PERGAMON

Available online at www.sciencedirect.com
SCIENCE DIRECT®

Vision Research 43 (2003) 1351–1363

Vision Research

www.elsevier.com/locate/visres

Direct parameter specification of an attention shift: evidence from perceptual latency priming

Ingrid Scharlau *, Ulrich Ansorge

Department of Psychology, Bielefeld University, P.O. Box 10 01 31, Bielefeld D-33501, Germany

Received 8 October 2002; received in revised form 20 January 2003

Abstract

In the direct parameter specification (DPS) mode of sensorimotor control, response parameters can be specified by stimuli that are not consciously perceived [Psychological Research/Psychologische Forschung 52 (1990) 207]. DPS is contingent on the current intentions. The invisible stimuli can be processed for the purposes of sensorimotor control only if they match the actual intentions, for example, share task-relevant features. The present experiments explore whether attentional capture by masked abrupt-onset stimuli is mediated via DPS. Participants judged which of two visual targets appeared first. Masked primes preceded one of the targets. The primes were either similar to the targets or not, in shape, or in color. Target-like (task-relevant), but not distractor-like (task-irrelevant), primes facilitated perceptual latencies of targets trailing at their positions. Thus, the latency effects resulted from DPS of an attention shift, rather than from bottom-up capture or from top-down search for dynamic features.

Keywords: Attention; Masking; Priming; Latency

1. Introduction

For several decades, visual stimuli masked by metacontrast have been used as a methodological tool for investigating human cognition (Breitmeyer, 1984; Exner, 1868; Werner, 1935; for reviews see Breitmeyer & Ogmen, 2000; Enns & Di Lollo, 2000; see also Marcel, 1983). *Metacontrast masking* is an efficient means for excluding a stimulus from conscious perception without obliterating other of its effects, especially influences that do not depend on awareness of the stimulus. In one of the first experimental studies of such dissociations, Fehrer and Raab (1962) demonstrated that simple responses towards a visual target were unimpaired by masking this target. Detection latencies were equally fast if the target was clearly visible and if it was masked by a temporally trailing visual stimulus. The dissociation between a lack of awareness on the one hand, and nonconsciously mediated effects of the masked stimulus on the other hand has been termed the *metacontrast dissociation* (e.g., Klotz & Neumann, 1999).

Masked visual *primes* presented prior to targets can influence target processing in a variety of ways. They can, for example, reduce spatial uncertainty or draw attention towards the target location. Evidence for such an attention-based effect of invisible primes has been found in cueing research (e.g., Jaśkowski, van der Lubbe, Schlotterbeck, & Verleger, 2002; Lambert, Naikar, McLachlan, & Aitken, 1999; McCormick, 1997; Steglich & Neumann, 2000). Among other effects, priming a location and thus summoning attention facilitates the perceived onset of stimuli trailing at this location (*perceptual latency priming*). [1] Compared with a stimulus that is not led by a prime, the perceived onset of a primed stimulus is predated. This phenomenon was demonstrated in several studies using a temporal order judgment paradigm (e.g., Scharlau, 2002; Scharlau &

* Corresponding author. Tel.: +49-521-106-4505; fax: +49-521-106-8075.
E-mail address: ingrid.scharlau@uni-bielefeld.de (I. Scharlau).

[1] The term *perceptual latency priming* refers to the perception that in a pair of two simultaneously presented stimuli, the primed one appears as the first one, rather than to a possible explanation of this phenomenon. Whether this phenomenon is due to a speeded processing of the target resulting in decreased latency or, alternatively, filtering costs (Kahneman, Treisman, & Burkell, 1983) or additional noise (e.g., Pashler, 1998) induced by the target at an unprimed location, is a topic not covered by the present experiments.

0042-6989/03/$ - see front matter
doi:10.1016/S0042-6989(03)00141-X

Neumann, in press; Shore, Spence, & Klein, 2001; Steglich & Neumann, 2000).

These studies supported an attentional explanation of perceptual latency priming by excluding several alternative explanations. (1) Perceptual latency priming does not vary with within-trial prime-target similarity. Thus, it is not due to perceptual or sensory priming of the target features (Scharlau & Neumann, in press). (2) Perceptual latency priming is elicited by masked primes that precede the target, but not by primes that follow the target. Thus, perceptual latency priming is not due to amalgamating prime and target into a compound event and judging an inferred perceptual center. Further, it is known that well-visible primes elicit the same amount of perceptual latency priming as masked primes (Scharlau & Neumann, in press), and that a visible prime's onset is perceived correctly (Scharlau, 2002). From this finding follows that a misperception of the prime's onset or a temporal integration of prime and target is no precondition for perceptual latency priming. (3) Under appropriate conditions, such as an independent variation of attentional allocation and judgment criteria, perceptual latency priming by peripheral cues is largely independent of response bias (Shore et al., 2001).

In sum, in accordance with recent studies on attention and temporal order judgment (Gibson & Egeth, 1994; Hikosaka, Miyauchi, & Shimojo, 1993; Maylor, 1985; Scharlau, 2002; Scharlau & Neumann, in press; Shore et al., 2001; Spence, Shore, & Klein, 2001; Stelmach & Herdman, 1991; Zackon, Casson, Zafar, Stelmach, & Racette, 1999), perceptual latency priming may be interpreted as an attention-mediated effect of a peripheral, masked or unmasked prime. Given that perceptual latency priming is indeed attentional in origin, it could be mediated by at least three different attentional control mechanisms.

(1) Visuo-spatial attention might be captured in a bottom-up fashion by *abrupt onsets* (*attentional* or *exogenous capture*; Jonides, 1981; Yantis & Jonides, 1984). The rapid capture of attention by abrupt onsets has been attributed to bottom-up processes, since shifts elicited by abrupt visual onsets neither depend on cue validity (Jonides, 1981; Posner & Cohen, 1984; Remington, Johnston, & Yantis, 1992), nor on processing load (Jonides, 1981), and the effects cannot easily be suppressed (Remington et al., 1992). Perceptual latency priming by invisible information might reflect such bottom-up capture by abrupt onset stimuli (McCormick, 1997).

(2) However, Folk, Remington, and Johnston (1992) reported that abrupt onset cues entailed capture only if participants searched for abrupt onset targets (or other dynamic features, e.g., motion, Folk, Remington, & Wright, 1994), but that capture was absent if this was not the case (see also Atchley, Kramer, & Hillstrom, 2000; Folk & Remington, 1998; Remington, Folk, & McLean, 2001). According to the *contingent-capture hypothesis*, top-down control settings mediate attention shifts. These settings can be directed to either dynamic features, such as abrupt onset and motion, or static features such as specific colors. Perceptual latency priming might be a case of top-down contingent capture. Once targets have abrupt onsets, abrupt-onset cues might capture attention.

(3) Finally, perceptual latency priming could be due to *direct parameter specification* (DPS) of an attention shift. According to the contingent-capture account, presenting abrupt-onset cues among abrupt-onset targets is a *necessary precondition* for attentional capture by the cues. Yet, whether presenting abruptly onsetting cues in the context of abrupt-onset targets is also a *sufficient* precondition for attentional capture by the cues is not so clear. If DPS accounts for the attentional effect, *sufficient preconditions* for attentional capture by cues or primes, and hence, for perceptual latency priming, only would be met if cues match the features which discriminate targets from irrelevant elements (the *intentionally searched-for, matching* or *discriminative* features). This holds irrespective of whether these features are dynamic or static. Therefore, even if cues and targets have abrupt onsets, effects should be contingent on the cue's match to the control settings directed to the static features of the targets (e.g., its color or shape). Originally, the DPS model was developed to account for sensorimotor effects of invisible stimulus features such as visual shape (Neumann, 1990; see also Klotz & Neumann, 1999). However, it may also be used to explain shifts of visuo-spatial attention. [2] In the following, the notion of DPS will be explained in some detail.

DPS is a mode of *action control*. Provided that an action plan has been completed, sensory information can be used to specify free parameters of the responses *directly*, that is, without a mediating conscious perception of the very same information. The term *direct* thus denotes a processing route from early stimulus encoding to action control that shortcuts perceptual awareness. [3]

[2] In accordance with other concepts, such as the premotor theory of attention (Rizzolatti, Riggio, Dascola, & Umiltà, 1987), the application of the DPS concept to attention shifts results in modelling visuo-spatial attention in a way highly similar to an overt action. However, we do not want to exclude other possibilities of attentional control, such as attending to objects or features (e.g., Baylis & Driver, 1993). In the present study, we thus test the possibility that attention *may* be under DPS control.

[3] The concept is not related to Gibson's theory of *direct perception* (1979). According to Gibson, direct pick-up of information from the environment means that perception needs not be mediated by much processing of the very same information at all.

The term *parameter* should not be understood too narrowly. It applies to any of a variety of continuously given response features, such as for instance grip force (Fellows et al., 2002) or pointing direction (Schmidt, 2002), as well as to discretely given response features, such as the side of the responding hand (Klotz & Neumann, 1999). The DPS model claims that action control is possible without conscious recognition of the relevant stimuli, and that this type of control depends critically on what the organism intends at a certain moment.

Early research on DPS has focused mainly on demonstrating action control by stimuli totally *absent from conscious perception*. To give an example, in the metacontrast paradigm, conscious perception of a prime's shape is prevented by metacontrast masking. Yet, the prime reliably reduces response time and error rate if its shape signals the same response as the target (*congruent condition*), and increases response time and error rate if its shape signifies the opposite response (*incongruent condition*) (e.g., Klotz & Neumann, 1999; Klotz & Wolff, 1995; Neumann & Klotz, 1994). Further, the specification of response parameters by masked, invisible primes is evident in the lateralised readiness potential of the EEG (Eimer & Schlaghecken, 1998; Leuthold & Kopp, 1998). Numerous other experimental studies have demonstrated aspects of visually guided action control either in the absence of conscious perception or dissociated from conscious perception. For example, manual actions such as grasping or pointing may not be subject to visual illusions (Aglioti, DeSouza, & Goodale, 1995; Bridgeman, Kirch, & Sperling, 1981; Haffenden & Goodale, 1998; though see Franz, 2001; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000).

The DPS concept also holds that visual action control is *top-down* and *flexible* rather than bottom-up and hard-wired. It depends on current behavioural intentions or action plans (Neumann, 1990). The notion of *intention-dependence* only recently has come into research focus. For example, Ansorge, Heumann, and Scharlau (2002) found that invisible primes which did not match to the response-relevant, static target features did not influence response times. Processing of the primes thus was selectively entailed by their match to the decisive, in this case static, features. Convergent evidence comes from a priming study by Damian (2001). Masked number primes facilitated or inhibited responses to visible number targets. Yet, the influence was restricted to prime numbers that were part of the target set. Evidently, intentions to respond to, to search for, or to otherwise process the decisive features of the targets are necessary preconditions for responses to be specified by non-consciously registered analogues of the targets.

Sensorimotor DPS effects thus depend on having the features of a masked prime match a corresponding top-down control setting directed to visible targets (the action plan). This holds even if both primes and targets are defined by dynamic features, that is, if both have abrupt onsets. Perceptual latency priming might be a case of DPS, with the parameters directly specified being the direction or the amplitude of an attention shift. In the current investigation, this hypothesis will be tested.

The hypothesis derived from the DPS account is that attention shifts can only be elicited by primes that match the current intentions, and that primes that do not match the current intentions will not attract attention, even if they have an abrupt onset. By contrast, based on the bottom-up attentional-capture account or on the assumption that search for abrupt-onset targets is a sufficient precondition for the priming effect, no such differential effects are expected. Perceptual latency priming will exclusively depend on the prime's abrupt onset. From the contingent-capture hypothesis, no clear predictions can be drawn. First, contingent capture has so far been reported only for visible cues (e.g., Folk et al., 1992; Folk et al., 1994). Second, in terms of contingent capture it is unclear for which features observers search in a temporal-order-judgment experiment. Since the task requires the observer to report the shape of the first or the second stimulus, they may search for onset, or for specific shapes or colors (e.g., Scharlau & Neumann, in press; Shore et al., 2001). If onset is a sufficient precondition for contingent capture when searching for abrupt onset, no differential effects of primes differing in shape or color should be expected.

2. Overview

In the present experiments, perceptual latency priming was assessed by temporal order judgments of a primed and an unprimed *target*. These targets were accompanied by task-irrelevant *distractor* stimuli. In Experiment 1, in addition to the targets that were to be judged, abrupt-onset distractors and abrupt-onset target-like primes were presented with variable onset intervals. All primes were masked. They were similar in shape to the targets, whereas the distractors had a different shape. If DPS accounts for perceptual latency priming, an effect of the masked target-like primes should be observed, but no influence of the distractors. However, if abrupt-onset stimuli capture attention irrespective of their other, static features, abrupt-onset distractors should compromise perceptual latency priming. In Experiment 2, priming by masked distractor-like and masked target-like primes was compared directly. According to the DPS account, perceptual latency priming was expected for target-like but not for distractor-like primes. Experiment 3a sought to replicate and extend the findings by using the feature of color. In Experiment 3b, we tested to which amount the color primes of Experiment 3a were masked.

3. Experiment 1

Experiment 1 assessed perceptual latency priming by masked abrupt-onset primes that are similar in shape to the targets, that is, contain the searched-for feature. It further tested whether these effects can be compromised by the presence of abrupt-onset distractors. A distractor was presented either leading the prime, between prime and target, or trailing the target. In the leading conditions, it preceded the critical prime-target sequence. If the distractor's onset automatically captured attention, perceptual latency priming should be compromised under these circumstances. In the intermediate condition, the distractor disrupted the critical sequence of prime and primed target, and might equally interfere. If trailing the target, the distractor should never interfere.

3.1. Method

3.1.1. Participants

Thirteen voluntary participants took part in the experiment (8 female; mean age 26.2 years). Informed consent was obtained. Participants received € 14 or course credits. There was an additional reward of € 5 for the best participant. All participants had normal or corrected-to-normal visual acuity. Two participants had to be excluded because they showed no discrimination of order (for reasons unknown).

3.1.2. General design

The experiment consisted of three task sessions. The sessions were devoted to speeded responses, temporal order judgments (TOJ), and signal discrimination. As the speeded-response task is not related to the question examined here, its results will not be reported. A session lasted about 45 min.

3.1.3. Apparatus, stimuli, and procedure in the TOJ task

Dark grey stimuli (14 cd/m^2) were presented on a light grey (103 cd/m^2) background on a 17 in. color monitor with a refresh rate of 60 Hz. Participants sat in a dimly lit room. Their head rested on a chin rest, their line of gaze was straight ahead, and viewing distance was fixed at 60 cm. They responded by pressing either the left or the right key of a mouse.

In each trial, a sequence of three or four visible stimuli was presented, a distractor and a target pair, sometimes accompanied by a prime. The targets (relevant stimuli) were a square and a diamond with star-shaped inner contours which allow for good metacontrast masking (Klotz & Neumann, 1999). Edge length of the targets was 2.3°. The distractor was a circle of the same intensity as the targets. It was task-irrelevant, and participants were instructed to ignore the distractor. Each of the stimuli appeared in one of the four quarters of the screen with a diagonal distance of 8.5° from fixation. In two thirds of the trials, an additional stimulus, the prime, preceded one of the targets. It was a small replica of one of the targets fitting into the inner contours of the target that appeared later at the prime's location and masked the prime by metacontrast. The prime had an edge length of 1.7°. Its shape was either congruent to the target (identical shape, e.g., a square prime preceding a square target) or incongruent (alternative shape; e.g., a diamond prime preceding a square target; for a sample trial, see Fig. 1). Prime-target congruency or incongruency thus was defined by shape similarity and not by location. (Location was always the same for the pair of prime and primed target because perceptual latency priming depends on that the prime draws visuo-spatial attention towards a location. The processing of further stimuli at this location is facilitated by attention.) Both congruent and incongruent primes

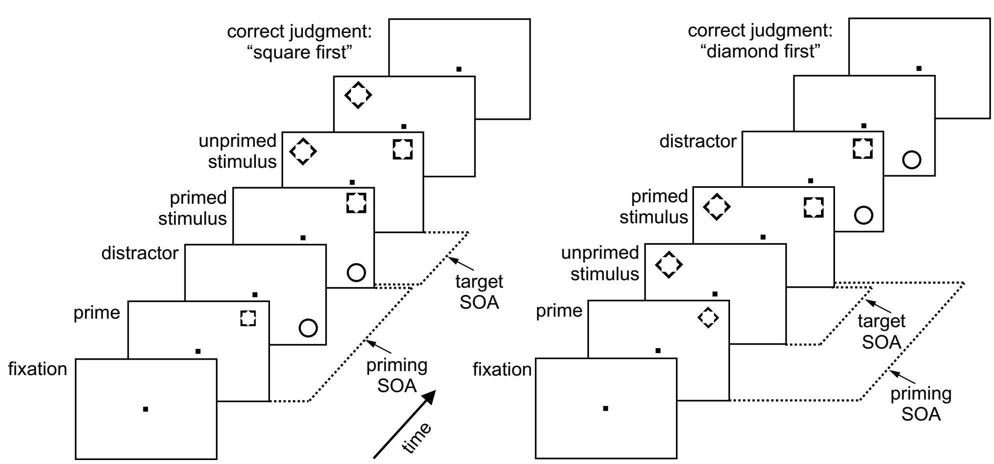

Fig. 1. Succession of events in two sample trials of Experiment 1. The prime precedes the primed target at its location. On the left, prime shape is congruent and the distractor timing intermediate, on the right, prime shape is incongruent and the distractor trails the sequence. Target, prime, and distractor shapes are not drawn to scale. Temporal order, but not durations, of the stimuli are given accurately. Primes were shown for one video cycle, the other stimuli for 10 cycles. The longer duration is indicated in that these other stimuli are depicted on two successive frames in the figure.

matched the set of intentionally searched-for features because shape was the task-relevant feature in Experiment 1. In a further third of the trials, no prime was shown (unprimed condition). A fixation spot consisting of a small black rectangle was visible on the screen throughout the experiment.

Target SOAs (stimulus onset asynchronies between the two targets) ranged between −96 and +96 ms in steps of 48 ms. Negative numbers indicate that the primed target was presented first, and positive that the unprimed target appeared first. The prime led the primed target by 64 ms. The distractor led either the prime or the primed target by 48 ms, or it followed the primed target by 48 ms. These three distractor conditions will be referred to as leading, intermediate, and trailing. Targets and distractor were presented for 160 ms, and the prime for 16 ms. All spatial sequences of distractors and targets were equally likely. There were 36 conditions (4 target SOAs × 3 distractor conditions × 3 priming conditions). Each condition was presented 24 times in a random order resulting in a total of 864 trials.

The participants were instructed to fixate a central fixation square throughout each trial. [4] They judged the temporal order of the targets. Half of the participants indicated with the left mouse button that they had seen the square first, and with the right button that the diamond was perceived first; for the other half the assignment was reversed. There might be two modes of following the instruction: either to attend to both targets and to report the shape of the first one, or else to attend to the first target and to report its shape. Most participants find it easier to use the first strategy. According to their reports they observe the pair of targets and determine the shape of the first of them. The instruction emphasised accuracy. Every 100 trials, a break was inserted automatically.

3.1.4. Stimuli and procedure in the signal discrimination task

Stimuli in the signal discrimination session were identical with the TOJ task with only one exception. Since participants had to discriminate the prime's shape, no unprimed trials were presented. Thus, there were 24 conditions (4 target SOAs × 3 distractor conditions × 2 priming conditions). Each condition was presented 24 times in a random order resulting in a total of 576 trials. Throughout each trial, the participants fixated a central fixation square. After the trial, they had to indicate whether the prime's shape was a square or a diamond. Half of the participants indicated a square prime with the left, and a diamond prime with the right mouse button; for the other half, this assignment was reversed.

3.2. Results

3.2.1. TOJ task

From the judgment data, psychometric functions were constructed. The frequency of the judgment "unprimed target first" was determined for each experimental condition (priming × distractor condition) and target SOA. The individual psychometric functions could best be approximated by logistic functions. Logit analysis (Finney, 1971) was used to estimate the point of subjective simultaneity (PSS) and the Difference Limen (DL) for each participant. PSS is the point on the fitted logistic function at which the two judgments are equally likely, that is, the observer cannot discriminate the temporal order (subjective simultaneity). PSS should be zero in unprimed trials. A positive shift of PSS in primed trials indicates perceptual latency priming: Simultaneity is perceived when the unprimed stimulus leads the primed one the latency of which is facilitated by the prime. DL indicates the slope of the psychometric function (interquartile range) and thus measures discrimination accuracy. The smaller DL, the better temporal perception. If necessary, degrees of freedom were corrected by the Greenhouse-Geisser-coefficient ε, and α was adjusted accordingly (Hays, 1988).

Fig. 2 indicates that priming shifted the psychometric functions horizontally to the right, that is, towards positive target SOAs. This shift indicates perceptual latency priming. Compared with the functions in unprimed trials, those of primed trials were displaced illustrating that simultaneity was perceived when the unprimed stimulus led the primed one by a considerable interval. Distractor condition had no influence on the shift. A differential effect of congruent and incongruent primes was also absent. Individual PSS were subjected to a two-way repeated-measures ANOVA. It revealed a significant main effect of priming ($F(2,20) = 21.82$, $P < 0.0001$). Bonferroni comparisons at the 0.05 level indicated a difference between the unprimed and both primed conditions. Neither a main effect of distractor condition nor an interaction of priming and distractor condition was found (both $F < 1$). In unprimed trials, the PSS amounted to −5 ms. In the primed trials, PSS was on average 44 ms. Perceptual latency priming thus was 49 ms.

A two-way ANOVA of DL revealed a significant main effect of distractor condition ($F(2,20) = 15.43$, $P < 0.001$). There were no significant Bonferroni comparisons (all $P > 0.05$). Neither a main effect of priming

[4] We did not monitor eye movements since, in a yet unpublished experiment, perceptual latency priming was found independent of eye movements. Targets were presented on the vertical midline of the display. Eye movements were assessed via the vEOG electrode. Trials with an vEOG amplitude of more than 40 μV were removed from further analysis. In the reduced set of data, perceptual latency priming amounted to 46 ms while it was 45 ms in the full data set. Further, the onset interval between prime and target was 96 ms in the present study which does not suffice for executing a saccade.

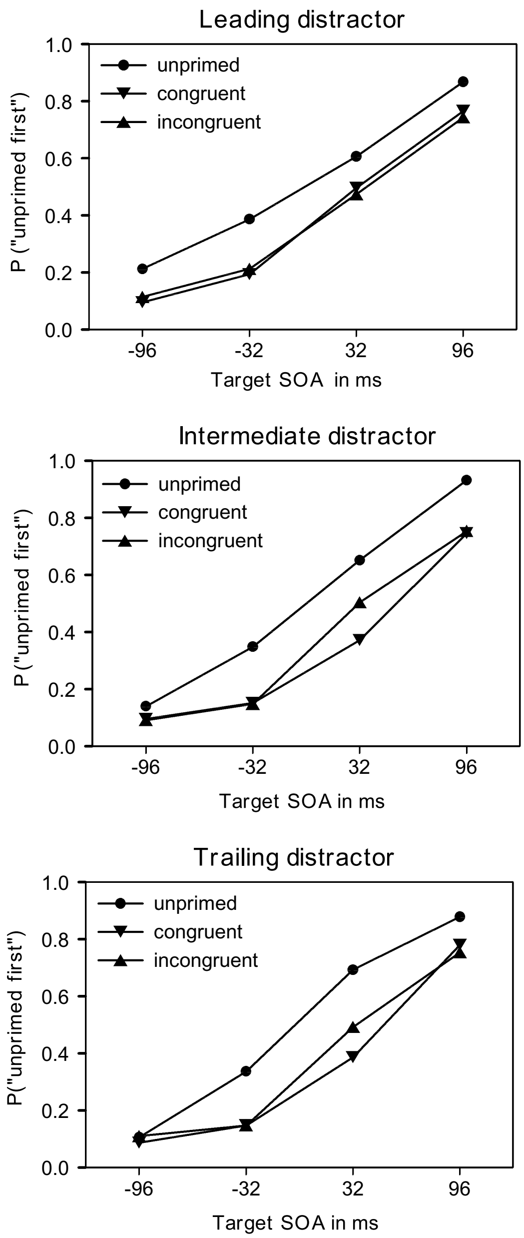

Fig. 2. Results of Experiment 1. Top: leading distractor; middle: intermediate distractor; bottom: trailing distractor. The horizontal displacement is the same in the three distractor conditions.

nor an interaction of priming and distractor condition was found (both $F < 1$). DL was largest (that is, performance lowest) when the distractor preceded the prime (54 ms), intermediate with an intermediate distractor (46 ms), and smallest with a trailing distractor (40 ms).

3.2.2. Signal discrimination task

From the judgments, d' was calculated as an index of discrimination performance (Green & Swets, 1966). Mean d' was -0.12 which is very close to zero (a d' value of zero indicates chance performance).

3.3. Discussion

Experiment 1 revealed a priming effect of 49 ms. Further, varying the timing of the distractor relative to the prime and the primed target had no influence on perceived order (PSS). It appears that irrelevant distractors do not compromise perceptual latency priming. Similar results have been reported in the visual search literature. For example, Theeuwes and Burger (1998) defined relevance by color. Distractors of a known color that appeared simultaneously with the targets did not capture attention. As in previous TOJ studies (Scharlau & Neumann, in press), no differential effect of congruent and incongruent primes was found. Thus, similarity between the primes and the set of searched-for features rather than similarity between the primes and the trailing targets at the very same positions was responsible for perceptual latency priming.

The distractor condition influenced discrimination performance (DL). The distractor impaired perception of the target pair, and the earlier in the sequence the distractor was presented, the larger was the influence. Thus, the distractors were processed, but evidently they did not capture attention, as indicated by the unchanged perceptual latency effects of the primes in the different distractor conditions. Likely, non-spatial filtering costs accounted for the DL effect of the distractors. For example, the latency of reading a single word is increased if a pattern of dots is presented simultaneously with the word (e.g., Kahneman et al., 1983). Filtering might delay the deployment of attention to the appropriate location, that is, distractors might have been filtered out preattentively.

However, different influences of distractors and primes could be due to confounding factors. For instance, distractor-target and distractor-prime SOAs were larger or smaller than prime-target SOAs in Experiment 1. Therefore, capture by the distractors cannot be directly compared to capture by the primes. To rule out that a confounding factor was responsible for the differential effects of distractors and primes, we compared perceptual latency priming of both masked target-like and masked distractor-like primes presented prior to one of the targets with identical SOAs in Experiment 2.

An additional signal discrimination task revealed a d' value that was very close to zero indicating no perception of the prime. This is in accordance with earlier studies that have demonstrated that the stimuli used in the present experiments are typically totally masked (Klotz & Neumann, 1999), and that perceptual latency priming is present if d' does not differ from zero (Experiment 2 in Scharlau & Neumann, in press). We will return to the question of masking in Experiment 3.

4. Experiment 2

Experiment 2 addressed the question whether perceptual latency priming is found if the prime's shape is similar to that of the distractor. If a distractor-like prime entailed perceptual latency priming, this would support the bottom-up-capture hypothesis or a priority for capture by abrupt onsets independently of a further match to the searched-for features. The DPS account predicts a strongly diminished, if not absent, priming effect of distractor-like primes. In Experiment 2a, the prime's shape resembles the distractor shape; in Experiment 2b, it resembles the targets' shapes.

4.1. Method

4.1.1. Experiment 2a

Participants. Eleven voluntary participants took part in the experiment (5 female; mean age 27.6 years). Participants received € 4.50 or course credits. All participants had normal or corrected-to-normal visual acuity. Two participants' data had to be removed since they were not able to discriminate temporal order.

General design, apparatus, stimuli, and procedure. The experiment consisted of one TOJ session which lasted about 45 min. Apparatus did not differ from Experiment 1. In each trial, 8 stimuli were presented, 6 distractors and a target pair. In half of the trials, a smaller replica of the distractor was shown as a prime. It preceded one of the targets at its location with an onset interval of 96 ms. Target and distractor shapes did not differ from Experiment 1. The stimuli appeared equidistantly on an imaginary circle centered on fixation with a radius of 9°. A fixation spot consisting of a small black rectangle was visible on the screen throughout the experiment.

Apart from the prime, a sequence of eight visual elements at 48 ms intervals was presented in each trial (see Fig. 3 for a sample trial). Six of the elements were distractors, and two were targets. Target SOAs were −144, −96, −48, +48, +96, and +144 ms. Distractors were presented at an interval of 48 ms to each other and to target stimuli. Any sequence began and ended with at least one distractor. In half of the trials, a prime preceded one of the targets. Priming SOA was 96 ms. In the other half, no prime was presented (unprimed condition). Targets and distractors were presented until the judgment was made. Prime duration was 16 ms. Spatial sequences of targets and distractors were created randomly. There were 12 conditions (6 target SOAs $\times$ 2 priming conditions). Each condition was repeated 64 times resulting in a total of 768 trials. Instruction did not differ from Experiment 1.

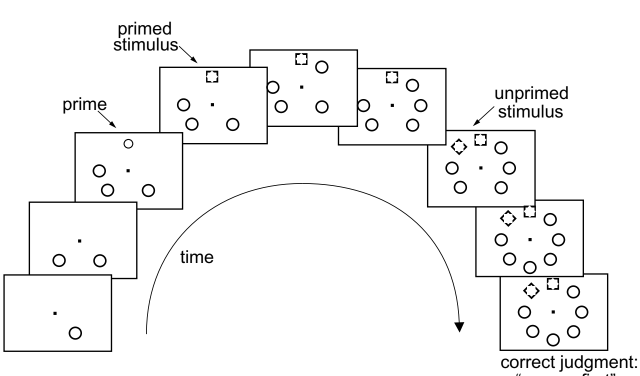

Fig. 3. Succession of events in a sample trial of Experiment 2a. The prime does not match the target shape. Again, target, prime, and distractor shapes are not drawn to scale, and temporal order, but not duration, is given accurately.

4.1.2. Experiment 2b

Participants. Twenty-two voluntary participants took part in Experiment 2b (12 female; mean age 23.5 years). Participants received € 4 or course credits. All participants had normal or corrected-to-normal visual acuity. One participant was not able to discriminate temporal order.

General design, apparatus, stimuli, and procedure. The experiment consisted of a TOJ session that lasted about 40 min. Apparatus did not differ from Experiments 1 and 2a. In each trial, 8 stimuli were presented, 6 distractors and a target pair. In two thirds of the trials, a target-like prime preceded one of the targets. Target, prime, and distractor shapes did not differ from Experiment 1. The sequence of events did not differ from Experiment 2a. Priming could either be congruent or incongruent, or no prime was presented. Thus, there were 18 experimental conditions (6 target SOAs $\times$ 3 priming conditions). Each condition was repeated 32 times in each session in a random order resulting in a total of 576 trials. Instruction did not differ from Experiments 1 and 2a.

4.2. Results

4.2.1. Experiment 2a

Data were analysed as above. As can be seen from Fig. 4 (upper part), a priming effect was absent. A two-way ANOVA of PSS did not reveal an effect of priming ($F < 1$). Mean PSS was −1 ms for unprimed, and 5 ms for primed conditions. Mean DL was 94 ms. No influence of priming on DL was found ($F(1,8) = 1.42$, $P = 0.27$).

4.2.2. Experiment 2b

In Experiment 2b, 5 out of 22 participants produced large negative priming effects. Their data were omitted and will be discussed separately below. Fig. 4 (middle part) indicates a PSS shift which is independent of prime congruency. There was a significant main effect of priming ($F(2,30) = 10.2$, $P < 0.01$). Bonferroni comparisons

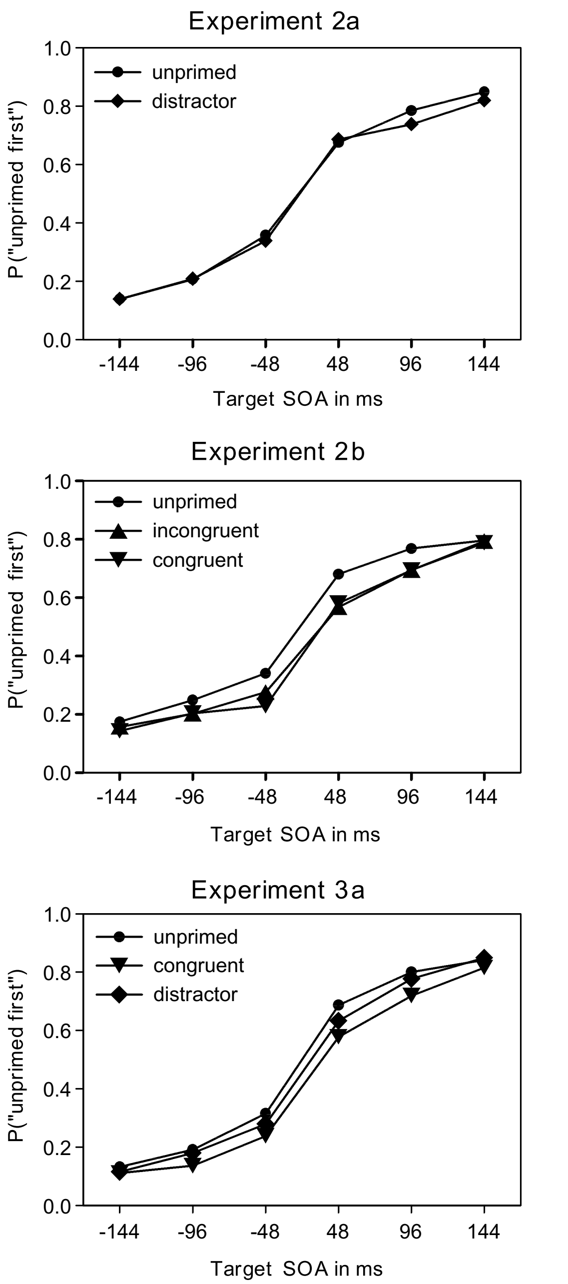

Fig. 4. Results of Experiments 2 and 3a. Top: Experiment 2a; middle: Experiment 2b; bottom: Experiment 3a.

at the .05 level indicated that the unprimed condition differed from both primed conditions. PSS were 1, 29, and 28 ms in the unprimed, congruent, and incongruent conditions resulting in an average priming effect of 28 ms. DL was not affected by priming ($F < 1$). Mean DL was 109 ms.

4.3. Discussion

In Experiment 2a, the prime's shape resembled the distractor elements. Although it onsetted abruptly, no perceptual latency priming was found. Thus, a distractor-like, not intentionally searched-for prime did not capture attention. In Experiment 2b, the prime's shape resembled a target shape, and perceptual latency priming was evident. Also, it was found to be about the same, irrespective of whether prime and masking target were of similar shapes (congruent condition) or not (incongruent condition). Thus, Experiment 2 replicated the results of Experiment 1. The observations support the DPS account of an attention shift to the masked primes: A necessary precondition for perceptual latency priming was that masked primes matched the intentionally searched-for target feature of shape which had to be processed in order to solve the task (see Ansorge et al., 2002; Ansorge & Neumann, 2001, for related results with speeded responses). Providing the prime with an abrupt onset was not sufficient to produce capture, although targets onsetted abruptly, too.

The finding that non-matching primes did not capture attention may seem to be at odds with earlier results from our laboratory: Scharlau and Neumann (in press) reported that masked primes similar and dissimilar in shape and color to the targets led to perceptual latency priming effects of the same size. However, in that study, no distractors were presented. Thus, all abrupt onsets in this earlier experiment indicated the location of one of the targets. (In the present experiments, most of the abrupt onsets were invalid and had to be disregarded.) Thus, an alternative precondition for another mode of intention-mediated capture by the masked stimuli (i.e., their predictability) was met in the study of Scharlau and Neumann (see Yantis, 1993).

5. Experiment 3

Experiment 3a aimed at further support for the DPS hypothesis. Influences of distractor-like and target-like primes were investigated as a within-participants factor rather than with different samples. Also, the generality of the DPS account was tested by using color instead of shape as the feature discriminating between targets and distractors. Again, according to the bottom-up-capture account, all abrupt-onset primes will entail perceptual latency priming since targets have abrupt onsets, too. According to the DPS account, only the target-like primes will entail perceptual latency priming since their color, but not that of the distractor-like primes, matches the target-directed control settings.

In Experiment 3b, we tested whether the color primes were masked. Masking was assessed by discrimination (i.e., the degree to which participants were aware of the prime's relevant feature) and detection (i.e., the amount to which they were aware of the presence of the prime). Discrimination performance is the critical test for the DPS model. Finding that the prime color is well masked would support the DPS hypothesis that control of attention shifts is possible without conscious discrimination of the prime. Finding that the prime's presence is well masked would further support this notion.

5.1. Method

5.1.1. Experiment 3a

Participants. Twenty-three voluntary participants took part in the experiment (12 female; mean age 26.9 years). Participants received € 10 or course credits. All participants had normal or corrected-to-normal visual acuity.

General Design, Apparatus, Stimuli, and Procedure. The experiment consisted of two TOJ sessions each of which lasted about 50 min. The sessions differed in the distractor color used and in the mappings of target colors to responses (see below).

Color stimuli of matched subjective brightness were presented in red, yellow, or blue on a dark grey background. Apart from that, apparatus did not differ from Experiments 1 and 2. One of the colors was chosen as the distractor color and had to be ignored. Distractor and target colors were balanced across participants and sessions. Targets were rings of 2.5°. Primes were smaller rings which fitted into the inner contours of the targets.

The sequence of events was the same as in Experiment 2b. Number and spatial arrangement of distractors also were the same as before. In two thirds of the trials, a prime preceded one of the targets. Prime color was either congruent (the color of the masking target) or distractor-like. There were 18 experimental conditions (6 target SOAs $\times$ 3 priming conditions). Each condition was presented 42 times in each session in a random order resulting in a total of 756 trials per session. Participants judged the temporal order of the targets by reporting the color of the first target. In the second session, the distractor color was exchanged with one of the target colors. Each session lasted approximately 45 min.

5.1.2. Experiment 3b

Participants. Twenty-four voluntary participants took part in the experiment (14 female; mean age 26.4 years). Participants received € 3 or course credits. All participants had normal or corrected-to-normal visual acuity.

Apparatus, stimuli, and procedure. The experiment consisted of one session which lasted about 30 min. Stimuli and apparatus did not differ from Experiment 3a. Participants were randomly assigned to either the discrimination or the detection group. Both groups received a total of 504 trials (6 SOAs $\times$ 2 priming conditions $\times$ 42 replications). In the discrimination group, a prime was present in each trial. In one half, it was congruent (had a target's color), in the other half, it had the same color as the distractor. The participants in this group judged if the prime's color was target-like or distractor-like. One half of them indicated "target color" with the left, and "distractor color" with the right mouse button; for the other half, this assignment was reversed. For the detection group, no prime was presented in half of the trials. In the other half, either a congruent or a distractor prime was presented. After each trial, the participants indicated whether they had seen a prime or not. One half of participants indicated presence of a prime with the left mouse button and absence with the right mouse button; for the other half, this assignment was reversed. The sequence of events in each trial was the same as in Experiment 3a.

5.2. Results

5.2.1. Experiment 3a

Data were analysed as before. Three participants had to be excluded from further analysis due to large negative priming effects; their data will be discussed separately below. Psychometric functions can be seen in Fig. 4 (lower part). The prime's influence on psychometric functions varied due to its features. A one-way ANOVA of PSS revealed a significant effect of priming ($F(2, 38) = 14.42$, $P < 0.01$). Post-hoc Bonferroni comparisons ($P < 0.05$) confirmed that the target-like condition differed from both the unprimed and the distractor-like condition which did not differ among themselves. PSS was 3 ms in unprimed trials, 31 ms in congruent trials, and 13 ms in distractor trials. Perceptual latency priming thus was 28 ms with a congruent prime, and no perceptual latency priming was found with a distractor-like prime that was not intentionally searched for. DL did not vary with priming condition ($F < 1$). Mean DL was 108 ms.

5.2.2. Experiment 3b

One set of data was lost due to computer malfunction. The d' for discrimination did not differ from zero which indicates chance performance (mean $d' = 0.14$; $t(11) = 1.74$, $P = 0.11$). The d' for detection was high and differed significantly from zero (mean $d' = 3.45$; $t(10) = 23.85$, $P < 0.0001$).

5.3. Discussion

Experiment 3a confirmed that perceptual latency priming depended on a match between the prime's color and the intentionally searched-for color of the target. Perceptual latency priming was much smaller with distractor-like than with target-like primes. Thus, Experiment 3a confirmed the DPS hypothesis of attentional control. Not abrupt onsets per se, but onsets of stimuli which share static searched-for features that are part of the observer's set reliably elicit an attention shift. The influence of distractor primes did not differ significantly from zero. However, there was a residual distractor effect. A distractor-like prime presented intermixedly with target-like primes thus probably can also elicit an attention shift, but either more rarely or less efficiently than a prime that contains the intentionally searched-for features.

The results of Experiment 3b indicated that participants were very good in detecting the presence of the prime, but only marginally better than chance in discriminating its color. The task-relevant or intentionally searched-for feature thus was well masked. This finding supports the DPS account which predicts that masked visual information may be used to specify response parameters. In contrast to discrimination, detection of the prime was very efficient. Certainly, higher detection than discrimination performance does not account for differential effects of distractor-like and target-like primes. Further, earlier studies have shown that both presence and magnitude of perceptual latency priming are independent of the amount to which participants are able to detect the prime (Scharlau & Neumann, in press). Also, the good detection performance should have fostered attentional or contingent capture. This is in marked contrast with the intention-dependent effect of the masked primes in Experiment 3a.

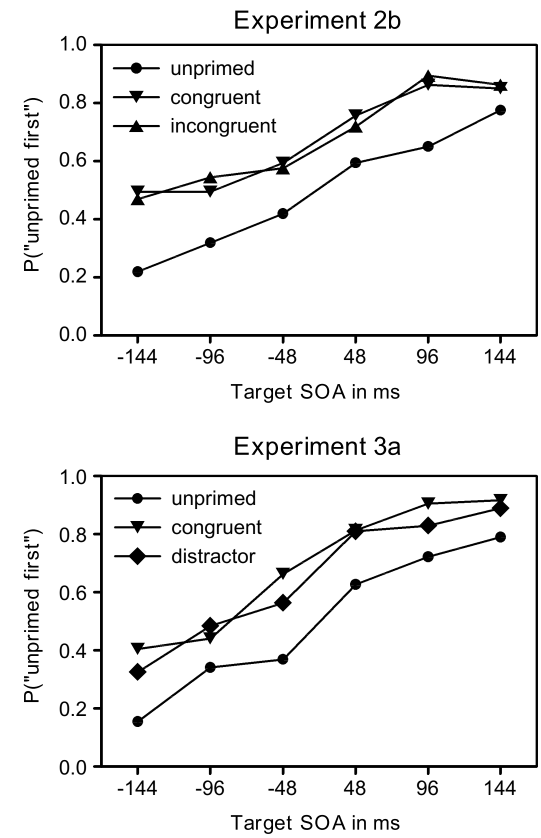

Fig. 5. Data of discarded participants. Top: Experiment 2b; bottom: Experiment 3a.

6. Analysis of discarded data

In Experiments 2b and 3a, 8 out of 45 participants revealed a reversed pattern of effects and were discarded from analysis. From the DPS concept, no hypotheses concerning these reversed effects can be derived. Fig. 5 depicts the averaged psychometric functions of the participants with reversed effects. Several features characterised the discarded data in contrast to those analysed above. (1) The psychometric functions did not seem to be of sigmoid shape but rather linear (unprimed) or non-symmetrical (primed) with respect to the range of target SOAs. (2) The primed and unprimed functions did not converge at the extreme target SOAs. The intervals used, however, covered those intervals in which psychometric functions typically converge (see, for example, Fig. 4, and Scharlau & Neumann, in press). The direction of a displacement cannot be inferred from a linear function. The functions thus may be vertically or horizontally shifted. (3) Priming effects on PSS were not only reversed but also *numerically larger* than the priming SOA which was 96 ms: −169/−131 ms in Experiment 2b, and −107/−97 ms in Experiment 3a. (4) Performance was lower.

The observations (2) and (3) hint at an explanation of the reversed priming effect. Participants with reversed performance possibly showed a massive *inhibition* of the primed location. A primed stimulus had to be presented much *earlier* than an unprimed target to be perceived as simultaneous. This inhibition seemed to be independent of the temporal interval between the targets. It even arose if the target SOA was as large as 144 ms, an interval in which temporal order is easy to discriminate. The reverse effect might thus be due to strategic decisions, for example favouring the unprimed location whenever a prime was detected. Such a strategy would also explain the size of the PSS shifts. For purely logical reasons, the attentional effect cannot be larger than the priming SOA. The reversed effects, however, clearly exceeded the priming SOA. Possibly related interference by valid cues has been reported in several studies in which cues and targets were almost identical (e.g., Berlucchi, Chelazzi, & Tassinari, 2000; Tassinari & Berlucchi, 1993). By contrast, other researchers reported facilitation by peripheral cues that were similar to the targets in location and color (e.g., Jonides, 1981; Remington et al., 1992). The differences between these studies may be explained by different strategies in dealing with processing of similar cues and targets. It is commonly assumed that the strategies participants use in experiments are homogeneous. Nevertheless, strategies are often heterogeneous if, as in the present study, intentions or control settings rather than mere procedural features are responsible for the effects (see, e.g., Hommel, 1993). Further research is needed to settle the question which strategies were favoured by participants that showed inhibition by valid primes or cues and those that showed facilitation.

7. General discussion

The experiments reported above used temporal order judgments to assess the influences of masked primes on perceived latency of the masking targets. Distractors and distractor-like primes defined by task-irrelevant features had no or small effects (Experiments 1, 2a, and 3a). By contrast, primes defined by the searched-for features of the task-relevant target facilitated perceived latency (Experiments 2b and 3a). Thus, orienting of attention which mediates perceptual latency priming was conditional upon a match of the primes to the intentionally searched-for features of the target, that is, its shape (Experiments 1 and 2) or its color (Experiment 3a). Also, similarity between the primes and the set rather than similarity between the primes and the targets at the same positions was responsible for perceptual latency priming: Congruent and incongruent primes had the same attentional effects (Experiments 1 and 2b; see also Scharlau & Neumann, in press). The differential effect of searched-for and task-irrelevant information on attention was present although this information was well masked (Experiments 3b and 1).

These findings invalidate a bottom-up capture account of perceptual latency priming since both abrupt-onset distractors and distractor-like primes did not entail attentional capture. An abrupt onset is not a sufficient means of capturing attention. The contingent-capture account could be easily modified to accommodate the findings of the present study. For instance, control settings for static features can be apparently narrowly defined in some conditions. If participants search for a specific color, irrelevant color singletons can be effectively ignored (e.g., Folk & Remington, 1998). Modifications of abrupt-onset perceptual latency priming effects by matches between static features of the prime and the corresponding control settings are possibly not at odds with the contingent-capture account.

In any case, DPS can explain the main findings of the present study. According to the DPS account, attentional capture depends strongly on the prior set-up of a corresponding top-down control setting (e.g., the completion of an action plan) directed to the features of the targets. For instance, Neumann and Klotz (1994) observed DPS-induced response priming only if participants had sufficient time to prepare shape-to-response mappings prior to the onsets of the invisible shape primes. The current study extends the previous findings to show that attention shifts induced by masked primes may be due to DPS. Attention was captured by the masked abrupt-onset stimuli which resembled the targets and thus matched top-down action plans for features such as shape or color (target-like primes). Correspondingly, abrupt-onset stimuli which were dissimilar in their features to the action plans (i.e., distractors and masked distractor-like primes) captured attention only weakly (Experiment 3a) or not at all (Experiments 1 and 2a). In sum, it seems that if the action plan is to shift attention in response to a defined target, irrelevant, to-be-ignored information may capture attention, though only if it matches the intentionally searched-for features.

One feature of the DPS model is that it treats the control of attention and sensorimotor control as closely related phenomena. This feature corresponds to recent views on attentional guidance. According to, for example, the premotor theory of attention, covert shifts of attention are coupled to motor commands for overt eye movements (Rizzolatti et al., 1987). In order to covertly shift attention, a motor program for a saccade has to be established although the eye movement does not need to be carried out. Deubel and Schneider (1996) demonstrated that, while preparing a saccade, attention and saccades are necessarily directed towards the same target. They instructed their participants with an exogenous cue to prepare a saccade. After preparation, a discrimination target appeared at or near the target location of the saccade. Discrimination of this target was improved exclusively if it was at the location to which the planned saccade was directed whereas non-saccade item discrimination was very difficult, even if the item was located more foveally than the saccade location, and even if the actual saccade (that was carried out later) by mistake terminated on the discrimination target rather than on the saccade target. The coupling between attention and sensorimotor saccade programming thus seems to be obligatory supporting the DPS concept of attention as a part of visually guided action control.

Following a related line of argumentation, Bekkering and Neggers (2002) demonstrated that visuospatial attention can be improved by actions at an early stage. Their participants searched for a target of a specific color or orientation and either grasped the target or pointed at it. In contrast to pointing, grasping includes processing of orientation. Saccadic accuracy was better if participants grasped those objects than if they pointed at them. This was only found for search by orientation and not for search by color. Bekkering and Neggers explain their findings as indicating that the intention of an action ameliorates attentional orienting, supporting the notion of top-down modulation of attentional processes in close relationship to action control.

Note also that according to the DPS account, attentional capture is not contingent on a prior conscious perception of the capturing stimuli. Therefore, the DPS account dovetails neatly with another aspect of the present investigation. Visibility of the primes was compromised by backward masking in all of the experiments of the present study. Yet, perceptual latency priming was possible under these conditions (for related results see also Jaśkowski et al., 2002; Lambert et al., 1999; Mattler, in press; McCormick, 1997; Scharlau, 2002; Scharlau & Neumann, in press; Steglich & Neumann, 2000).

Acknowledgements

The research reported in this paper was supported by the Deutsche Forschungsgemeinschaft (DFG), grants NE 366/5-2 and NE 366/6-1 to Odmar Neumann. Thanks to Elena Carbone, Manfred Heumann, Matthias Kaper, Werner Klotz, Odmar Neumann and Dirk Vorberg, and to Adam Reeves and two anonymous reviewers for valuable comments on earlier versions of the manuscript. A preliminary version of this manuscript containing parts of the experimental data was presented at the 44th Conference of Experimental Psychologists, 25–27 March 2002, Chemnitz, Germany and at the 43rd Conference of the German Society for Psychology (DGPs), 22–26 September, Berlin, Germany.

References

Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology, 5*, 679–685.

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., & Neumann, O. (2001). Intentions determine the effect of nonconsciously registered visual information: Evidence for direct parameter specification in the metacontrast dissociation. Proceedings of the AISB '01 Symposium on nonconscious intelligence: From natural to artificial (pp. 1–8). York, UK: AISB.

Atchley, P., Kramer, A. F., & Hillstrom, A. P. (2000). Contingent capture for onsets and offsets: Attentional set for perceptual transients. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 594–606.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 451–470.

Bekkering, H., & Neggers, S. (2002). Visual search is modulated by action intentions. *Psychological Science, 13*, 370–374.

Berlucchi, G., Chelazzi, L., & Tassinari, G. (2000). Volitional covert orienting to a peripheral cue does not suppress cue-induced inhibition of return. *Journal of Cognitive Neuroscience, 12*, 648–663.

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

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

Bridgeman, B., Kirch, M., & Sperling, A. (1981). Segregation of cognitive and motor aspects of visual function using induced motion. *Perception & Psychophysics, 29*, 336–342.

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

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36*, 1827–1837.

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

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

Exner, S. (1868). Über die zu einer Gesichtswahrnehmung nöthige Zeit [On time necessary for a visual perception]. *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften zu Wien, mathematisch-naturwissenschaftliche Classe, 2*, 601–632.

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

Fellows, S., Tabaza, R., Heumann, M., Klotz, W., Neumann, O., Schwarz, M., Noth, J., & Töpper, R. (2002). Modification of a functional motor task by non-consciously perceived sensory stimuli. *Neuroreport, 13*, 637–640.

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

Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 847–858.

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

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

Franz, V. (2001). Action does not resist visual illusions. *Trends in Cognitive Sciences, 5*, 457–459.

Franz, V., Gegenfurtner, K., Bülthoff, K., & Fahle, M. (2000). Grasping visual illusions: No evidence for a dissociation between perception and action. *Psychological Science, 11*, 20–25.

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

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin Company.

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

Haffenden, A. M., & Goodale, M. A. (1998). The effect of pictorial illusion on prehension and perception. *Journal of Cognitive Neuroscience, 10*, 122–136.

Hays, W. L. (1988). *Statistics* (fourth 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.

Hommel, B. (1993). Inverting the Simon effect by intention. *Psychological Research, 55*, 270–279.

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

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

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

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

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

Lambert, A., Naikar, N., McLachlan, K., & Aitken, V. (1999). A new component of visual orienting: Implicit effects of peripheral information and subthreshold cues on covert attention. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 321–340.

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

Marcel, S. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15*, 197–237.

Mattler, U. (in press). Priming of mental operations by masked stimuli. *Perception & Psychophysics*.

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

McCormick, P. A. (1997). Orienting attention without awareness. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 168–180.

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

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., & 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: Erlbaum.

Remington, R., Folk, C. L., & McLean, J. P. (2001). Contingent attentional capture or delayed allocation of attention? *Perception & Psychophysics, 63*, 298–307.

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Perception & Psychophysics, 51*, 279–290.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia, 25*, 31–40.

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., & Neumann, O. (in press). Perceptual latency priming by metacontrast-masked stimuli: Evidence for an attentional interpretation. *Psychological Research*.

Schmidt, T. (2002). The finger in flight: Real-time motor control by visually masked color stimuli. *Psychological Science, 13*, 112–117.

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

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

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

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

Tassinari, G., & Berlucchi, G. (1993). Sensory and attentional components of slowing of manual reaction time to non-fixated visual targets by ipsilateral primes. *Vision Research, 33*, 1525–1534.

Theeuwes, J., & Burger, R. (1998). Attentional control during visual search: The effect of irrelevant singletons. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1342–1353.

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

Yantis, S. (1993). Stimulus-driven attentional capture and attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 676–681.

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

Zackon, D. H., Casson, E. J., Zafar, A., Stelmach, L., & Racette, L. (1999). The temporal order judgment paradigm: Subcortical attention contribution under exogenous and endogenous cueing conditions. *Neuropsychologica, 37*, 511–520.