the same shape as the standard target. The comparison target was either primed congruently (i.e., preceded by a prime of the same shape) or incongruently (preceded by a prime of the alternative shape). The experiment consisted of 36 conditions (3 net priming SOAs × 2 prime congruency × 6 target SOAs), each repeated 32 times resulting in a total of 1,152 trials. The trials were divided into two sessions.

Procedure

The procedure was the same as in Experiment 2.

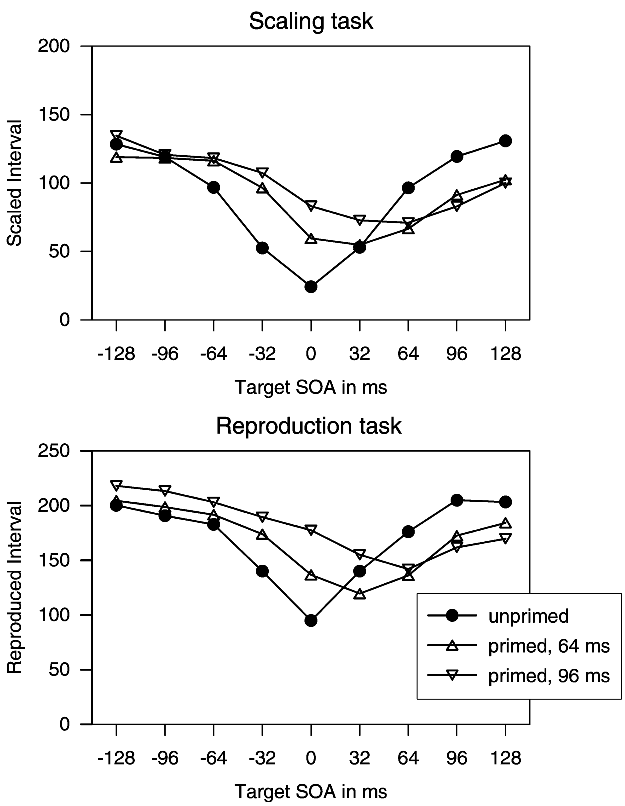

Fig. 7 Results of Experiment 5. The *upper part* shows the results of the scaling response. In the *lower part*, the data from interval reproduction are shown

Results

Data were treated as described in Experiment 2. Psychometric functions are depicted in Fig. 6. Net priming SOA influenced TOJs whereas congruency had virtually no influence. A two-way ANOVA of PSS revealed a highly significant effect of net priming SOA ($F[2, 22] = 139.38$, $p < .0001$). Neither congruency as main effect nor the interaction of congruency and net priming SOA reached significance (all $F < 1$). A PSS difference between the two congruency conditions was absent, even numerically (0 ms). Averaged, PSS were −25 ms for negative net priming SOA, 0 ms with zero priming SOA, and +25 ms with positive priming SOA. Neither main effects nor an interaction of net priming SOA and congruency were found for DL (congruency: $F[1, 11] = 1.21$, $p = .30$; net priming SOA: $F[2, 22] = 2.53$, $p = .13$; interaction: $F[2, 22] = 1.61$, $p = .23$). Mean DL was 36 ms.

Discussion

Experiment 4 demonstrated that perceptual latency priming depends exclusively on location-specific mechanisms. Shape or judgment congruency of the prime did not influence the perceived order. A motor bias can thus be excluded; it is numerically zero. This evidence is in line with earlier studies in which differential effects of congruent and incongruent primes were absent (Scharlau & Neumann, in press).

Experiment 5

Experiment 5 uses a new experimental task which ascertains temporal perception and manipulates attention. One main reason for response-bias arguments was that in usual (binary) TOJ experiments, participants have to choose between two predefined judgment categories and may use the (binary) existence of the prime to do so. Thus, a task with more than two or even three possible responses would be another way of examining the response-bias argument. Methods of scaling offer such a possibility. Here, participants are provided with a variety of response alternatives.

Perceptual latency priming should not be limited to TOJ as a dependent measure, but should show up in other measures of temporal perception, e.g., the perceived interval between the onsets of the targets. If the perceived onset of the comparison stimulus is predated in primed trials, the perceived interval between the target stimuli will be influenced by the prime. If the primed target is the first one in the stimulus pair, the perceived interval will be prolonged. If the primed target appears after the unprimed, the interval should be shorter compared with unprimed trials. In Experiment 5, participants had to judge the temporal interval between the two target stimuli. Two methods were used: in one block, participants scaled the perceived interval with the help of a visual device and in the other block, they reproduced the interval manually.

Several hypotheses regarding the data can be derived from the attentional explanation. From the prolonging and shortening of the perceived interval due to priming, I expect an interaction of target SOA and priming. A main effect of priming may arise, but is not necessary. The minimal perceived intervals will be found at the zero SOA in unprimed trials, but at an SOA with the unprimed stimulus preceding the primed one in primed trials. Additionally, I expect that the size of the effect will be influenced by priming SOA, i.e., the interval by which the prime precedes the primed target.

Method

Participants

Sixteen voluntary participants (6 female; mean age 28.5 years) took part in the experiment and received € 12 or course credits. All participants reported to have normal or corrected-to-normal visual ability.

General design

The experiment consisted of two sessions. In one session, participants judged a perceived temporal interval between two visual stimuli using a scaling method. In the other session, they reproduced it using the mouse buttons. The order of the sessions was randomly assigned to the participants.

Apparatus and stimuli

The apparatus and stimuli did not differ from the previous experiments apart from the following points. There were 9 target SOAs ranging from −128 to +128 ms in steps of 32 ms. In a third of the trials, no prime was presented. In another third of the trials, the prime preceded the primed target by 64 ms, and in the last third, by 96 ms. Each session consisted of 576 trials (9 × 2 conditions each repeated 32 times) and lasted about an hour.

Procedure

Participants judged the temporal interval between two visual stimuli. In the scaling part, a horizontal ruler appeared after the presentation of the imperative stimuli. Its ends were marked as "very long" and "very short". The position of the labels varied randomly from trial to trial. Participants moved a button on the ruler with the mouse and adjusted a position corresponding to the perceived interval. The ruler was 200 pixels long, and a number between 0 and 199 was returned by the procedure, 0 denoting the shortest and 199 the longest interval. Participants were instructed to use the whole length of the slider for their judgment.

In the reproduction part, participants reproduced the perceived interval and the order of the stimuli with the mouse buttons. For example, when they had seen the left stimulus followed rapidly by the right one, they had to press the left button and shortly after this the right button. The time between the two mouse clicks was measured to the nearest millisecond and returned by the procedure. Before each experimental part, participants had the opportunity to practice the tasks.

Results

The mean scaling results and reproduced intervals of each condition were computed, scaling results as means and reproduction results as medians. The effect of priming can be seen in Fig. 7. In unprimed trials, the target SOA zero was perceived as the shortest interval. In primed trials, the subjectively shortest interval was shifted towards positive target SOAs, i.e., intervals in which the (unprimed) standard stimulus preceded the comparison stimulus by 32 ms. Additionally, the distributions behaved as predicted. When the comparison stimulus was the first one in the pair, the perceived intervals were longer in primed than in unprimed trials (left half of Fig. 7, upper part). With the standard stimulus first, perceived intervals were shorter in primed than in unprimed conditions (right half of Fig. 7, upper part, with exception of the region of interception).

A two-level ANOVA (priming × target SOA) of the mean scaling results per participant was computed. In the scaling part, there was a significant effect of priming ($F[2, 30] = 6.28$, $p < .05$), a highly significant effect of target SOA ($F[8, 120] = 31.23$, $p < .0001$), and, most importantly, a highly significant interaction ($F[16, 120] = 20.73$, $p < .0001$).

For the reproduction part, the results were similar: highly significant main effects of priming ($F[2, 30] = 10.49$, $p < .0001$) and target SOA ($F[8, 120] = 11.89$, $p < .001$), and again a highly significant interaction ($F[16, 240] = 6.41$, $p < .0001$).

Discussion

Experiment 5 demonstrated effects of priming on temporal perception using scaling and reproduction methods. As predicted by the attentional explanation of perceptual latency priming, a masked prime preceding one of two targets altered the perceived interval between the targets. It prolonged perceived intervals if the prime preceded the first stimulus, and shortened the interval if it preceded the second stimulus in the display. This finding further invalidates the response-bias argument against binary TOJ methods in attention manipulation research and corroborates an attentional explanation.

The priming effect cannot be quantified from the data presented above. TOJ data provide a quantitative estimate of temporal perception (PSS or threshold). With the scaling method, many more target SOAs in small steps would be necessary to gain quantitative estimates of perceptual latency priming. However, the minimum perceived intervals in the present data indicate a shift of about 32 ms with 64 ms priming SOA and 32 to 64 ms with 96 ms priming SOA. This estimate is in good accordance with results from TOJ studies in which the PSS shift amounted to little more than half the priming SOA with priming SOAs of approximately 40 to 100 ms (Scharlau & Neumann, in press).

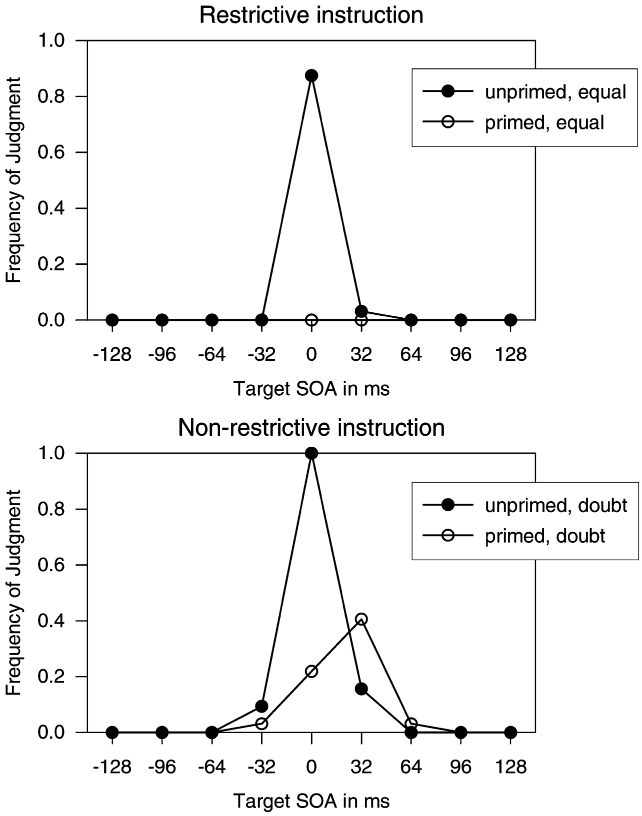

Fig. 8 Data from a single participant in Experiment 1, "equal doubtful judgment", restrictive instruction in the *upper part*, and nonrestrictive instruction in the *lower part*

General discussion

The experiments reported above were conducted to assess response bias influences in temporal order tasks with the manipulation of attention by masked primes. Several methods revealed only marginal—if any—response bias contributions to perceptual latency priming. The four experiments with TOJ were conducted with a task in which participants indicated the shape of the first of two different stimuli. This method is free of a *first-order location response bias*. A further variant of the response bias argument, the *two-alternative forced-choice response bias* can also not account for perceptual latency priming. Attentional facilitation of perceived latency was found if participants used three alternatives for their judgment (Experiment 1). Further, the *mere presence of a prime* or an attended location does not elicit a response bias. Even if both locations were primed, perceptual latency priming was found, depending on the relative interval with which the two targets were primed (Experiment 2). The amount of a *second-order response bias* was assessed directly in Experiment 3 in which the judgment criterion was changed between sessions. Facilitation of the latency of the primed target was found to be independent of judgment criterion. Experiment 4 investigated a motor bias, which was numerically zero. Finally, priming effects on the duration of perceived intervals were found with scaling and reproduction as dependent measures (Experiment 5). Neither of the methods are prone to response bias. Taken together, all five findings invalidate a response-bias account according to which perceptual latency priming is an artifact arising if participants cannot discriminate order, but have to decide upon a judgment in which case they will decide in favor of the attended channel (Jaskowski, 1993; Pashler, 1998).

The processes underlying perceptual latency priming have been clarified in the *asynchronous updating model* (Neumann & Müsseler, 1990; Scharlau, 2002; Scharlau & Neumann, in press). It links perceptual latency priming to the asynchrony of two processes, *feature coding* in a spatial map (e.g., Treisman, 1986; Wolfe, 1992) and *attentional allocation*, which mediates stimulus transfer to an internal model (e.g., Wolfe, 1992). Feature coding takes place at a preattentive and preconscious level; its updating is fast and nonselective. The contents of the internal model are consciously available. They are updated selectively as a consequence of visuo-spatial attention. Changes in stimulation trigger both processes simultaneously. Compared with feature coding, attentional orienting is slow (e.g., Müller & Findlay, 1988). This asynchrony explains perceptual latency priming (as well as other phenomena, such as metacontrast masking; see Neumann & Müsseler, 1990). During attention shifts to the location of a change, initial stages of the stimulus representation (such as the features of the prime) decay or are overwritten by later codes (such as the features of the mask). Only the later codes are transferred into the internal model (which explains metacontrast masking). Furthermore, the transfer process for the later codes is accelerated because attentional orienting has been triggered by the prime (which explains perceptual latency priming).

Facilitation by visuo-spatial attention may explain the present findings, but it is not the only model that would predict them. The concept of *perceptual retouch* (Bachmann, 1994, 1999) is formally very similar to the asynchronous updating model. Perceptual retouch is an interactive process that is necessary for visual information to surpass the preattentive level of encoding and become consciously available. Facilitation of the perception of the mask relies on the asynchrony of two processes, cortical *specific encoding* of basic features, and processing in *nonspecific pathways* (thalamic nuclei) that feed into specific representations and modulate them. This modulation or upgrading is a necessary precondition for conscious availability. The nonspecific thalamocortical activations trail the specific cortical processing by about 50 to 80 ms. Perceptual latency priming results from the fact that the conscious representation of the mask is established faster because of modulation by nonspecific activation that was initially triggered by the prime.

The distinction between these two explanations is beyond the scope of the present study. However, I will briefly sketch some questions that may help to decide between them. According to the asynchronous updating model, the size of perceptual latency priming should be related to the duration of an exogenously triggered attention shift (about 100 to 200 ms; e.g., Eriksen & Collins, 1969; Müller & Findlay, 1988); according to perceptual retouch, it should be related to the asynchrony of specific and nonspecific activation (about 50 to 80 ms). Scharlau and Neumann (2003) reported that perceptual latency priming did not rise much above 80 ms. However, this evidence may not be conclusive since they also found that the increasing visibility of the prime with large priming SOAs increased error rates so that PSS shifts are less easy to measure. Further, nonspecific activation in perceptual retouch has a low spatial resolution whereas attentional orienting is spatially more precise. Studies with prime-mask pairs presented at different locations may help to decide between the two models. Finally, perceptual retouch is a spontaneous interplay of bottom-up processes. It is yet unclear how top-down influences may be related to perceptual retouch (Müller & Elliott, 1999). By contrast, the asynchronous updating model has recently been linked to top-down control of attention shifts. Perceptual latency priming critically depends on whether the masked primes share target features, i.e., match the current intentions to process the targets. Target-similar primes elicited an attention shift whereas the influence of primes that did not contain the relevant target feature was much smaller (Scharlau & Ansorge, 2003).

With respect to the ternary TOJ paradigm, a further observation should be mentioned. Most TOJ models (see Sternberg & Knoll, 1973) assume that simultaneity is perceived if a detection of temporal order was not possible. However, perceived simultaneity may be of different origin than perceived order (see Jaskowski, 1991). There is some additional information about perceived simultaneity in the data from Experiment 1 reported above. Figure 8 plots data from one of the observers. With restrictive instruction, he used the "simultaneous" judgment in unprimed, but never in primed trials. Under nonrestrictive instruction, the "equal" category was chosen in primed trials, too. This may indicate that in trials with simultaneous targets, a double stimulus (and not two stimuli) is perceived. In primed trials, this double phenomenon cannot arise since several onset signals (both targets and the prime) and thus asynchrony (without order) will be registered. According to these data, simultaneity may not be identical with events whose order cannot be perceived. On the contrary, it is a category for two perceptual events falling into a common focus of attention and thus appearing as a double event. Simultaneity may thus be an object-feature rather than a temporal feature.

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