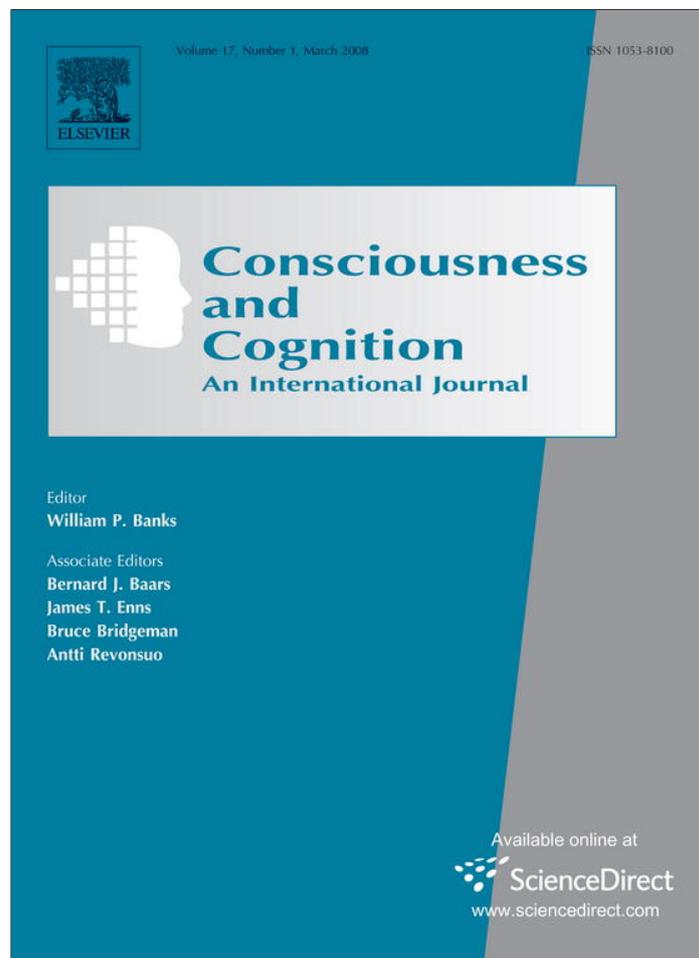


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No difference between conscious and nonconscious visuomotor control: Evidence from perceptual learning in the masked prime task [☆]

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Received 10 August 2006

Available online 28 December 2006

Abstract

Negative compatibility effects (NCEs) in the masked-prime paradigm are usually obtained when primes are masked effectively. With ineffective masks—and primes above the perceptual threshold—positive compatibility effects (PCEs) occur. We investigated whether this pattern reflects a causal relationship between conscious awareness and low-level motor control, or whether it reflects the fact that both are affected in the same way by changes in physical stimulus attributes. In a 5-session perceptual learning task, participants learned to consciously identify masked primes. However, they showed unaltered NCEs that were not different from those produced by participants in a control group without equivalent perceptual learning. A control experiment demonstrated that no NCEs occur when prime identification is made possible by ineffective masking. The results suggest that perceptual awareness and low-level motor control are affected by the same factors, but are fundamentally independent of each other.

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Keywords: Low-level motor control; Perceptual learning; Masked priming; Negative compatibility effect

1. Introduction

Visual backward-masked prime stimuli, presented at or near the threshold of conscious awareness, can trigger a specific and rather unusual pattern of priming effects. When primes are immediately followed by a target stimulus, responses to the target benefit if the prime is a stimulus assigned to the same response as the target. However, when the target follows prime offset/mask onset with an interval of approximately 150 ms, the reverse is true: Responses benefit if the prime is assigned to the opposite response to the target, and are impaired when it is assigned to the same response (e.g., Aron et al., 2003; Eimer & Schlaghecken, 2002; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Praamstra & Seiss, 2005; Schlaghecken & Eimer, 2002; Seiss & Praamstra, 2004).

[☆] This research was supported by a grant from the Economic and Social Research Council of Great Britain (Grant No. RES 000-22-0988).

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This sequence of positive and negative prime–target compatibility effects has been interpreted as reflecting activation and self-inhibition processes within low-level, direct perceptuo-motor links, where self-inhibition acts as an ‘emergency brake’ mechanism, preventing motor activations from affecting overt behavior when the perceptual evidence supporting this activation has suddenly been removed (Schlaghecken, Bowman, & Eimer, 2006; Schlaghecken & Eimer, 2002, 2006). This hypothesis is based on the finding that when the mask does not contain any potentially response-relevant features (cf. Jaśkowski & Przekoracka-Krawczyk, 2005), negative compatibility effects (NCEs) are only observed with effectively masked, ‘subliminal’ primes, whereas unmasked or ineffectively masked, ‘supraliminal’ primes result in positive compatibility effects (PCEs) (Eimer & Schlaghecken, 2002; Klapp & Hinkley, 2002).

There are alternative interpretations of the NCE, which assume that the mask—by virtue of having some similarity with primes and targets at the feature level—actively triggers an activation of the opposite response irrespective of whether or not it successfully masks the prime. For example, Jaśkowski and Przekoracka-Krawczyk (2005) used primes and targets consisting of arrow lines (< or >), and masks consisting of an array of filled arrow heads (▶ and ◀). With these masks, NCEs occurred despite high prime visibility. Conversely, masks that were not similar to the response relevant features of primes and targets failed to trigger NCEs (e.g., Jaśkowski & Przekoracka-Krawczyk, 2005; Lleras & Enns, 2004; Verleger, Jaśkowski, Aydemir, van der Lubbe, & Groen, 2004). Recent results, however, suggest that NCEs obtained with relevant-feature masks and NCEs obtained with non-relevant but effective masks might reflect two different processes. In particular, significant NCEs have been found with ‘non-relevant’ masks that do not contain features similar to primes and targets, but nevertheless successfully reduce prime visibility (Klapp, 2005; Schlaghecken & Eimer, 2006; for further evidence, see Aron et al., 2003; Schlaghecken & Maylor, 2005). At present, it therefore seems most likely that motor responses triggered by successfully masked primes are subject to self-inhibition but that, in addition to and independently of this, potentially response-relevant features in the mask might trigger a response opposite to the primed response (Sumner, 2006). This second process, although interesting in itself, is not of interest in the present context and will not be discussed further. Instead, the current study focuses on the question of whether conscious awareness of the primes plays a causal role in determining the presence or absence of the NCE, regardless of whether or not this effect is triggered by self-inhibition.

For non-relevant masks, the fact that opposite results are obtained with subliminal and supraliminal primes suggests that subliminal stimuli are in some way ‘special’—they might be processed in a way that is fundamentally different from the way supraliminal stimuli are processed. In fact, observing qualitative (rather than merely quantitative) differences between supposedly conscious and supposedly unconscious processes has long been regarded as the most convincing demonstration that unconscious processes exist at all (e.g., Cheesman & Merikle, 1986). Thus Klapp and Hinkley (2002) have argued that the NCE itself can be regarded as direct evidence for the subliminal nature of the masked primes, as this effect is qualitatively different from (namely, opposite to) the effect observed with supraliminally presented primes.

However, a different interpretation needs to be considered: Perhaps NCEs are usually obtained with subliminal primes, and PCEs with supraliminal primes, because both the direction of priming effects and prime visibility are affected by the same set of parameters, without one being causally related to the other. Brief presentation and subsequent masking might make conscious awareness of the prime difficult or even impossible and might also make (early stages of) the motor system more likely to self-inhibit—however, this does not mean that the former must be a prerequisite for the latter (see also Eimer & Schlaghecken, 2002).

The present study addressed this issue by dissociating prime identification performance (as an indicator of conscious perception of the prime) and direction of priming effects. In earlier studies, manipulation of prime visibility always involved corresponding changes in stimulus timing and/or structure. For example, Klapp and Hinkley (2002) omitted the mask in order to turn subliminal into supraliminal primes (and, correspondingly, NCEs into PCEs). Eimer and Schlaghecken (2002) employed a mask constructed from randomly distributed lines of different orientation, and decreased the efficiency of this mask (i.e., increased the visibility of the primes) by decreasing the line density. In a second experiment, the mask remained unchanged, but prime duration was increased. In both cases, increasing prime visibility was accompanied by a corresponding shift from NCEs to PCEs. Finally, several experiments have reported PCEs when prime visibility was high because ‘non-masking’ masks had been chosen that had no similarity to the primes at the feature level (e.g., Jaśkowski & Przekoracka-Krawczyk, 2005; Lleras & Enns, 2004; Verleger et al., 2004). In summary, changes in prime

visibility were always caused by changes in physical stimulus properties. Consequently, any change in the direction of priming effects might have been due to either a change in stimulation or a change in participants' conscious awareness. In the present study, however, we increased participants' awareness of the primes from subliminal to supraliminal perception *without* altering the physical properties of primes or masks. Thus if prime awareness and direction of priming effects are causally related, then this should result in a closely corresponding change of priming effects from NCEs to PCEs. In contrast, if the direction of priming effects depends only on the physical characteristics of primes and masks, then NCEs should be unaffected by the change in prime awareness.

To alter stimulus visibility without altering the physical characteristics of the stimulus, we exploited the phenomenon of perceptual learning—the “increase in the ability to extract information from the environment as a result of practice and experience with stimulation coming from it” (Gibson, 1969, p. 3)—which has been observed in visual discrimination and texture segmentation tasks (e.g., Karni & Sagi, 1991; Shiu & Pashler, 1992). Perceptual learning enables participants eventually to correctly identify and subjectively perceive a masked stimulus, even though at the beginning of the experiment they were unaware of this stimulus and could not respond to it with better than chance accuracy.

This type of learning crucially depends on the masking stimulus remaining constant across trials (Schubö, Schlaghecken, & Meinecke, 2001). This enables participants to gradually learn to ignore the mask—to filter it out as irrelevant noise—and thus to perceive the relevant stimulus. No such learning occurs if the mask changes randomly from trial to trial: Under this condition, masking remains effective (i.e., identification performance remains close to chance level) even after prolonged training (Schubö et al., 2001). Here, we employed this method to dissociate prime visibility and physical attributes of primes and masks. In earlier studies (e.g., Aron et al., 2003; Eimer & Schlaghecken, 2002; Praamstra & Seiss, 2005; Schlaghecken et al., 2006; Schlaghecken & Eimer, 2002, 2006; Seiss & Praamstra, 2004), a new random pattern mask was created on every trial in order to prevent perceptual learning. Here, the random mask was created only once at the beginning of the experiment, individually for each participant, and participants were presented with this ‘personal’ mask throughout the rest of the experiment. There were five 1-h sessions, each comprising a short masked priming task at the beginning and the end, and a longer masked prime identification task as the main part. To test whether prolonged training would alter prime identification performance and/or priming effects even with a variable rather than a fixed mask, a control group was tested under identical conditions but with the usual (i.e., variable) masking procedure. A second experiment was conducted to confirm that no NCEs were obtained when prime identification levels were high because of ineffective masking.

2. Methods

2.1. Participants

Twenty-four volunteers (6 male) participated in Experiment 1 (half assigned to the experimental fixed-mask group, half to the variable-mask control group), and 15 volunteers (5 male) in Experiment 2. Participants were 18–33 years old ($M = 22.3$ years). According to self-report, all but two were right-handed, and all had normal or corrected-to-normal vision.

2.2. Stimuli and apparatus

Stimuli were virtually identical to those used previously (e.g., Schlaghecken & Eimer, 2002, 2004; Schlaghecken & Maylor, 2005): Left- and right-pointing double-arrows served as primes and targets. Masks were constructed from a 9×9 matrix, randomly filled with overlapping lines of different length (0.1° – 0.6°) and orientation. About 80% of the lines were tilted, with angles of approximately 12° , 35° , 145° , and 168° (lines forming prime and target arrows were tilted at angles of approximately 20° and 160°). The remaining lines were horizontal and vertical (exact proportions of diagonal and non-diagonal lines differed from participant to participant in the fixed-mask condition and from trial to trial in the variable-mask condition due to the random generation of masks). In Experiment 1, all matrix cells were filled; in Experiment 2, 18.5% of the cells were filled.

2.3. Procedure

Both experiments consisted of a priming task and a forced choice task, beginning with one practice block each. For the fixed-mask group, a random pattern mask was generated on the first practice priming trial for each participant, which was then used on each subsequent trial this participant encountered (both priming and forced choice trials, practice and experimental, in each session). For the control group of Experiment 1, and for all participants in Experiment 2, a different random pattern mask was generated on each trial. Each session started with 2 priming blocks (80 trials each) followed by 8 forced choice blocks (60 trials each), followed by another 2 priming blocks.

Fig. 1 depicts the trial structure in priming blocks (left) and in forced choice prime identification blocks (right). In priming blocks, primes were presented for 17 ms, immediately followed by a 100-ms mask. Fifty milliseconds after mask offset, the target was presented for 100 ms. Prime and target arrows pointed in the same direction (compatible trials) or in opposite directions (incompatible trials) randomly and with equal probability. Participants responded with a left key-press to targets pointing to the left and with a right key-press to targets pointing to the right. In the forced choice blocks, primes were presented for 17 ms on 50% of all trials, and for 33, 50, or 67 ms on the other 50%, presented randomly within each block. Primes were immediately followed by a mask, which remained on the screen until a response was made (at least 100 ms; see Schubö et al., 2001). Experiment 1 consisted of five sessions, conducted within one week. Experiment 2 consisted of a single session, structurally identical to the first session of Experiment 1.

3. Results and discussion

3.1. Experiment 1

A repeated measures analysis of variance (ANOVA) was conducted on the percentage of correct responses in the forced choice task for the between-subject factor Experimental Group (fixed-mask, control), and the within-subject factors Duration (17, 33, 50, and 67 ms) and Session (1–5). Greenhouse–Geisser adjustments to the degrees of freedom were performed where appropriate and corrected p -values are reported.

As expected, identification performance was better in the fixed-mask group than in the control group, $F(1, 22) = 5.79$, $MSe = 2069.55$, $p = .025$, better for longer primes, $F(3, 66) = 102.19$, $MSe = 164.09$, $p < .001$, and improved with practice, $F(4, 88) = 26.52$, $MSe = 35.25$, $p < .001$ (see Fig. 2). Importantly, these factors showed a highly significant interaction, $F(12, 264) = 3.31$, $MSe = 16.07$, $p = .008$: Practice effects

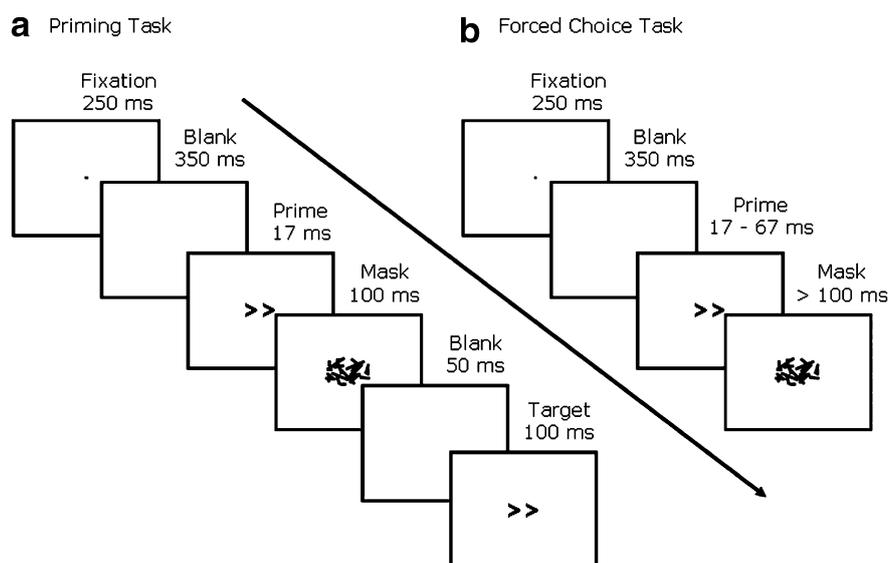


Fig. 1. Trial structure in (a) the priming task and (b) the forced choice task.

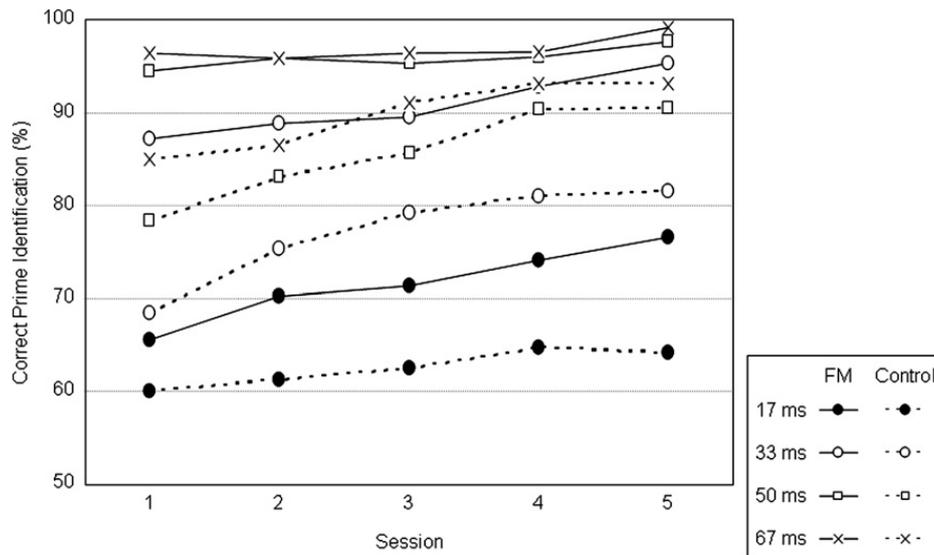


Fig. 2. Prime identification performance for different prime durations (17–67 ms) across sessions, separately for the experimental fixed-mask (FM) group (solid lines) and the control group (dashed lines) of Experiment 1.

mainly occurred with longer-duration primes in the control group, but with shorter-duration primes in the fixed-mask group (where identification of longer-duration primes was nearly perfect almost from the beginning).

The analysis was repeated with the crucial 17-ms prime identification performance values only. Again, performance in the fixed-mask group was better than in the control group, $F(1, 22) = 4.44$, $MSe = 546.00$, $p = .047$, and improved over time, $F(4, 88) = 15.11$, $MSe = 14.28$, $p < .001$. In line with the perceptual learning account, this practice effect was more pronounced in the fixed-mask group than in the control group, $F(4, 88) = 2.59$, $MSe = 14.28$, $p = .042$. The linear regression of 17-ms prime identification performance over sessions was calculated for each participant. The mean slope of these learning curves was significantly steeper in the fixed-mask group (2.59) than in the control group (1.14), $t(22) = 2.31$, $p = .031$.

For the masked prime task, ANOVAs were computed on correct RTs and on error rates for the between-subject factor Experimental Group and the within-subject factors Compatibility (compatible, incompatible), Session, and Part (before forced choice task, after forced choice task). As can be seen from Fig. 3, responses became faster with practice, $F(4, 88) = 4.93$, $MSe = 529.62$, $p = .006$, and were faster on incompatible than on compatible trials, $F(1, 22) = 21.57$, $MSe = 1173.10$, $p < .001$. Within sessions, this NCE was larger before the forced choice task than after, $F(1, 22) = 10.81$, $MSe = 60.67$, $p = .003$, possibly because participants became tired toward the end of the experiment. There was no significant change of NCEs across sessions, $F(4, 88) = 1.97$, $MSe = 63.68$, $p = .14$. Importantly, none of these effects differed between groups (see Fig. 4), all $F_s < 1.4$, all $p_s > .25$. Follow-up analyses confirmed the existence of significant NCEs in each group, $F(1, 11) = 9.78$, $MSe = 1547.28$, $p = .010$, and $F(1, 11) = 13.00$, $MSe = 798.92$, $p = .004$, for the fixed-mask and control groups, respectively, the size of which remained largely unaltered over sessions, both $F_s < 2.3$, both $p_s > .12$.

Priming effects on error rates generally mirrored those on RTs, although only the main effect of Compatibility (error rates on incompatible trials smaller than on compatible trials) was statistically significant, $F(1, 22) = 26.56$, $MSe = 51.30$, $p < .001$. Again, follow-up analyses confirmed significant NCEs in both groups, $F(1, 11) = 10.79$, $MSe = 65.31$, $p = .007$, and $F(1, 11) = 17.65$, $MSe = 37.29$, $p = .001$, for the fixed-mask and control groups, respectively.

Experiment 1 clearly demonstrates that perceptual learning in a masked prime task can lead to substantially improved prime identification performance yet unaltered priming effects (NCEs). The control group, who received a new random mask constructed on each trial, showed little perceptual learning of 17-ms masked primes, with identification performance well within normal limits for this type of prime and mask (60–64% correct from first to last session). The fixed-mask group, in contrast, who received the same mask on every single trial, showed substantial perceptual learning with 17-ms primes (66–77% correct from first to last

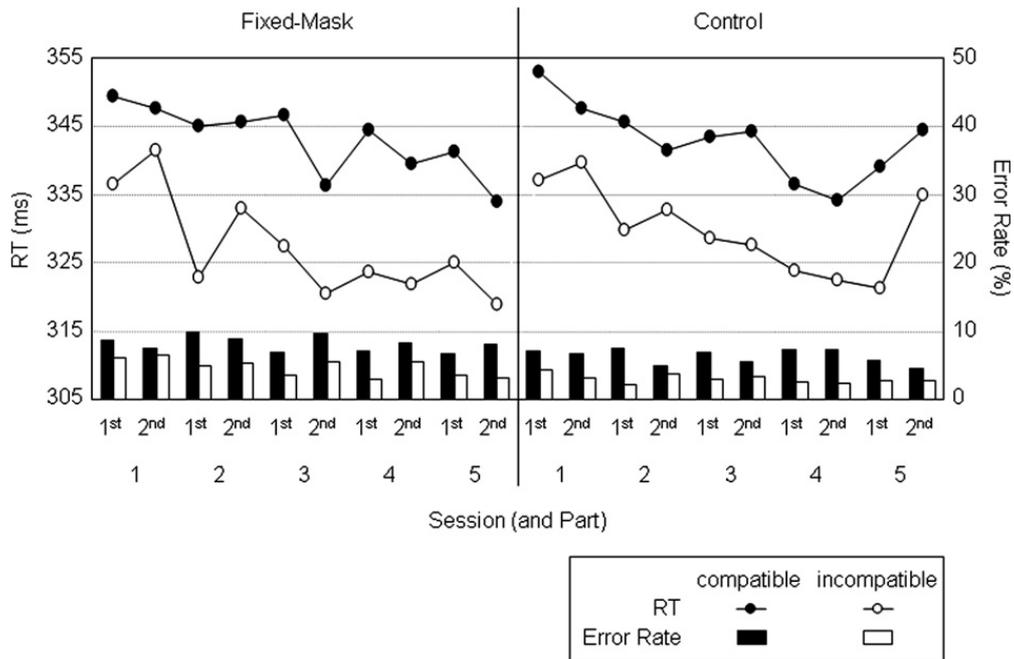


Fig. 3. Reaction times (lines) and error rates (bars) on compatible (black) and incompatible (white) trials for the first and second parts of each of Sessions 1–5, separately for the fixed-mask group (left panel) and the control group (right panel).

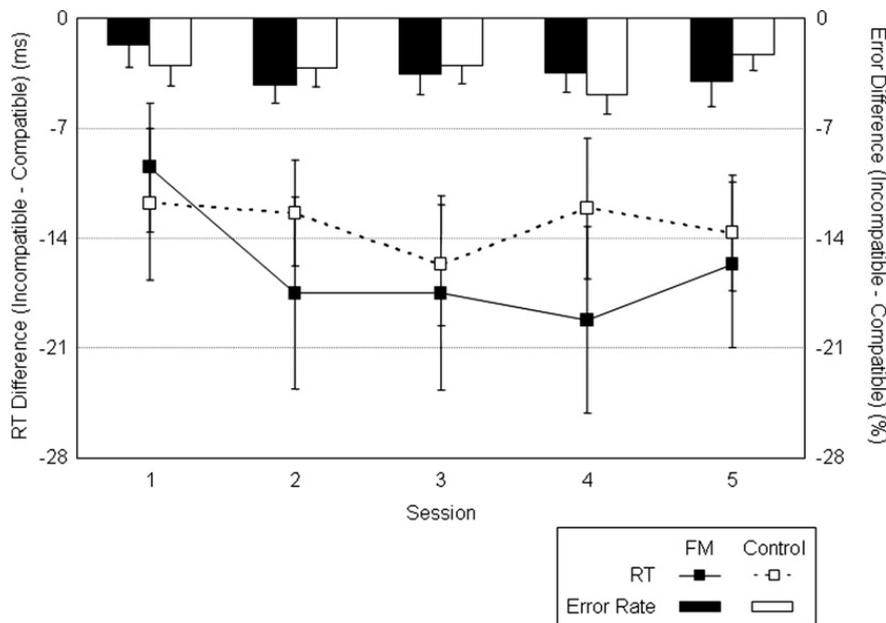


Fig. 4. Masked priming effects (incompatible minus compatible) for reaction times (lines) and error rates (bars) across Sessions 1–5, separately for the fixed-mask (FM) group (black) and the control group (white). Error bars represent 1 SEM.

session). Moreover, several participants in this group—but none in the control group—spontaneously reported in the last session that during the priming task, they had seen the prime arrow, and that this had not been the case in the early sessions. At least in the last session, participants in the fixed-mask group thus were consciously aware of the primes, whereas the same primes were still close to the threshold of conscious awareness for control participants.

Interestingly, there was no corresponding group difference in compatibility effects. In particular, even in the last session, fixed-mask participants produced NCEs that were not smaller than those produced by control participants (numerically, they were even larger, see Fig. 4). It thus has to be concluded that even with non-relevant masks that do not contain features similar to primes or targets, the absence of conscious prime awareness is not a necessary prerequisite for NCEs to occur. Together with the fact that identification performance, but not NCEs, changed across sessions, this result suggests that perceptual awareness of the prime and the direction of compatibility effects are not causally linked.

Conversely, one might argue that the link between prime identification and compatibility effects allows a wider margin of ‘near-threshold’ perception than previously thought. It seems possible, for instance, that identification performance in forced choice tasks—where participants’ attention is focused on the prime, and where no target follows the mask—overestimates the level of prime awareness during the masked prime task (where participants focus on the target that follows the mask). If so, then with an identification performance of 77% in the forced choice task, many primes in the priming task might still have been subliminal. Hence, high forced choice identification performance could still be consistent with the notion that NCEs only occur with subliminal primes. This argument is weakened by the spontaneous complaints by some fixed-mask participants that visible primes interfered with the task. If primes have to be subliminal to enable NCEs, then these participants should have produced PCEs or substantially reduced NCEs—but this was not the case.

Alternatively, it might be that when using 17-ms arrow primes, random-lines masks, and arrow targets, NCEs will be obtained even with ineffectively masked primes, regardless of perceptual learning. However, current evidence does not support this argument: Results from Eimer and Schlaghecken (2002) show that NCEs disappear when primes are so ineffectively masked that identification performance rises above 66%. Experiment 2 aimed to confirm these results by employing masks with a reduced line density of 18.5%. This value was based on Eimer and Schlaghecken (2002), where such a mask had resulted in identification performance levels similar to those achieved by fixed-mask participants in the last session of the present experiment. This allowed us to directly compare priming effects elicited by ineffectively masked, supraliminal primes, and priming effects elicited by initially effectively masked, subliminal primes that had become supraliminal due to perceptual learning.

3.2. Experiment 2

As expected, forced choice correct response rate was high and increased with increasing prime duration, $F(3, 42) = 19.56$, $MSe = 31.65$, $p < .001$. In order to assess the amount of ‘unlearned’ prime identification performance, subsequent analyses were restricted to 17-ms primes from the first block of the forced choice task. There was no discernable difference between this unlearned 17-ms correct response rate ($M = 78\%$, $SD = 16$) and the learned (5th session) 17-ms correct response rate in the fixed-mask group of Experiment 1 ($M = 77\%$, $SD = 15$), $t(25) < 0.5$, confirming that the reduced mask density led to identification levels comparable to those achieved by perceptual learning.

As Fig. 5 shows, there was no significant compatibility effect on either RTs or error rates in either part of Experiment 2, all t s < 1.7 , all p s $> .12$, replicating earlier results (Eimer & Schlaghecken, 2002). The difference between the absence of NCEs in Experiment 2 and their presence in (Session 5 of) the fixed-mask group in Experiment 1 was further confirmed by a significant interaction between compatibility effects and experimental group for RTs, $F(1, 25) = 4.97$, $MSe = 140.76$, $p = .035$.

This finding is in conflict with a ‘mask effectiveness is irrelevant’ interpretation of the above results. In contrast, it is perfectly in line with the assumption that when masks are genuinely ineffective, no self-inhibition will be triggered and therefore no NCE will occur (Eimer & Schlaghecken, 2002; Schlaghecken & Eimer, 2002, 2006). According to this model, primes activate their corresponding motor response, and self-inhibition is triggered whenever the sensory evidence—that is, the supporting bottom-up input from the visual system—for a strongly activated (strongly primed) response is suddenly removed by a subsequent masking stimulus. If this happens on a substantial majority of trials, NCEs will be observed. If it happens only on a minority of trials or not at all, PCEs will be observed. If there are roughly equal proportions of self-inhibition and non-inhibition trials, no overall priming effects will be observed. The present results suggest that this is the case for primes

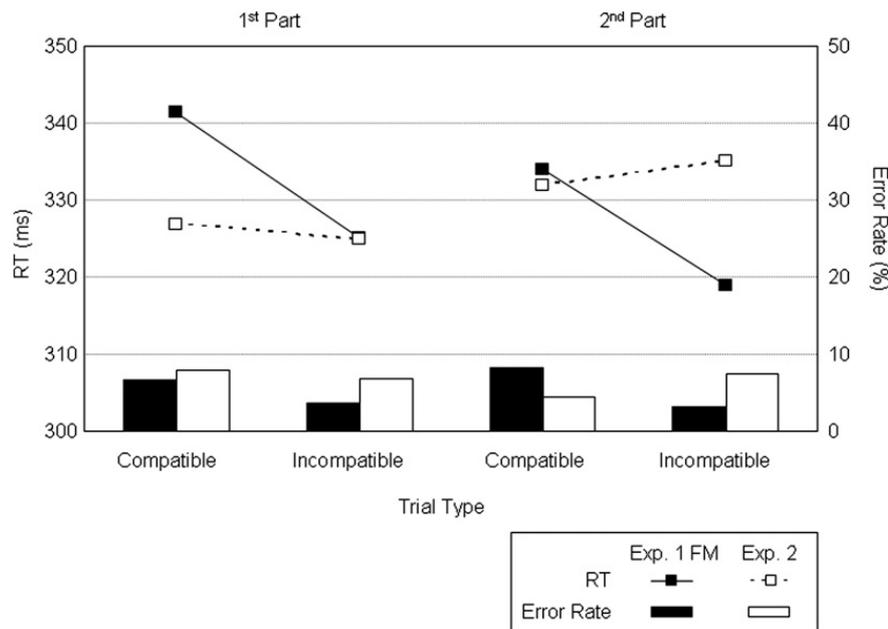


Fig. 5. Reaction times (lines) and error rates (bars) on compatible and incompatible trials for the first and second parts of the last session for the fixed-mask (FM) group of Experiment 1 (black) and for the first and second parts of (the only session of) Experiment 2 (white).

identified with 78% accuracy. This is, of course, hardly surprising: After all, an identification level of approximately 75% in a two-alternative forced choice task suggests that participants consciously ‘saw’ the prime on approximately 50% of the trials—not on approximately 75%.¹

4. General discussion

The present study provides evidence that in the masked prime task, the direction of compatibility effects depends on the physical features of the mask (NCE with densely spaced lines, no NCE with sparsely spaced lines), but not on the subjective visibility of the prime (NCE with subjectively invisible primes in the control group, as well as with subjectively visible primes in the fixed-mask group). These results rule out the assumption that conscious prime awareness and direction of compatibility effects are causally linked. Rather, the results suggest an indirect relationship such that low-level motor control and conscious awareness are both affected in the same way by a third factor, namely, changes in the physical stimulus characteristics.

Perceptual learning has often been equated with structural changes to the visual system at levels as early as the primary visual cortex (e.g., Sagi & Tanne, 1994): Practicing a perceptual task ‘fine-tunes’ neural responses in early visual areas, which results in improved perceptual representations throughout the visual processing pathways. It seems doubtful, however, that this kind of learning occurred in the present study. Fine-tuning of neural responses is usually observed in studies employing ‘difficult’ stimuli (e.g., very small spatial orientation differences) under normal viewing conditions, rather than ‘normal’ stimuli under difficult viewing conditions (e.g., briefly-presented backward-masked arrows). There is reason to believe that improved discrimination of difficult stimuli, and improved identification of simple, but backward pattern-masked stimuli, might involve two different mechanisms: Neural fine-tuning in the former case, and filtering out the ‘perceptual noise’ of the mask at subsequent, decision-related processing stages in the latter (Doshier & Lu, 1999; Maehara & Goryo, 2003; Schubö et al., 2001). Given that the present study employed visual backward pattern

¹ An identification performance of 100% would indicate that participants were consciously aware of the primes on all trials, while an identification performance of 50% would indicate that they never consciously saw the prime and were guessing on each trial. Assuming a roughly linear relationship between identification performance and percentage of ‘seen’ primes, an identification performance of approximately 75% suggests conscious prime awareness on approximately 50% of the trials.

masks, it seems likely that the fixed-mask group's improved prime identification performance resulted from this type of late-stage learning, rather than from early learning at the level of the primary visual cortex.

This interpretation also fits with earlier results of a roughly U-shaped distribution of compatibility effects in masked priming. Perceptually very weak (e.g., low-contrast) primes generally elicit small PCEs, stronger (but still effectively masked) primes elicit NCEs, and very strong (e.g., unmasked) primes elicit large PCEs. This pattern has been attributed to an inhibition threshold in low-level motor control (Schlaghecken & Eimer, 2000, 2002): Perceptually weak primes trigger correspondingly weak motor activations, which fail to self-inhibit when they are no longer supported by sensory evidence because activation did not cross the inhibition threshold. Stronger primes trigger stronger motor activations, which need to self-inhibit when the supporting sensory evidence is suddenly removed (i.e., when primes are successfully backward masked), causing NCEs. Finally, with unmasked or ineffectively masked primes, strong motor activations again fail to self-inhibit, this time because the supporting sensory evidence is not (or not sufficiently) removed.

Within this framework, one would have expected that NCEs in the fixed-mask group would have turned into PCEs if perceptual learning had resulted in stronger perceptual representations of the primes due to neural fine-tuning. Obviously, this was not the case, supporting the notion that perceptual learning in this group affected post-perceptual processing stages. Interestingly, a recent study has found corresponding results with respect to attentional modulations (Sumner, Tsai, Yu, & Nachev, 2006). Drawing participant's attention to the location of a masked prime led to improved prime detection performance at that location. Crucially, however, this did not result in a corresponding shift from NCEs to PCEs: Rather, NCEs at the attended location were enhanced, suggesting that attention directly modulated perceptuo-motor processes outside and independent of conscious awareness.

Taken together, these results suggest that perceptual awareness (as measured in prime identification and detection tasks) and direct perceptuo-motor control processes (as measured in priming tasks) are independent of one another. This interpretation fits with the notion that beyond V1, visual processing occurs within two specialized visual streams—a dorsal stream linking the visual cortex to parietal cortical areas for the extraction of action parameters, and a ventral stream linking it to temporal cortical areas involved in conscious perception and object identification (Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). Masked priming effects might reflect dorsal-stream processing, whereas prime identification performance might reflect ventral-stream processing.

Neuropsychological evidence, however, suggests that dorsal and ventral pathways are functionally interconnected, such that information processing in one will be influenced by ongoing processes in the other (Himmelbach & Karnath, 2005). Furthermore, compatibility effects from successfully masked primes have been observed even when stimuli were mapped onto verbal responses, which are assumed to be mediated by ventral rather than dorsal cortical areas (Eimer & Schlaghecken, 2001), suggesting that the ventral–dorsal distinction might not be sufficient to account for the present findings.

An alternative interpretation is that conscious perception requires top-down recurrent processing, whereas perceptuo-motor behavior can already be triggered by the initial feedforward sweep of neural activation (e.g., Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2003). This initial sweep is likely to be affected by physical stimulus strength, but—by definition—has not yet been affected by higher-level processes (e.g., late-stage perceptual learning). Consequently, perceptuo-motor priming effects triggered by this sweep should not be altered by changes that affect subsequent recurrent processing and, hence, conscious awareness. They would be affected, however, by (top-down induced) changes to the structure or sensitivity of the perceptuo-motor system itself, in line with findings showing that masked priming effects are modulated by attention (Sumner et al., 2006) and task instructions (Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004).

To summarize, the present results demonstrate that conscious awareness of a masked stimulus and the impact this stimulus has on the motor system can be dissociated and thus are not causally related to each other. This finding is interesting for two reasons. First, it suggests that top-down influences may play a role in establishing the current configuration of the perceptuo-motor system, but that processing within this system occurs without high-level 'supervision.' Second, it casts some doubt on the notion that 'subliminal' and 'supraliminal' processes are fundamentally different from each other: To say that perceptuo-motor processing is independent of conscious control is to say that it can be the same under subliminal and supraliminal conditions. Consequently, one might speculate that in those cases where qualitatively different results have been

obtained under subliminal and supraliminal stimulation conditions, these differences did not reflect the role of consciousness in information processing, but rather reflected differences in physical stimulus attributes.

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