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# On the role of mask structure in subliminal priming

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**Abstract**. Choice reaction times to visual stimuli may be influenced by preceding subliminal stimuli (primes). Some authors reported a straight priming effect i.e., responses were faster when primes and targets called for the same response than when they called for different responses. Other authors found a reversed pattern of results. Our results suggest that the sign of the priming effect depends on mask structure. Inverse priming was obtained only for masks containing the searched-for feature even though informational content of the masks was neutral. With masks of irrelevant structure, straight priming effects were found. Thus, masks are not passive stimuli whose roles are limited to rendering the prime invisible. Processing of the mask may interact with prime and target processing. Implications of the results are discussed for two hypotheses trying to account for straight and inverse priming (the self-inhibition hypothesis and object-updating hypothesis).

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**Key words:** backward masking, straight priming, inverse priming

## INTRODUCTION

A recent series of studies has suggested that stimuli that are not consciously perceived may nevertheless be processed sufficiently to affect choice reactions. For example, Neumann and Klotz (1994) presented pairs of different shapes, left and right of fixation. One stimulus was defined as the target to which participants had to respond with their left or right hand depending on its side of presentation. These shapes were preceded by two stimuli (primes) that were small replicas of the stimuli. Given that the mask is spatially adjacent to the prime and follows it by around 50 ms, the primes becomes essentially invisible, a phenomenon known as metacontrast. Although primes were not identifiable (which was verified in a separate prime discrimination experiment), reaction times (RTs) were shorter for targets preceded by congruent primes i.e., if the prime on the target side was a small copy of the target, and thus called for the same response, rather than a small copy of the non-target. This finding was successfully replicated several times (Ansorge et al. 1999, 2002, Jaśkowski et al. 2002, 2003, Klotz and Neumann 1999, Klotz and Wolff 1995).

Such priming effects have also been found with other types of visual backward masking. Unlike metacontrast experiments, where the mask is the response-relevant stimulus, in experiments with pattern masking, a prime is followed by a mask, and it is only after the mask that an imperative stimulus is presented. In spite of this difference, RTs to congruently primed stimuli were often found to be shorter than to incongruently primed stimuli (Cheesman and Merikle 1984, Dehaene et al. 1998, Merikle and Joordens 1997a, 1997b).

This pattern of results has, however, been complicated by Eimer and Schlaghecken's recent findings (1998). They used arrows pointing to the left or right as primes and imperative stimuli. The mask was a compound of the left- and right-pointing arrows. They showed that reactions in congruent trials were delayed rather than facilitated. We will refer to the priming effect in which performance in congruent trials is better than in incongruent trials as the straight priming effect and to the priming effect in which performance in compatible trials is worse than in incompatible trials as the inverse priming effect. Their RT data were supported by lateralized readiness potential (LRP) recordings: as is usually the case, primes and imperative stimuli evoked higher EEG activation of motor cortex on the contralateral than on the ipsilateral side with respect to the direction of the arrows resulting in two peaks of activation. In the congruent situation, however, there was a wave visible between those two peaks, implying higher activation of ipsi- than contralateral motor cortex. Eimer and Schlaghecken suggested that this pattern of activity reflected "selective inhibition of the response that was initially triggered by the prime" (Eimer and Schlaghecken 1998, p. 1746). In other words, Eimer and Schlaghecken postulated that every prime automatically evokes an activation of motor processes within a short interval after prime onset, triggering response preparation consistent with the prime's identity. When the target appears shortly after the prime, this activation facilitates the response to a target that is congruent with the prime and impairs the response when prime and target are incongruent. This activation phase is followed by a self-inhibitory process that results in an opposite effect: inhibition of the response to a target proceeded by a congruent prime and facilitation to a target preceded by an incongruent prime. Therefore, if the target appears shortly after the prime, it falls on an activation phase, leading to straight priming. Given longer prime-target intervals, the self-inhibition phase starts and inverse priming effect takes place. With this it was possible to account for Schlaghecken and Eimer's earlier findings (Schlaghecken and Eimer 1997, 2000, 2002) showing that inverse priming occurred only if the delay between prime and target was sufficiently long. The second important assumption is that the inhibitory phase switches on only if the sensory input crosses a threshold (Schlaghecken and Eimer 2002). This means that weak sensory input is not able to evoke inhibitory processes. With this assumption, the model accounts well for another finding: inverse priming was found only for central presentation of primes and targets (and long prime-target intervals) while straight priming occurred for all other situations (Schlaghecken and Eimer 2000). This could be due to the weaker input from the peripheral than from the central visual field or "due to differences in the strength of sensory traces elicited by peripheral and foveal stimuli" (Schlaghecken and Eimer 2002). We will call this hypothesis the self-inhibition (SI) hypothesis.

The SI hypothesis assumes that priming effects are independent of how the mask looks provided that it is neutral with regard to the response choice. But "neutral" may mean two different things, either calling for no response at all or calling equally for both responses. Eimer and Schlaghecken's double-arrow mask called for both responses. However, Lleras and Enns (2004), and Verleger and coauthors (2004), found straight priming for masks formed by elements irrelevant to the participants' task. On the basis of their experiments, Lleras and Enns concluded that besides decay over time of the priming induced by the masked stimuli, a mask interacts with processes evoked by the primes. The visual system compares the incoming information with an existing representation of a scene to update the representation. If nothing changes, the old representation is reinforced. However, once the scene changes, this new information is processed, leading to the preparation of the response indicated by the identity of the new object. For example, let the left pointing arrow be masked by the mask that is formed by overlapping left and right arrows. When the mask appears, the novel object in the scene representation involves the right pointing arrow. Therefore, processing switches to the new object, the previous preparation is interrupted and replaced by the preparation of the opposite hand. This might have led to delayed responding in congruent trials and to speeded responses in incongruent trials. This was suggested recently by Lleras and Enns' object-updating (OU) hypothesis (Enns et al. 2005, Lleras and Enns 2004, see Verleger et al. 2004 for similar account).

In their more recent experiments, however, Eimer and Schlaghecken (e.g., 2002) reported an inverse priming effect not only with the masks being formed by juxtaposing two primes/targets pointed to different direction but also with masks made up of assemblies of short lines of different lengths and orientations, varying over trials. Moreover, by varying the number of line elements that constituted the mask, they showed (Eimer and Schlaghecken 2002) that priming effects depended strongly on prime visibility: when the mask contained only few lines, leaving the primes visible, priming effects were straight. The effects became inverse once the mask contained more line elements, so that the primes became unidentifiable. Eimer and Schlaghecken concluded that the absence of response inhibition with supra-threshold primes is due to the fact that consciously accessible perceptual information counteracts the automatic operation of self-inhibitory motor control circuits. This finding was incorporated into the SI hypothesis: they assumed that the inhibitory phase (and thus inverse priming) appears only if the prime is completely masked. Otherwise, when masking is not efficient enough to prevent the prime from being consciously identifiable, straight priming occurs (Eimer and Schlaghecken 2002, Schlaghecken and Eimer 2002). One can argue that, in agreement with this assumption, irrelevant masks used in Lleras and Enns' (2004) study seemed to mask less efficiently than relevant ones. With irrelevant masks, participants had usually more than 60% of correct responses in forced-choice tasks. Therefore, it was hardly to accept that their primes were subliminal.

We will show in the present paper, however, that in contrary to Eimer and Schlaghecken's (2002) SI hypothesis, straight priming is possible even though masking is quite efficient and, *vice versa*, reversed priming is possible even if primes are visible in a considerable number of trials, and *vice versa*.

## EXPERIMENT 1

### Method

#### *PARTICIPANTS*

Twenty-one volunteers (13 males and 8 females; age 19–30 years) recruited from the student population of the Adam Mickiewicz University of Poznań took part in the experiment. They obtained either course credit, or they were paid for their participation (20 zł = 4 € per session). Some participants were not paid for their participation, being friends of the authors. All had normal of corrected-to-normal visual acuity.

#### *APPARATUS AND PROCEDURE*

All stimuli (black figures on white background) were displayed on a 17-in. computer monitor with refresh rate either 60 Hz driven by Presentation software (v. 0.71, Neurobehavioral Systems Inc.).

Participants sat in an armchair in a darkened room in front of the monitor. The observation distance was 100 cm.

The experimental session consisted of 2 parts. In the initial part (RT block), we measured choice RT to target stimuli. The participants' task was to respond

according to target identity, by pressing the Left-ctrl or the Right-ctrl key of the computer keyboard, as quickly and accurately as possible. In the final block (prime discrimination (PD) block), the prime recognition was checked. In this part, participants were required to respond according to prime identity without pressure with respect to speed. Trials started with a warning signal, serving as fixation aid: four points appeared 5° above, below, left, and right of the screen center, moved inwards for 0.9 s and then "crystallized" as fixation cross. Then, the prime appeared for a short time (16.7 ms) and was replaced by a mask displayed for 100 ms. Thereafter the target was displayed for the next 100 ms. Inter-trial interval was equal to 0.8 s.

In the PD blocks, no targets were presented after the masks and the subjects' task was to guess which of the two primes was presented (2AFC).

The primes and targets were similar to those used by Eimer and Schlaghecken (1998) in their Experiment 1: pairs of left- or right-pointing double arrow-heads. Four different masks presented in Fig. 1 were applied. Mask 1 and 3 contained task relevant features being formed from arrow-like elements, while Masks 2 and 4 contained no task relevant features being formed of non-arrow elements only. The masking efficiency of the mask was also manipulated. Pilot data showed that Masks 1 and 2 were more efficient than Masks 3 and 4. Primes subtended 4.2 × 4.6 deg and masks subtended 4.4 × 5.0 deg. The prime was presented centrally for 16.7 ms.

The RT block contained 144 (= 4 masks × 36 repetitions) congruent trials (i.e., arrows in the prime and target pointed to the same side) and 144 incongruent trials (arrows in the prime and target pointed to different sides). The PD block consisted of 144 (= 4 masks × 36 repetitions) left- and 144 right-pointing primes.

*DATA ANALYSIS*

Response times and percentage of correct responses were measured relative to the target stimulus. Mean latencies of the correct responses were evaluated statistically by analysis of variance (ANOVA) for repeated measurements with three within-subjects factors: congruence (congruent vs. incongruent), type of mask (task relevant mask vs. task irrelevant mask; Mask 1 and 3 vs. Mask 2 and 4) and mask density (low vs. high; Mask 3 and 4 vs. Mask 1 and 2).

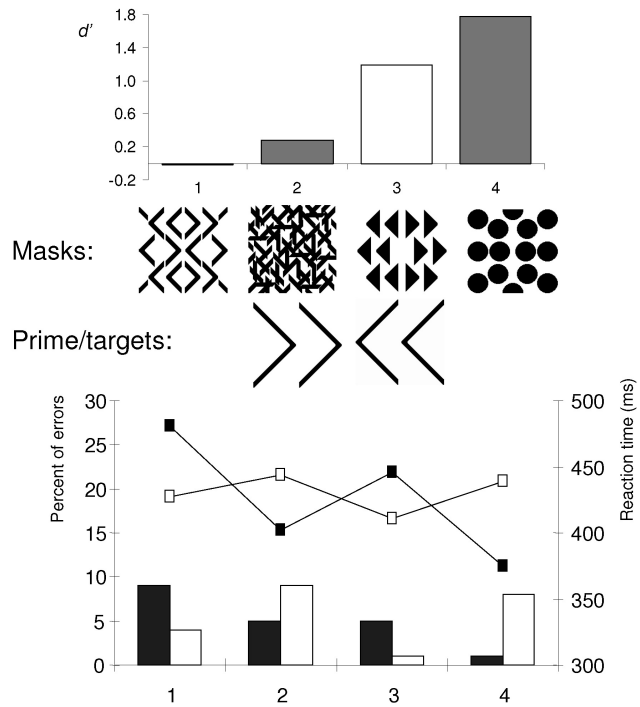


Figure 1. Stimuli and results of Experiment 1 (upper row): Upper plot: *d'* for the masks showed. Lower plot: reaction times (lines), and percentages of incorrect responses (bars) for congruent (filled symbols/bars) and incongruent (open symbols/bars) trials for all masks used.

**Results**

*PRIME DISCRIMINATION*

Mean *d'*[1] calculated from the percentage of correct choices (Smith 1982) amounted to -0.02, 0.27, 1.18 and 1.68 for Mask 1–4, respectively (Fig. 1, upper panel). The *t*-Student test showed that for all masks except Mask 1, *d'*s were significantly higher than 0 ($t_{20}$=-0.36, $P$=0.72; $t_{20}$=4.6, $P$<0.001; $t_{20}$=6.23; $P$<0.001; $t_{20}$=6.60, P<0.001, for Mask 1–4, respectively). An ANOVA showed that primes masked by the task relevant masks were less visible than primes masked by the task irrelevant masks (0.58 vs. 0.98, $F_{1,20}$=7.1, $P$=0.015). Moreover, in accordance with our pilot data, Masks 1 and 2 were more efficient than Masks 3 and 4 (0.13 vs. 1.43, $F_{1,20}$=68.4, $P$<0.001). The interaction of the factors was insignificant.

*PRIMING EFFECT ON CHOICE–RESPONSES*

RTs (Fig. 1, lower panel) were shorter for non-arrow than for arrow masks (415 vs. 440 ms; $F_{1,20}$=77.5;

[1] *d'* is a bias-free psychophysical measure of sensitivity of a observer in detecting or discriminating stimuli. *d'* = 0 under given conditions means no ability to detect or discriminate stimuli

$P<0.001$) and for trials with less dense than denser masks (417 vs. 437 ms, $F_{1,20}=40.9$, $P<0.001$). RTs were equally long for congruent and incongruent trials but, of most interest, the effect of congruence depended on the mask used. First, the significant interaction between type of mask and congruence ($F_{1,20}=195$, $P<0.001$) reflects the fact that congruence effects were clearly straight for task irrelevant masks ($RT_{incongruent}$ - $RT_{congruent}$=53 ms) and inverse for task relevant masks ($RT_{incongruent}$ - $RT_{congruent}$=-44 ms). Second, the significant interaction between mask density and congruence ($F_{1,20}=16.6$, $P<0.001$) reflected the fact that congruence effects were more positive with less dense (14.6) than with denser masks (-6 ms).

*ERRORS*

With more efficient masks, the overall number of errors was slightly larger than with less efficient masks (6.1% vs. 3.7%, $F_{1,20}=4.82$, $P=0.040$). Type of mask affected the congruency effect ($F_{1,20}=12.3$, $P=0.002$). There were more errors in congruent than in incongruent trials with the task relevant masks (6.8 vs. 2.3%) and *vice versa* with the task irrelevant masks (2.8% vs. 7.8%). There were no other significant effects.

#### Discussion

The results obtained with the task relevant masks are in accordance with those obtained by Eimer and Schlaghecken (Eimer 1999, Eimer et al. 2002, Eimer and Schlaghecken 1998, 2001, 2002) and others (Klapp and Hinkley 2002, Lleras and Enns 2004, Verleger et al. 2004): in congruent trials i.e., when the prime pointed to the same side as the target, RTs were longer than in incongruent trials. With the irrelevant masks the effect was inverse: RTs were shorter in congruent than in incongruent trials. Therefore, we can conclude that the inverse priming effect occurred only for the task relevant masks. This was true even with masks of poor effectiveness. These results clearly contradict the SI hypothesis.

One can, however, argue that these effects, especially straight priming for the task irrelevant Mask 2, was caused by some details of our experimental procedure. Indeed, one potential critique could be raised as to our prime discrimination part, which could be considered as demotivating, being relatively long in comparison to those used in Eimer and Schlaghecken's studies. This fact might have resulted in an underestimation of subjects' conscious prime discrimination abilities.

Therefore, Experiment 1 was repeated under slightly different conditions. We used stimuli of sizes used in the original Eimer and Schlaghecken's papers. Moreover, the PD part was shortened to make the task less frustrating.

## EXPERIMENT 2

#### Method

*PARTICIPANTS*

A group of 10 persons (5 males and 5 females, age 20–28 years) participated in the experiment.

*PROCEDURE*

Experiment 2 was virtually identical to Experiment 1 except for three changes. First, stimulus size was reduced so that primes and targets fit into a 1.05 × 0.80 deg rectangle and masks fit within 1.62 × 1.15 deg rectangles. Second, the PD task was shortened to 24 stimuli per mask and divided into two blocks with a short pause in between. Third, the structure of Mask 2 was slightly changed to eliminate all elements that could be seen to resemble an arrow and to improve mask efficiency.

#### Results

*PRIME DISCRIMINATION*

Mean *d'* amounted to -0.02, 0.05, 0.60, 1.5 for Mask 1–4, respectively. The *t*-Student test showed that only for less dense masks (Mask 3 and 4), *d'*s were significantly higher than 0 ($t_9$=-0.138, $P=0.90$; $t_9=0.37$, $P=0.72$; $t_9=2.77$; $P=0.022$; $t_9=3.7$, $P=0.004$, for Mask 1–4, respectively).

*REACTION TIME*

RTs obtained in Experiment 2 are depicted in Fig. 2. The pattern of results is similar to that obtained in Experiment 1. RTs were slightly shorter for non-arrow than for arrow masks (418 vs. 428 ms; $F_{1,9}=4.6$; $P=0.06$). The effect of congruency depended on the mask used: the interaction between type of mask and congruency was significant as before ($F_{1,9}=77.2$,

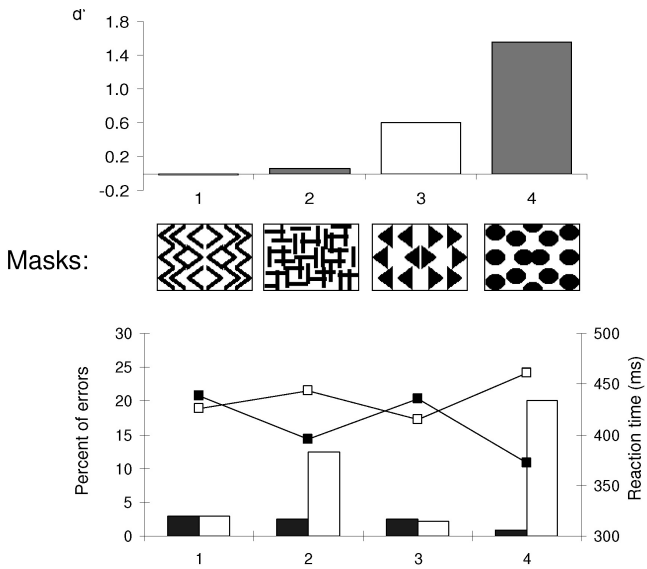


Figure 2: Stimuli and results of Experiment 2 (upper row): Upper plot: *d'* for the masks showed. Lower plot: reaction times (lines), and percentages of incorrect responses (bars) for congruent (filled symbols/bars) and incongruent (open symbols/bars) trials for all masks used

*P*<0001). The congruency effects were large and straight for the task irrelevant masks ($RT_{incongruent}$ - $RT_{congruent}$=68 ms) and smaller ($RT_{incongruent}$ - $RT_{congruent}$=-16 ms) but still inverse for the task relevant masks (as estimated by a separate ANOVA performed only for arrow masks: $F_{1,9}$=5.1, *P*=0.05). Unlike Experiment 1, RTs in congruent trials were generally shorter than in incongruent trials ($F_{1,9}$=14.1, *P*=0.004). The interaction between visibility and congruency was only marginally significant ($F_{1,9}$=3.7, *P*=0.085) but reflected the same tendency as in Experiment 1 i.e., the congruence effects were more positive with less dense (35 ms) than with denser masks (17 ms).

*ERRORS*

More errors were made for the task irrelevant than task relevant masks (7.6 vs. 2.7%, $F_{1,9}$=29.4, *P*<0001), and for incompatible than compatible trials (8.0 vs. 2.2%, $F_{1,9}$=18.1, *P*=0.002). Type of mask affected the congruency effect ($F_{1,9}$=21.2, *P*=0.001). For the task relevant masks the error rates were virtually equal for congruent and incongruent trials (2.7 vs. 2.6%). For the task irrelevant masks, participants made considerably more errors for incongruent than congruent trials (13.5.% vs. 1.7%). There were no other significant effects.

**Discussion**

Generally, the results of Experiment 2 were in good agreement with those obtained in Experiment 1. Although the stimuli were as small as in Eimer and Schlaghecken's experiments, the priming effects were straight with non-arrow masks and reversed with arrow masks. Similar results were found also by Lleras and Enns (2004), and by Verleger and coauthors (2004).

According to Eimer and Schlaghecken, there are some additional constraints that need to be met, besides perfect masking, for inverse priming to occur. They argued that the straight effect in priming studies results when the temporal distance between prime and target is short (Eimer 1999, Eimer and Schlaghecken 1998) and primes are presented peripherally rather than centrally (Schlaghecken and Eimer 1997, 2000). We have shown in Experiments 1 and 2 here that straight priming can occur under conditions favorable to inverse priming i.e., with relatively long temporal distance between prime and target, with central presentation, and with high effectiveness of masking. It is not easy to reconcile these findings with the SI hypothesis.

Results of our Experiments 1 and 2 are consistent with the OU hypothesis. If formed from arrow-like elements, the mask evokes an updating process that results in inhibition of the response preparation elicited by the prime and starts preparation of the opposite hand because the novel features in the mask calls for the opposite hand. Given that the mask is formed from neutral elements that call for neither left nor right responses, the process of preparation is not inhibited, leading to straight priming.

Summing up, although the experimental conditions in Experiment 2 were very close to those used by Eimer and Schlaghecken (1998), the priming effects were straight with non-arrow masks and inverse with arrow masks. Nevertheless, the change of mask structure may result in change in priming efficiency.

## GENERAL DISCUSSION

**The prime visibility and the OU hypothesis**

In the OU hypothesis, it is assumed that information conveyed by the mask is automatically analyzed in search of relevant features. Initial activation is evoked by features found in the prime. These are in turn updat-

ed by objects presented in the mask. If the mask is formed by superimposing two primes calling for different responses, the update yields features that are opposite to those in the prime and the opposite response is prepared.

The OU hypothesis is able to account easily for inverse priming by both subliminal and supraliminal primes (see also Lleras and Enns 2004, Verleger et al. 2004). Second, it also provides a plausible account of the relation between visibility and priming originally demonstrated by Eimer and Schlaghecken (2002), and refined in the present study. Eimer and Schlaghecken (2002) used masks composed of randomly arranged short and long lines in their study. To manipulate visibility Eimer and Schlaghecken varied mask density and prime duration independently. One may speculate (Lleras and Enns 2004) that because the masks were formed from lines of different lengths and orientations of the same width as the arrow stimuli, they were likely to contain arrow elements similar to those that were intended to be relevant to the participants' task[2]. Moreover, it is plausible that denser masks not only cause faster decay over time of the straight priming induced by the masked stimuli but also make higher the probability that a relevant object will be formed from randomly distributed lines.

**Object updating and inverse priming**

Unfortunately, the OU hypothesis seems to be at odds with a recent experiment by Jaśkowski (unpublished results). He demonstrated that inverse priming can occur even if the mask is composed of two objects different from that displayed in the prime. He used two different categories of figures which can form primes, masks and targets. All figures were relevant for the task: one from each category was mapped to the left hand and one of each category was mapped to the right hand. Having these two different categories allowed Jaśkowski to use two figures from one category to form the prime and the target and two figures from the other to form neutral masks. According to the OU hypothesis, the straight priming was expected because such a mask calls for updating and provides two contradictory cues as to which response should be prepared. In contrast to this prediction, he found clear inverse priming.

**The prime visibility and the SI hypothesis**

In its most recently updated version (Schlaghecken and Eimer 2002), the SI hypothesis postulates that each prime automatically evokes activation followed by self-inhibition of motor processes. Depending on the timing of stimuli and responses, this leads to straight or inverse priming.

In our view, the SI hypothesis encounters even more difficulties than the UO hypothesis in accounting for experimental data so-far collected. In the present study, we demonstrated the inverse priming effect only for masks consisting of arrow-like elements. When we used masks consisting of non-arrow elements, the effect was straight, even though the conditions were preferable for inverse priming: the prime-target distance was long (Eimer 1999, Eimer and Schlaghecken 1998) and the primes were presented centrally (Schlaghecken and Eimer 1997, 2000). Conversely, we obtained inverse priming under conditions that favored straight rather than inverse priming i.e., when masking efficiency was rather poor and, consequently, the primes were recognizable in a considerable proportion of trials (Lleras and Enns 2004). These results clearly contradict the inhibition hypothesis in its original formulation. Thus it is necessary to add an extra assumption to this hypothesis, as Bowmann and coauthors (in press) did recently, that prime-mask interaction might be involved in priming.

**The mask-triggered inhibition hypothesis**

We argued above that none of the hypotheses proposed so far i.e., the OU and the SI hypothesis, encounter serious problems when trying to account for all experimental results. Below we present another hypothesis which seems to fit well with the data collected so far (Jaśkowski, unpublished results). This hypothesis, which we will call the mask-triggered inhibition (MTI) hypothesis, assumes that a prime evokes response preparation according to the prime identity. The role of mask is twofold. First, it stops the processing of prime thereby the prime-induced motor activation is not accumulated anymore. Second, it starts processes leading to the inhibition of the motor cortex activated by the prime (Praamstra and Seiss 2005, Verleger, Kötter, Jaśkowski, Sprenger, Siebner, unpublished results). We further assume that this inhibition is more effective for relevant than for irrelevant masks.

[2] By the same token, the negative priming demonstrated by Klapp and Hinkley (2002) might also be accounted for by the special mask they used (WXXW or XWWX), as both these letter chains contain elements relevant to the searched-for features: especially X might be perceived as a compound of two opposing arrows (see Lleras and Enns 2004).

The MTI hypothesis is a hybrid containing features taken from the OU and the SI hypothesis. From the SI hypothesis it inherits inhibitory processes that follow prime-induced motor activation. Unlike the SI hypothesis, however, we assume that these inhibitory processes are triggered by the mask rather than simply reflecting a late phase of prime-induced activity. In this regard our hypothesis resembles the OU hypothesis. However, we claim that it is not necessary to assume that only novel elements of the mask call for processing and thereby can affect motor preparation. Rather each stimulus calls for processing and automatically inhibits ongoing activation, especially when it is formed from searched-for objects/features because the appearance of such objects signals the need to change current behavior.

With these assumptions it is possible to account for a majority of the experimental results concerning straight and inverse priming. Some of them are quite obvious, bearing in mind the features that the MTI model inherited. In the following, we review briefly the most crucial issues.

1. As the mask is responsible for triggering inhibitory processes, only straight priming can occur when the mask is not inserted between prime and target. This is in accordance with the results of many studies where metacontrast masking was used (e.g., Verleger et al. 2004).

2. Further, straight priming occurs whenever the prime is visible, the masking is ineffective, or the mask contains irrelevant features. Under such conditions, relatively strong motor activation evoked by the prime remains unchanged till target presentation (no mask) or the effect of the mask is too weak to turn activation into inhibition (ineffective or irrelevant mask).

3. Conversely, inverse priming occurs whenever the mask contains relevant features or searched-for objects. In such a situation, the mask appearance evokes inhibitory processes much stronger than in the case of the irrelevant mask, leading to a reversal of the priming effect.

4. Inverse priming is more likely to occur if the time between the prime and the target is longer (e.g., Schlaghecken and Eimer 2000). This is because elongation of the prime-target interval leads also to the elongation of the mask-target interval, permitting the mask to work. In other words, both recognition of the relevant features and subsequent inhibitory processes need time to develop.

5. Schlaghecken and Eimer (2000) found a peripheral-central asymmetry in the priming effect: priming is more likely to be inverse when the prime is presented centrally than when it is presented peripherally. They argued that this is because a strong perceptual representation of the prime is needed for inverse priming to occur. According to our interpretation, this effect results from the fact that the mask features are more easily identifiable when the mask is presented centrally than when it is presented peripherally.

## CONCLUSIONS

Our main aim was to show that priming effects can be straight or reversed depending on the mask structure, irrespectively of whether the primes were subliminal or not. It is usually implicitly assumed that the mask by itself does not contribute to the priming effect provided that it is neutral as to the information relevant to the task. We showed, however, that the mask structure can dramatically change the priming effect. The role played by the mask in subliminal stimulation has usually been overlooked although some contradictions or failures to replicate previous studies might result from different masks and masking procedures.

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### REFERENCES

Ansorge U, Heumann M, Scharlau I (2002) Influences of visibility, intentions, and probability in a peripheral cueing task. Conscious Cogn 11: 528–545.

Ansorge U, Klotz W, Neumann O (1999) Manual and verbal responses to completely masked (unreportable) stimuli: Exploring some conditions for the metacontrast dissociation. Perception 27: 1177–1189.

Bowman H, Schlaghecken F, Eimer M. A neural network model of inhibitory processes and cognitive control. Vis Cogn (in press)

Cheesman J, Merikle PM (1984) Priming with and without awareness. Percept Psychophys 36: 387–395.

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

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

Eimer M, Schlaghecken F (1998) Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. J Exp Psychol Hum Percept Perform 24: 1737–1747.

Eimer M, Schlaghecken F (2001) Response facilitation and inhibition in manual, vocal, and oculomotor performance: Evidence for a modality-unspecific mechanism. J Mot Behav 33: 16–26.

Eimer M, Schlaghecken F (2002) Links between conscious awareness and response inhibition: Evidence from masked priming. Psychon Bull Rev 9: 514–520.

Eimer M, Schubö A, Schlaghecken F (2002) The locus of inhibition in the masked priming of response alternatives. J Mot Behav 34: 3–10.

Enns JT, Lleras A, Di Lollo V (2005) A reentrant view of visual masking, object substitution, and response priming. In: The First Half Second: The Microgenesis and Temporal Dynamics of Unconscious and Conscious Visual Processes (Ogmen H, Breitmeyer BG, eds.). MIT Press, Cambridge, MA (in press)

Jaśkowski P, Skalska B, Verleger R (2003) How the self controls its "automiatic pilot" when processing subliminal information. J Cogn Neurosci 15: 911–920.

Jaśkowski P, Van der Lubbe R, Schlotterbeck E, Verleger R (2002) Traces left on visual selective attention by stimuli that are not consciously identified. Psychol Sci 13: 48–54.

Klapp ST, Hinkley LB (2002) The negative compatibility effect: Unconscious inhibition influences reaction time and response selection. J Exp Psychol Gen 131: 255–269.

Klotz W, Neumann O (1999) Motor activation without conscious discrimination in metacontrast masking. J Exp Psychol Hum Percept Perform 25: 976–992.

Klotz W, Wolff P (1995) The effect of a masked stimulus on the response to the masking stimulus. Psychol Res 58: 92–101.

Lleras A, Enns JT (2004) Negative compatibility or object updating? A cautionary tale of mask-dependent priming. J Exp Psychol Gen 133: 475–493.

Merikle PM, Joordens S (1997a) Measuring unconscious influences. In: Scientific Approach to Consciousness (Cohen JD, Schooler JW, eds.). Erlbaum, Mahawah, NJ, p. 109–123.

Merikle PM, Joordens S (1997b) Parallels between perception without attention and perception without awareness. Conscious Cogn 6: 219–236.

Neumann O, Klotz W (1994) Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In: Conscious and Unconscious Information Processing (Umiltá C, Moscovitch M, eds.). MIT Press, Cambridge, MA, p. 123–150.

Praamstra P, Seiss E (2005) The neurophysiology of response competition: Motor cortex activation and inhibition following subliminal response priming. J Cogn Neurosci 17: 483–493.

Schlaghecken F, Eimer M (1997) The influence of subliminally presented primes on response preparation. Sprache und Kognition 16: 166–175.

Schlaghecken F, Eimer M (2000) A central-peripheral asymmetry in masked priming. Percept Psychophys 62: 1367–1382.

Schlaghecken F, Eimer M (2002) Motor activation with and without inhibition: Evidence for a threshold mechanism in motor control. Percept Psychophys 64: 148–162.

Smith JE (1982) Simple algorithms for M-alternative forced-choice calculations. Percept Psychophys 31: 95–96.

Verleger R, Jaśkowski P, Aydemir A, Van der Lubbe RHJ, Groen M (2004) Qualitative differences between conscious and non-conscious processing? On negative and positive priming effects induced by masked arrows. J Exp Psychol Gen 133: 494–515.

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