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How Much Like a Target Can a Mask Be? Geometric, Spatial, and Temporal Similarity in Priming: A Reply to Schlaghecken and Eimer (2006)

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The authors make 3 points in response to F. Schlaghecken and M. Eimer's (2006) proposal of self-inhibition as an explanatory factor in the negative compatibility effect: (a) The self-inhibition hypothesis lacks empirical support for its main tenets; (b) considering the roles of geometric, spatial, and temporal similarity of primes and masks makes self-inhibition unnecessary; and (c) the negative compatibility effect occurs even when the main tenets of self-inhibition are violated. The authors propose that understanding what is "relevant" in a masked-priming task applies not only to geometric features that are shared with the target but to spatial and temporal ones as well. Briefly, target–mask similarity determines how motor preparation is accumulated during the prime–mask sequence.

Keywords: priming, similarity, suppression, masking, object updating

Schlaghecken and Eimer (2002, 2006) have proposed that the *negative compatibility effect* (NCE) reflects a natural tendency for motor activation to self-inhibit. Specifically, (a) prime objects that resemble target objects activate corresponding motor responses, (b) this activation automatically self-inhibits whenever perceptual evidence for the prime is removed, and (c) self-inhibition occurs only when the prime's strength is sufficiently large to trigger this inhibitory mechanism. When these preconditions are not met, a *positive compatibility effect* (PCE) is predicted.

There is a broad agreement in the literature regarding the first point above, that priming facilitates responses to subsequent similar target objects. Here we question whether the second and third points are needed to explain the NCE. We begin by considering the second point, that self-inhibition automatically follows the activation of a response when sensory evidence regarding the prime is removed from the system. This predicts that an NCE ought to occur whenever primes are effectively masked and a PCE ought to occur for the same primes when they are more visible. We address this point with Figure 1,[1] which summarizes data showing that positive priming is obtained under a wide range of prime visibility, as indexed by accuracy in a forced-choice discrimination task (see Lleras & Enns, 2004, and Schlaghecken & Eimer, 2006). We restrict our comparison to only those conditions in which the mask contains features irrelevant to the target identification task, so that we do not confound predictions based on the self-inhibition hypothesis with those derived from object updating effects (Lleras & Enns, 2004) or other prime–mask interactions (Verleger, Jaśkowski, Aydemir, van der Lubbe, & Groen, 2004).

Note especially the data for the first two experiments on the left side of Figure 1. Both involve very low prime visibility (49.6% and 59.2%), and yet reliable positive priming effects were obtained. This is strong evidence that prime visibility is not a unique predictor of the direction of priming. But perhaps we are not taking proper account of the third point above, that prime strength must be strong enough to cross a threshold controlling the self-inhibitory processes (Schlaghecken & Eimer, 2002). The problem we encounter in trying to implement this prediction is that it is not clear how to measure prime strength. The lack of any relationship between priming magnitude and prime visibility in Figure 1 implies that prime strength is not itself indexed by prime visibility. Without an independent measure of this construct, it is possible to attribute any positive priming effect to weak prime strength, as Schlaghecken and Eimer (2006) did in interpreting the positive priming shown in the first bar of Figure 1. On the other hand, when an NCE was observed with equally effective masking, Schlaghecken and Eimer argued the prime's strength was sufficiently strong to trigger self-inhibitory processes. There seems to be no way to falsify this logic.

How then should the NCE be explained? We are in agreement with Schlaghecken and Eimer (2006) that aside from the question of self-inhibition, several other factors are at play. We acknowledge the role of perceptual interactions between the features of the prime, mask, and target in determining the direction of masking. In Lleras and Enns (2004), we proposed the object updating theory,

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[1] This figure was drawn to illustrate that significant positive priming effects have been found over the entire range of prime visibility levels and under very comparable experimental conditions. It is not meant as an exhaustive compilation of all experiments studying NCE or PCEs.

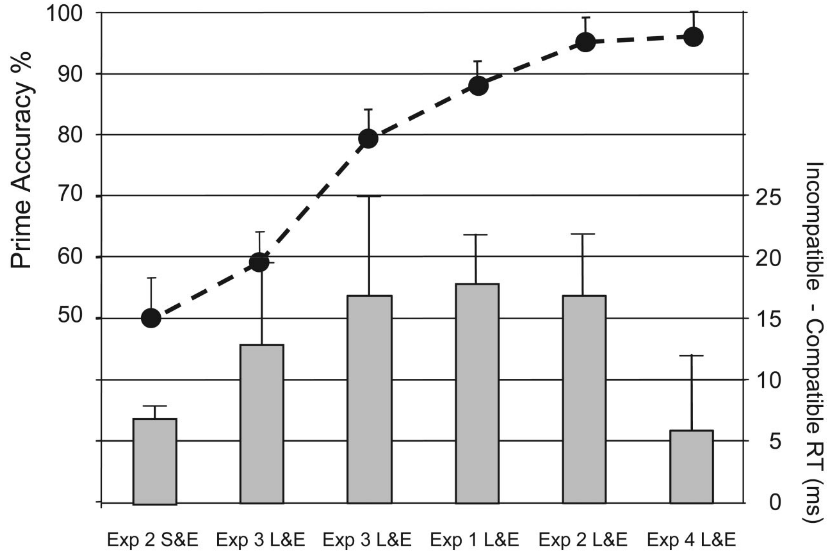

Figure 1. Positive compatibility priming effects obtained under a range of prime visibility conditions in two recent studies (L&E = Lleras & Enns, 2004; S&E = Schlaghecken & Eimer, 2006). Prime visibility is indexed by the accuracy of prime discrimination (left-hand vertical axis) and is plotted with the black dots and the dashed line. The magnitude of positive priming is indexed by the difference between incompatible response time (RT) and compatible RT (right-hand vertical axis) and is indicated by the gray bars. Error bars represent one standard error of the mean for each measure.

which says that the visual system is interpreting the distinct physical events of prime and mask as an instantiation of a single object evolving over time. The critical factor for predicting positive or negative priming is therefore the relation between the features in the mask and the target. A pattern mask containing features relevant to the target task (i.e., evidence for a right or left arrow) should lead to strong updating of the prime representation with the new features. The NCE occurs in this view not because of inhibition induced by the prime but rather because of more recent activation from the updated mask features. On the other hand, when masks do not contain features relevant to the task at hand (our so-called irrelevant masks), they should lead to less updating (because of greater prime–mask dissimilarity; see Moore & Lleras, 2005), and more important, they should not alter the direction of priming, because in such cases the content of the updating is unrelated to all possible motor responses in the task.

Because object updating theory has no place for self-inhibition, it is important for us to examine Schlaghecken and Eimer's (2006) empirical support for the construct. To our best understanding, the claim derives from an earlier study (Eimer & Schlaghecken, 2002) in which the authors reported a correlation between the number of lines in a mask that yielded a 66% prime visibility level and the number of lines in a mask that caused the priming effect to turn from being positive to negative. They interpreted the positive correlation they observed as indicating that negative priming required a threshold level of prime strength (as the presence of more lines in the mask was taken as an indication of more effective masking). However, as we noted in Lleras and Enns (2005), their masks consisted of randomly oriented line masks, and therefore inhibition could not be readily separated from object updating in our interpretation. In fact, the observed correlation is consistent with our theory: As the number of lines increases in the mask, so does the likelihood that these lines will intersect in arrowlike patterns and therefore be seen as carrying relevant information. Furthermore, the data also showed that beyond a minimum number of lines, negative priming was constant across different levels of mask density; it did not continue to increase as predicted by the idea that reduced visibility should further strengthen the inhibitory effects.

We also note that other data from these authors speak against a direct link between prime visibility and the NCE. In studies using the same randomly oriented line masks, Schlaghecken and Eimer (2002) consistently found negative priming effects when prime identification was well above the 66% threshold (Experiments 1 and 2), and in fact, priming magnitude increased as prime visibility increased. The same positive correlation between visibility and priming magnitude occurred when the primes were below the 66% visibility threshold (Experiments 3 and 4). Thus, when considered in detail, the data cited in support for the threshold mechanism of inhibition in Schlaghecken and Eimer's account can also be accounted for in terms of object updating.

Object updating theory has had two other notable successes and one important failure in predicting the results of subsequent experiments since its publication. One success is that it correctly predicted that masks with relevant features usually result in negative priming and irrelevant masks usually lead to positive priming (Klapp, 2005; Lleras & Enns, 2004, 2005; Verleger et al., 2004). A second success is that the theory does not rely on prime visibility as an explanatory factor. Its predictions are made independently of whether the prime reaches the conscious awareness of the participant. There is now ample evidence that both positive and negative priming can be observed over the entire range of prime visibility, from near threshold to near ceiling prime identification accuracy (Lleras & Enns, 2004, 2005). In fact, a reexamination of Lleras and

Enns's (2004) data sheds significant light on these two points. We note that the experimental conditions in Experiments 1–4 of Lleras and Enns (2004) were very comparable to each other. The only differences involved the number of lines present in the mask and, in one case, the specific prime–mask interval. Because there were independent manipulations of mask type and prime visibility, we used both factors as predictors of priming magnitude in a regression model. When we used prime visibility alone as the predictor (ignoring mask type), the correlation was not significant: $r(N = 16) = .394$, $p = .131$. Yet, one could argue that a positive trend was present. However, the more critical analysis is whether prime visibility predicted priming magnitude over and above mask type. To test that, we ran a stepwise regression in which mask type was first used as the sole predictor. This yielded a significant correlation, $B = -0.894$, $t(15) = -7.450$, $p < .001$ ($R^2 = .80$). When we then entered visibility into the regression we again obtained a significant effect of mask type, $B = -0.861$, $t(15) = -6.635$, $p < .001$, but no effect of prime visibility, $B = 0.096$, $t(15) = 0.738$, $p = .474$. The R^2 for Model 2 with both variables as predictors was .81. We interpret this to mean that prime visibility explained no variance beyond that already accounted for by mask type, which is entirely consistent with the object updating theory and directly at odds with the threshold mechanism for self-inhibition account of Schlaghecken and Eimer (2002, 2006).

The major failure of the object updating theory is that negative priming has now been observed under some conditions even when masks contain only irrelevant features (Klapp, 2005; Lleras & Enns, 2005; Schlaghecken & Eimer, 2006). Specifically, when the prime, mask, and target objects are all presented at fixation, an NCE occurs even when the masks contain no relevant features. We agree that this observation limits the explanatory power of the object updating theory as currently stated. Yet we are not convinced that a self-inhibitory mechanism is the solution. Instead, we have sought to identify other factors that can explain why the NCE can occur with irrelevant features in the mask. These factors are onset-triggered suppression and a repeated location advantage, and we believe they are generalizations of the ideas first articulated in Lleras and Enns (2004).

Onset-triggered suppression refers to the observation that when participants are awaiting a target, other nontarget objects that appear suddenly cause an overall suppression of response preparation (Di Lollo, Enns, Yantis, & Dechief, 2000). One can think of this as an "oh no" response. Jaśkowski and colleagues (Jaśkowski, 2006; Jaśkowski & Przekoracka-Krawczyk, 2005) have proposed a similar idea they call *mask-triggered inhibition*. According to these authors, the sudden appearance of a mask halts the response activation initiated by the prime, with this inhibitory effect being greater for an already-activated response. It is important to note that this inequality of response suppression does not depend on a self-inhibitory mechanism but occurs simply because suppression of one response in a forced-choice situation automatically places the nonsuppressed response at a relative advantage. Mask-triggered inhibition therefore shares with our proposal the idea that self-inhibition is not needed to explain why an alternative response may be more active following the mask. Mutual inhibition of response alternatives is enough. Yet it also differs critically from onset-triggered suppression in that the proposed response inhibition is not distinguished theoretically from the differential object updating effects of masks with task-relevant features. In our view, the response inhibition stemming from the temporal similarity between mask (a nontarget object) and target is theoretically separable from the response activation stemming from the shared geometric and spatial features of masks and targets. Last, it is worth noting that this type of onset-triggered suppression has been proposed before in different settings. Notably, it is analogous to the suppression role of the reset mechanism proposed by Grossberg and colleagues in their adaptive resonance theory (see Carpenter & Grossberg, 1987a, 1987b, 2003) in the context of their neural network models of information processing, in general, and pattern recognition, in particular.

The *repeated location advantage* refers to the well-established observation that priming is most effective when prime and target are presented in the same or nearby locations (Gordon & Irwin, 1996; Moore & Lleras, 2005; Posner, 1980). This is consistent with the principles of object updating theory because features occurring in spatial locations closer to the target will generally be considered more task relevant by the participant. And further, the closer together the physical stimuli are to each other, the more likely it is that the visual system will interpret them as different instances of a single object, changing over time.

Experiment 1: Geometric, Temporal, and Spatial Similarity in Priming

To test these ideas, we compared all three factors: geometric similarity in the features of primes and masks (object updating); similarity in the temporal dynamics of masks and targets (onset-triggered suppression); and similarity in the spatial locations in which the primes, masks, and targets are presented (repeated location advantage). We expected positive priming to be largest when the masks contained task-irrelevant features, when they did not resemble targets in their temporal characteristics, and when they appeared in a different location from the prime and target. At the other extreme, we expected to find the strongest negative priming when masks contained task-relevant features, when they also appeared with an abrupt onset, and when they were presented in the same location as the prime.

Method

Twenty undergraduate students at the University of British Columbia participated for extra credit in psychology courses. Ten were randomly assigned to each of two testing conditions (continuous flankers and flashed flankers). The factors of target location (on fixation and off fixation) and mask type (relevant and irrelevant) were examined as repeated measures factors, with target location varying across two counterbalanced testing sessions and mask type varying randomly within each block of trials. Participants completed 400 trials (eight blocks of 50 trials) in a session lasting about 45 min. All were naive to the purpose and all reported normal or corrected-to-normal vision.

The primary differences between stimulus sequences are illustrated in Figure 2A. In each condition, the participant's task was to discriminate the direction of the arrows in the target display as rapidly as possible. The relevant mask consisted of superimposed double arrows; the irrelevant mask consisted of only vertical and horizontal lines (identical to Lleras & Enns, 2005). For on fixation, prime and target arrows both appeared in the same location (at fixation), whereas the mask stimuli were presented as flanking stimuli centered 1° to either side of fixation (a small gap of 0.10° separated the central and flanking stimuli). For off fixation, the prime and

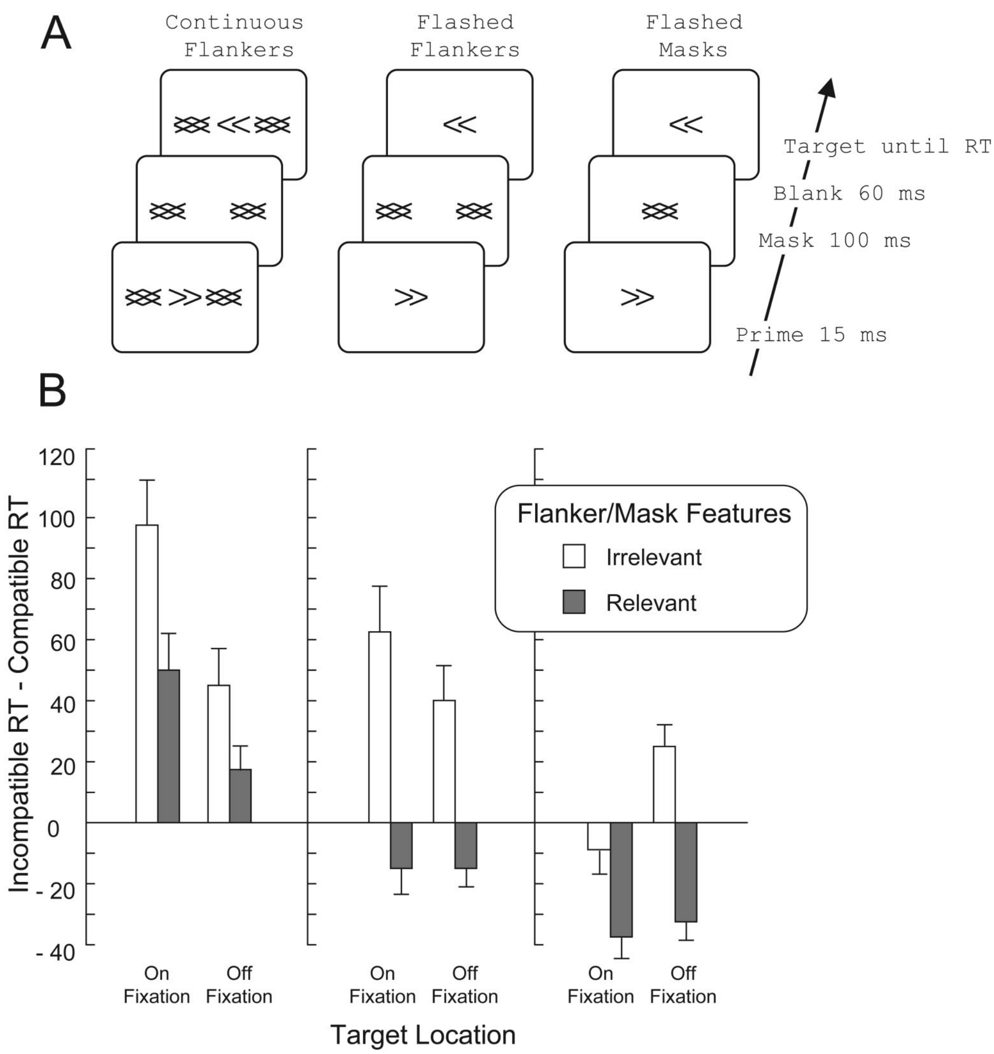

Figure 2. A: An illustration of the differences in spatial layout for the three priming conditions compared in Experiment 1. In addition to the factors illustrated here, the final position of the target was either at fixation (as shown) or off fixation (1.5° above or below fixation, not shown), and the features of the flankers and masks were either task relevant (as shown) or irrelevant (only vertical and horizontal lines, not shown). B: Mean priming (incompatible response time [RT] − compatible RT) as a function of condition (continuous flankers, flashed flankers, and flashed masks), target location (on fixation and off fixation), and flanker/mask features (relevant and irrelevant). Error bars represent one standard error of the mean.

masks appeared at fixation, but the target was presented randomly 1.5° above or below the fixation point.

The between-groups factor of continuous versus flashed flankers differed only in the temporal course and duration of the flanking masks. For continuous flankers, the flanking masks came on simultaneously with the prime and then remained on the screen until the participant responded to the target. For flashed flankers, the timing was identical to the 60-ms blank interval condition in Lleras and Enns (2005): One of two primes was presented at fixation for 15 ms, followed by one of the two types of masks for 100 ms, and then a blank interval 60 ms before one of two targets was presented for 100 ms. We compared both of these conditions with flashed masks, the standard masking conditions reported in Lleras and Enns (2005). Participants were not tested formally for the visibility of the prime in the flanker conditions, because pilot testing indicated that accuracy for prime identification was near 100% in all conditions.

Results

Participants were very accurate ($M > 95\%$) and mean priming effects (incompatible response time [RT] − compatible RT) are shown in Figure 2B. The effects of the various factors can be seen most easily if we begin with the continuous flanker condition (left side of Figure 2B). There was strong positive priming overall, but a target that appeared in a new location (off fixation) was primed only half as strongly as one that appeared in the same location (on fixation). Visible features in the flankers related to the targets (relevant) reduced the positive priming by half again when compared with features that were unrelated (irrelevant). Thus, these data suggest that object updating cannot be entirely prevented, even when primes and masks do not appear in the same location as the target. These observations were supported by analysis of variance (ANOVA): Priming was significantly reduced in the off fixation condition, $F(1, 18) = 6.23$, $p < .03$, Cohen's $d = 0.81$, and was also reduced for relevant flankers, $F(1, 18) = 34.49$, $p < .01$, Cohen's $d = 1.91$. The interaction was not significant, $F(1, 18) = 1.56$, Cohen's $d = 0.59$.

For the flashed flanker condition (middle panel of Figure 2B), it is clear that positive priming was reduced even further when the flankers flashed briefly instead of staying in view. When they contained no relevant features (irrelevant), priming was entirely positive, but at half the magnitude of the previous condition, consistent with onset-triggered suppression. With task-relevant features, these priming effects became negative for on and off fixation conditions. An ANOVA indicated a significant difference in mask type, $F(1, 18) = 79.58$, $p < .01$, Cohen's $d = 2.84$. The negative priming effects for relevant masks were significantly less than zero, $t(18) = 2.57$, $p < .05$, Cohen's $d = 0.63$. Note that this negative priming was obtained at ceiling levels of prime visibility, providing further evidence against the proposal that the NCE is caused by self-inhibition triggered by removing perceptual evidence for the prime from the sensory system.

Priming in the flashed mask sequence is shown on the right side of Figure 2B (based on data from Lleras & Enns, 2005). Overlaying the mask features directly on the prime location makes the negative priming for relevant features even stronger and the positive priming from irrelevant features even weaker. In the most extreme combination, negative priming is even obtained for an irrelevant mask when both the prime and the target are presented at fixation, that is, when the mask is temporally and spatially most similar to the target. An ANOVA indicated a significant main effect of mask type, $F(1, 28) = 7.83$, $p < .01$, Cohen's $d = 1.68$, and a Mask Type × Target Location interaction, $F(1, 28) = 4.21$, $p < .05$, Cohen's $d = 0.54$. These differences between the patterns of priming in the three conditions were supported by a three-way interaction of Condition × Target Location × Mask Type, $F(2, 64) = 4.49$, $p < .02$, Cohen's $d = 1.00$, and two-way interactions of Target Location × Mask Type, $F(2, 64) = 7.40$, $p < .01$, Cohen's $d = 1.28$, and Condition × Mask Type, $F(2, 64) = 3.00$, $p < .05$, Cohen's $d = 0.82$.

These data show that in addition to the large effect of geometric similarity on priming, there are equally large influences of spatial and temporal similarity. But note that the effects of temporal similarity are reversed: Masks that resemble targets in their temporal features result in a suppression of motor preparation. When this effect is combined with other feature similarities (related spatial and geometric characteristics), it results in even greater suppression. That is, spatial and temporal similarity between mask and target combine with the geometric similarity in their features to result in a net effect of strong negative priming. But critically, no self-inhibition is required in this account. Instead, the system simply works to reduce the likelihood of making false responses to nontarget objects (Di Lollo et al., 2000).

General Discussion

We see no need for the concept of motor self-inhibition to understand the NCE. At the same time, we do not dispute that more than one factor is at play. At this point there is widespread agreement that the geometric similarity of the mask to the target is critical to reducing the positive activation initiated by the prime and especially toward driving the direction of the priming in a negative direction (Lleras & Enns, 2004; Klapp, 2005; Schlaghecken & Eimer, 2006; Verleger et al., 2004). The object updating theory provides a succinct account of this factor.

There is also growing agreement that the abrupt onset of a new object sharply reduces the activation initiated by the prime, even when that object does not reduce prime visibility (e.g., Jaśkowski & Przekoracka-Krawczyk, 2005; the present experiment). This reduced activation may indeed come about because of reciprocal inhibition among several response alternatives, as proposed by Praamstra and Seiss (2005) and Seiss and Praamstra (2004), but self-inhibition of a single response alternative is not required to explain the NCE. In our data, the suppressive effect of a suddenly appearing flanker or mask is roughly additive with the activating effects of geometric and spatial similarity. Each of these factors contributes to the reduction in positive priming that occurs in our data, even to the point of ultimately resulting in negative priming. The NCE seems to come about in some cases because flankers with relevant features appear suddenly (middle panel of Figure 2B) or because masks without any relevant features share the same location as prime and target (right panel of Figure 2B). The important point in our opinion is that zero on this scale holds no special status, just as it doesn't for any other interval scale of behavior.

Our interpretation shouldn't be taken to mean that motoric self-inhibition does not exist; it simply means that it is not required to account for the NCE. Furthermore, we also see no need for a visibility requirement on the NCE, whereby only near-threshold primes produce negative priming effects. In fact, it seems clear that both PCEs and NCEs can be obtained at all levels of prime visibility, given an appropriate combination of geometric, temporal, and spatial similarity factors between prime, mask, and target stimuli. Taken this way, the masked priming paradigm provides us with a unique window into how the visual and motor systems become optimally prepared to respond to information, given a specific perceptual discrimination task. To do this, these systems are constantly performing an assessment of "targetness" (i.e., the similarity of geometric, spatial, and temporal properties to those of the target) to both hasten responses to targets and yet halt responses to nontargets. Thus conceived, a priming effect is an index of the aggregated forces influencing this behavioral trade-off.

Last, we note that our interpretation has no implications for whether priming is based on processes that result in conscious or unconscious visual images. In fact, the short latency with which the prime influences motor processes (i.e., 100–200 ms, Verleger et al., 2004) suggests that these priming effects are all based on consciously inaccessible processes. Whether these processes also eventually result in visible images of the primes is a moot question, in our view, simply because those images would be accessible in consciousness only after any responses had already been made.

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