Research Article

UNCONSCIOUS MASKED PRIMING DEPENDS ON TEMPORAL ATTENTION

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Abstract—*The cognitive processes at work in masked priming experiments are usually considered automatic and independent of attention. We provide evidence against this view. Three behavioral experiments demonstrate that the occurrence of unconscious priming in a number-comparison task is determined by the allocation of temporal attention to the time window during which the prime-target pair is presented. Both response-congruity priming and physical repetition priming vanish when temporal attention is focused away from this time window. These findings are inconsistent with the concept of a purely automatic spreading of activation during masked priming.*

In current theories of human cognition, unconscious processes are considered automatic processes that do not require attention (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). In this article, we question this view within the domain of masked priming. It occurred to us that in most masked priming experiments, subjects make considerable effort to focus their temporal attention on the time window when the target appears. We wondered whether the processing of the masked primes, which are presented temporally close to the targets, benefits from this focused attention. This would imply that, on identical trials, we might either obtain or fail to obtain unconscious priming depending on whether subjects allocated attention to the prime-target pair.

Most masked-priming paradigms use only a few masks and a fixed temporal onset of primes and targets, thus letting subjects focus their temporal attention on a narrow time window. In contrast, we presented subjects with a continuous stream of visual masks, within which the primes and targets suddenly appeared. Thus, subjects could not focus their attention on a specific time window, unless the context provided them with additional temporal cues. Manipulating those cues allowed us to manipulate the allocation of temporal attention. In Experiment 1, we compared the amount of priming on the very same trials, depending on whether the time of target occurrence was fixed or variable. In Experiment 2, we used a temporal cuing procedure to explicitly draw attention to the target onset. Finally, in Experiment 3, we used a verbal cuing procedure to determine if the conscious endogenous allocation of temporal attention suffices to modulate masked priming.

We measured masked-priming effects using a numerical priming paradigm. In previous studies**,** we showed that masked numerical primes can be processed all the way up to quantity-coding (Naccache & Dehaene, 2001a, 2001b) and motor response (Dehaene, Naccache, et al., 1998) stages. When subjects had to compare target numbers against a fixed reference of 5, they were faster when the prime and target numbers fell on the same side of 5, and therefore called for the same motor response, than when they did not (response-congruity effect). They were also faster when the same number was repeated as prime and target (repetition priming effect). In the present experiments, we examined whether these priming effects vanish when temporal attention is focused away from the time of target onset.

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METHOD

Subjects

Thirty-six individuals (12 in each experiment; 20 females, 16 males; mean age = 24 years) participated and gave their written informed consent. All were right-handed, had normal or corrected-to-normal vision, and were naive to the purpose of the experiments.

Stimuli

The prime-target pairs consisted of all 16 combinations of the arabic numbers 1, 4, 6, and 9. Primes were presented for 29 ms, immediately preceded and followed by geometric masks each presented for 71 ms. Target duration was 200 ms. All stimuli were presented on a computer screen in EGA mode (70-Hz refresh). The experiments were controlled by the Expe6 software package (Pallier, Dupoux, & Jeannin, 1997). Primes and targets were centrally presented in a Borland Pascal Litt font, 10 mm high. Subjects were located 50 cm from the screen in a dimly lit room.

Procedure

In all the experiments reported here, subjects were engaged in a number-comparison task. They were told that they would see a target number between 1 and 9, excluding 5, and that they would have to compare it with a fixed standard of 5, pressing the right button for targets larger than 5 and the left button for targets smaller than 5. Unbeknownst to them, another number, surrounded by geometric masks that made it invisible, was presented for 29 ms immediately before the target.

Response Time Analysis

Analyses of variance (ANOVAs) were performed on median correct response times (RTs) between 250 and 1,000 ms. We derived standard errors of the mean from the error terms of the interactions in the ANOVAs (Loftus & Masson, 1995).

EXPERIMENT 1: DEPENDENCE OF UNCONSCIOUS SEMANTIC PRIMING ON TEMPORAL PREDICTABILITY

In Experiment 1, temporal attention was manipulated implicitly by varying the temporal predictability of the target stimuli. In the fixed-

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prime, fixed-target condition, the timing of events was the same on every trial: The prime and the target always appeared, respectively, 710 and 810 ms after trial onset, yielding a prime-target stimulus onset asynchrony (SOA) of 100 ms (see Fig. 1). In this condition, subjects could allocate temporal attention to the target because it appeared systematically at the same time on each trial. In the fixed-prime, variable-target condition, the same trials were mixed with two other types of distractor trials in which prime onset was kept fixed at 710 ms after trial onset, while the target appeared at 1,094 or 1,449 ms after trial onset, yielding prime-target SOAs of 384 ms and 739 ms. In this condition, subjects were not able to predict target onset. Finally, in the variable-prime, fixed-target condition, the same trials again were mixed with other distractor trials in which the prime onset varied (71 or 426 ms) while the target onset was fixed at 810 ms after trial onset. In this control condition, the prime-target SOA was as variable as in the variable-target condition, but target onset was fixed and subjects could still allocate temporal attention to targets, as in the fixed-prime, fixed-target condition. The three conditions were presented in separate sessions, and the order of the three sessions was balanced across subjects using a Latin square.

We analyzed RTs from the subset of trials that had exactly the same SOA and prime and target onsets in the three conditions. Subjects responded faster on predictable-target trials than on unpredictable-target trials, $F(2, 22) = 8.70$, $p = .002$. This effect probably reflects the allocation of temporal attention to predictable targets (Miniussi, Wilding, Coull, & Nobre, 1999). There was no significant difference between the two conditions with predictable targets ($F < 1$), thus confirming that subjects could not make use of the predictability of the unconscious prime.

We also observed faster RTs on congruent trials than on incongruent trials, $F(1, 11) = 7.88$, $p = .02$. Crucially, this congruity effect interacted strongly with target predictability, $F(2, 22) = 6.56$, $p = .005$ (see Fig. 2). No semantic priming was observed on unpredictable-target trials ($F < 1$). Semantic priming was present only on predictable-target trials, $F(1, 24) = 7.24$, $p = .01$ (effect size = 19 ms). Again, this effect did not differ between the fixed-prime, fixed-target and variable-prime, fixed-target trials ($F < 1$, effect size = 3.5 ms). Finally, it is noteworthy that in the variable-prime, fixed-target condition, no priming was found (both Fs < 1) on trials with prime onset earlier than 710 ms (with prime onset of 71 ms, mean RT = 406 ms; with prime

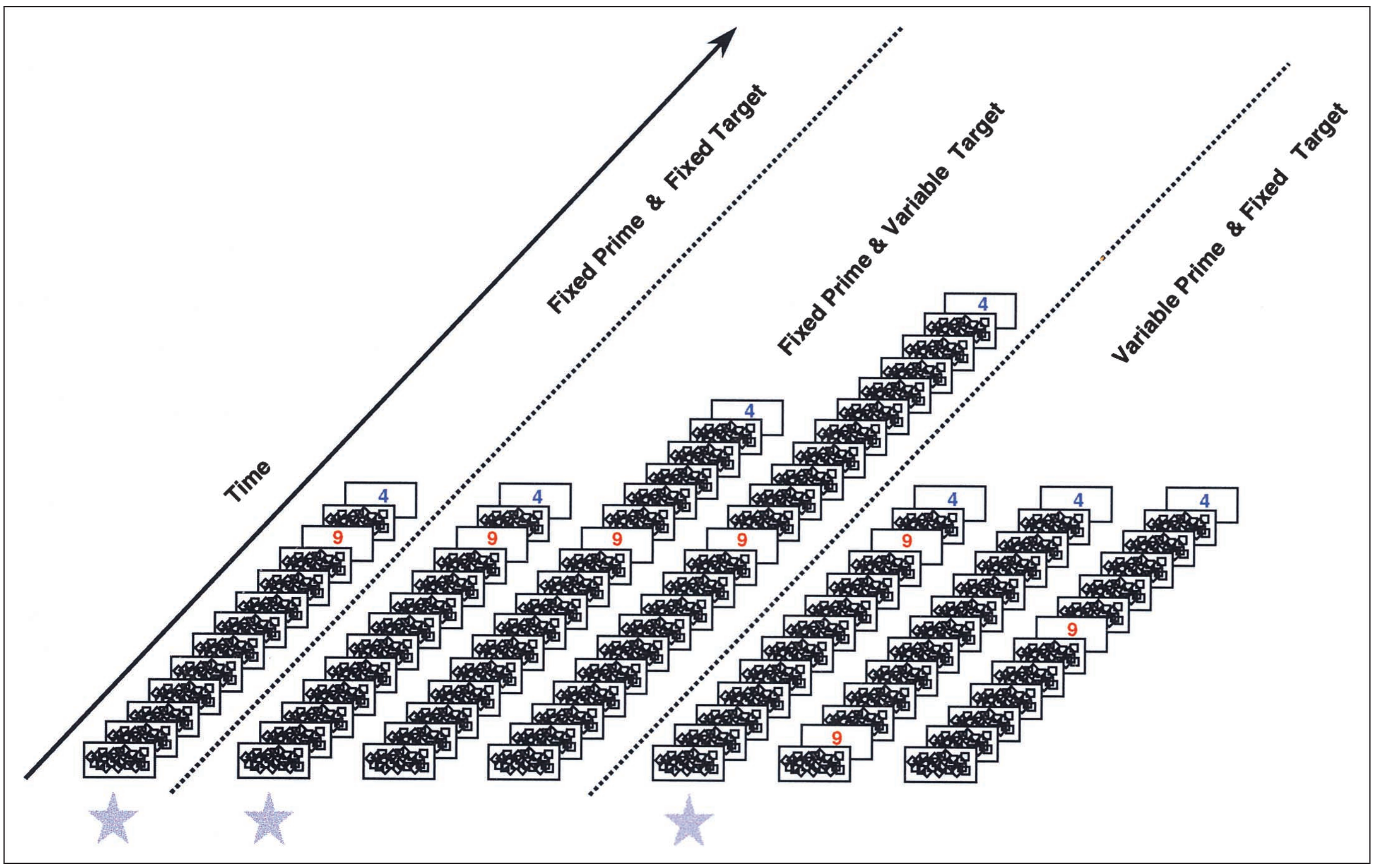

Fig. 1. Schematic depiction of the temporal structure of the three experimental conditions in Experiment 1. Black geometric figures represent masks presented for 71 ms. Red arabic numbers represent the primes and were presented for 29 ms. Blue numbers represent the targets and were presented for 200 ms. Statistical analyses were performed on exactly the same trials, across the three conditions (violet stars). In each condition, the 80 critical trials—corresponding to five presentations of each set of prime-target pairs—were presented either alone (fixed prime, fixed target) or randomly intermixed with two other sets of 80 trials that had different stimulus onset asynchronies. The actual stimuli were white on a black background.

onset of 426 ms, mean RT = 407 ms). These results can be interpreted as reflecting a quick vanishing of the prime-related activation (Greenwald, 1996), but are also compatible with our hypothesis that unconscious processing of the primes depends on subjects' ability to focus their temporal attention on the time window when the target appears.

EXPERIMENT 2: DEPENDENCE OF UNCONSCIOUS SEMANTIC PRIMING ON TEMPORAL CUING

Whereas Experiment 1 relied on subjects' recognition that the targets appeared at a fixed point in time, Experiment 2 explicitly manipulated temporal attention by cuing the time of target onset. We embedded the critical trial structure from Experiment 1 (SOA = 100 ms) in a continuous stream comprising a randomized number of visual masks. For the manipulation of attention, one third of the trials were preceded by an alerting green square cue (cue duration = 200 ms, SOA with target = 584 ms), whereas the remaining trials occurred without warning (see Fig. 3). Subjects were trained on 96 trials.

A main effect of cuing was observed, $F(1, 11) = 19.76$, $p = .001$ (effect size = 26 ms), with faster RTs on cued trials than on uncued trials. We also observed a main effect of congruity, with faster RTs on congruent trials than on incongruent trials, $F(1, 11) = 7.32$, $p = .02$. Crucially, we found an interaction of congruity with cuing, $F(1, 11) = 8.69$, $p < .01$ (see Fig. 3). This result reflected the absence of semantic priming on noncued trials ($F < 1$, effect size = 0.7 ms). The congruity effect was present only on predictable-target trials, $F(1, 11) = 11.98$, $p = .005$ (effect size = 13.5 ms).

EXPERIMENT 3: DEPENDENCE OF UNCONSCIOUS SEMANTIC PRIMING ON ENDOGENOUS TEMPORAL ATTENTION

The type of cuing used in Experiment 2 might have implicated both exogenous and endogenous attention orienting. We designed Experiment 3 to isolate the contribution of the top-down endogenous orientation of temporal attention by using a verbal cuing paradigm (see Fig. 4a). All prime-target pairs were preceded by a verbal cue presented for 500 ms, the word “tôt” (“early”) or “tard” (“late”). This word signaled, with 80% validity, how soon after the cue the target was likely to appear, 884 ms afterward (“early”) or 2,020 ms afterward

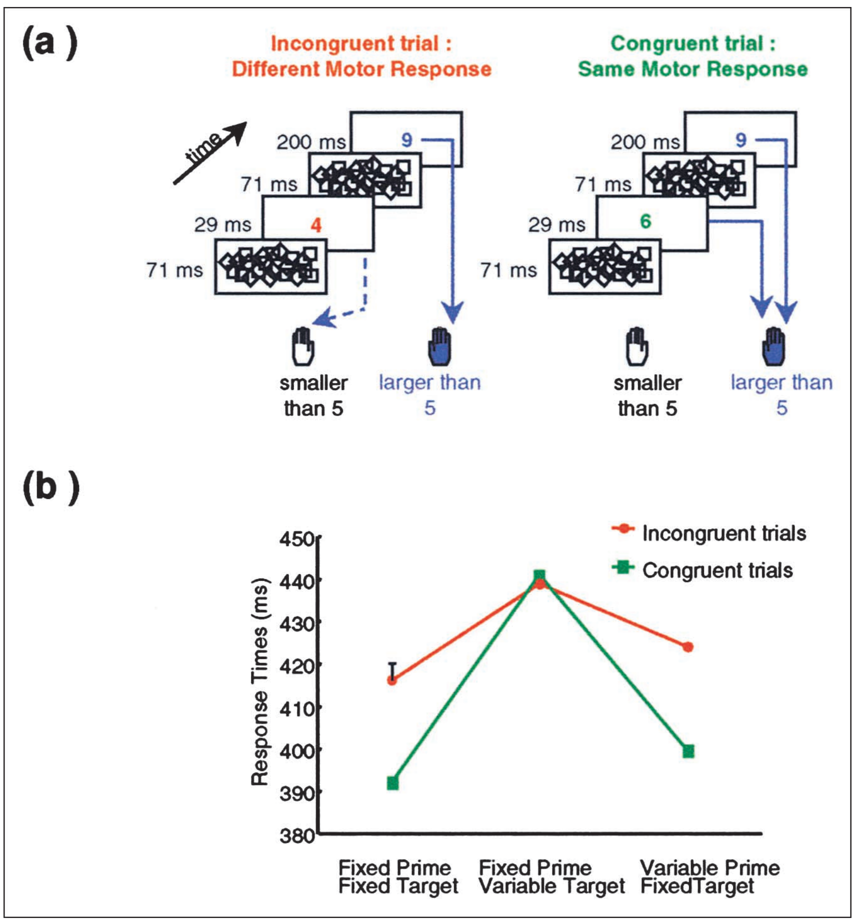

Fig. 2. Schematic depiction of sample congruent and incongruent trials (a) and response times for the three conditions (b) in Experiment 1. The motor response was congruent when the prime and the target numbers were both either greater than 5 or less than 5; if one was greater than 5 and the other was less than 5, they were incongruent. The error bar shows the standard error of the mean.

("late"). For a given subject, the word "early" was always presented either in green or in red, and the word "late" was presented in the alternative color. This word-color association was balanced across subjects. Subjects were first trained with a block of 48 validly cued trials, with the instruction to use the verbal cue to estimate the temporal onset of the target. Before the experimental session, they were instructed that on rare occasions, the cue would be incorrect, but that they should still perform the task as if all trials were correctly cued.

As can be seen in Table 1, we designed the paradigm in order to obtain the same number of trials in the early-target, valid-cue condition and in the early-target, invalid-cue condition. We predicted the verbal cuing would be less effective when the target occurred late because when subjects are incorrectly cued to an early time point, they remain able to refocus their temporal attention to a later time interval (Miniussi et al., 1999). Thus, the main analysis of interest was the interaction between the congruity and cue factors on early-target trials. As in our first two experiments, the interaction between the temporal-attention manipulation and congruity was significant, $F(1, 11) = 9.23$, $p = .01$ (see Fig. 4c). There was a strong priming effect for early targets with valid cues, $F(1, 11) = 10.00$, $p = .009$ (effect size = 14.4 ms), but no priming for early targets with invalid cues ($F < 1$, effect size = 2.5 ms).

The joint analysis of both early- and late-target trials revealed a main effect of cue validity, $F(1, 11) = 73.99$, $p < .0001$ (see Fig. 4b). However, cue validity interacted with the time of target onset, $F(1, 11) = 31.76$, $p = .0002$, revealing a larger effect of cuing on early targets, $F(1, 11) = 131.9$, $p < .0001$, than on late targets, $F(1, 11) = 6.2$, $p = .03$. This interaction was consistent with the predicted temporal asymmetry of cuing (see Fig. 4b), and reproduces earlier findings (Miniussi et al., 1999). Interestingly, within the validly cued trials, RTs were faster for early targets than for late targets, suggesting that it is easier to pay attention to a nearer time point than to a later one. Correspondingly, the priming effect followed the same pattern, with strong priming for early targets with valid cues, $F(1, 11) = 9.23$, $p = .01$, and weaker priming for late targets with valid cues, $F(1, 11) = 3.97$, $p = .035$, one-tailed; the Congruity × Target Onset interaction for validly cued trials was significant, $F(1, 11) = 7.59$, $p = .02$. Finally, masked priming was also observed for late targets with invalid cues, $F(1, 11) = 5.34$, $p = .04$. As noted earlier, however, such trials probably receive attention too, because subjects come to expect a late target once they have noticed that the early cue was invalid.

EXAMINATION OF RT DISTRIBUTIONS

In each of the three experiments reported here, attention was confounded with response latency because RTs were always faster in the attended condition than in the unattended condition. Given that visual masking effects are short-lived (Greenwald, 1996), it could be argued that unconscious processing occurred in all conditions, but had vanished by the time the motor response was being programmed on the slower unattended trials. To assess this hypothesis, we examined across the three experiments the influence of the speed of responding on the amount of priming. For each subject's data set, RTs from each condition (attended, unattended) were classified as faster or slower than the median for that condition. We then entered those RTs in a new ANOVA, including all 36 subjects, with factors of experiment (3), condition (attended vs. unattended), congruity (congruent vs. incongruent), and response speed (faster or slower than the median).

As in the analyses of the three experiments separately, a significant interaction was observed between the congruity and condition factors, $F(1, 33) = 10.8$, $p = .002$, $MSE = 480$, indicating that priming was found only in the attended condition. This interaction did not interact with response speed ($F < 1$; see Fig. 5), indicating that the congruity effect present in the attended condition was observed on both fast and slow RTs. Finally, a restricted analysis contrasting the slow RTs from the attended condition against the fast RTs from the unattended condition

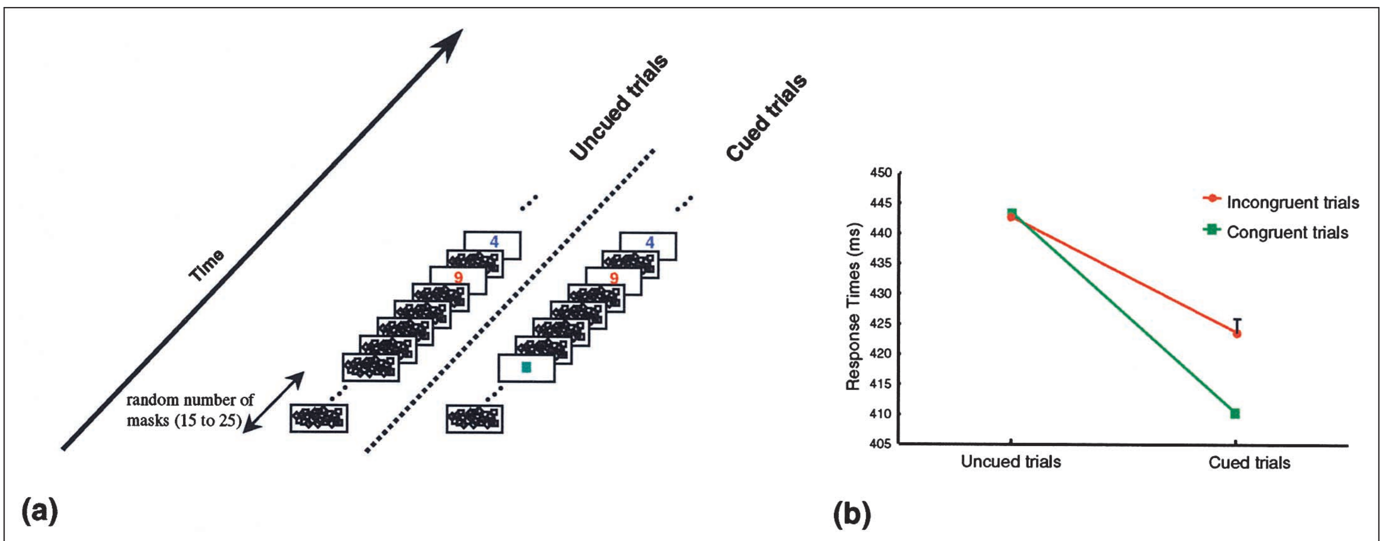

Fig. 3. Design (a) and results (b) of Experiment 2 (temporal cuing). The experimental design included 288 trials (96 cued, 192 uncued), half of which were congruent and half of which were incongruent. A training set of 96 trials was run before the experimental trials. Each trial began with a random number (from 15 to 25) of visual masks (71 ms each), followed by a sequence of either four masks or a green square cue and three masks, and then the mask-prime-mask-target sequence used in Experiment 1. Trials followed one another seamlessly in a continuous stream. The graph shows response times for congruent and incongruent trials that were cued and uncued. The error bar shows the standard error of the mean.

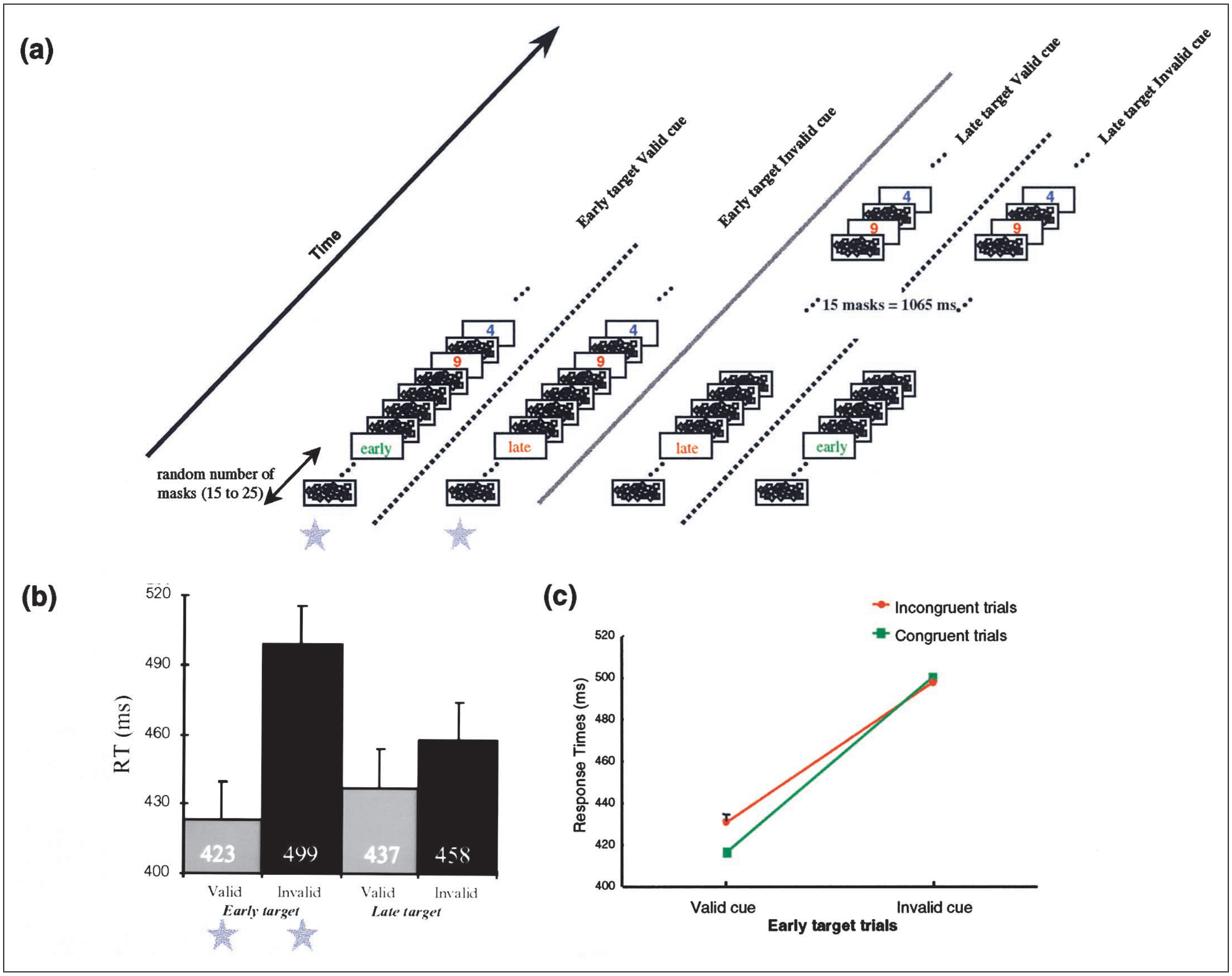

Fig. 4. Design (a) and results (b, c) of Experiment 3 (verbal cuing). Trials of special interest were the early-target trials (violet stars). The same continuous stream as in Experiment 2 was used, but each trial began with a verbal cue ("early" or "late"), followed by either an early target (cue-target stimulus onset asynchrony, SOA = 884 ms) or a late target (cue-target SOA = 2,020 ms). In this 2 × 2 design, 80% of the cues were valid and 20% were invalid (see Table 1 for details). The graphs show the mean response times (RTs) across the four conditions (b) and for congruent versus incongruent trials with early targets (c). The error bars show the standard errors of the means.

demonstrated that although RTs were faster in the unattended condition than in the attended condition, $F(1, 33) = 254.5$, $p < .0001$, $MSE = 585$, the congruity priming effect still interacted with the attentional condition, $F(1, 33) = 9.22$, $p = .005$, $MSE = 155$. Priming was present on attended trials with slow RTs, $F(1, 33) = 22.38$, $p < .0001$ (effect size = 16.4 ms), and absent on unattended trials with fast RTs, $F(1, 33) = 2.0$, $p = .2$ (effect size = 3.8 ms). These analyses clearly eliminate interpretations based on the relative slowness of subjects on unattended trials.

Table 1. *Set of trials in Experiment 3*

	Cue	
Target	"Early"	"Late"
Early	80 trials (80% of "early" cue trials)	80 trials (20% of "late" cue trials)
Late	20 trials (20% of "early" cue trials)	320 trials (80% of "late" cue trials)

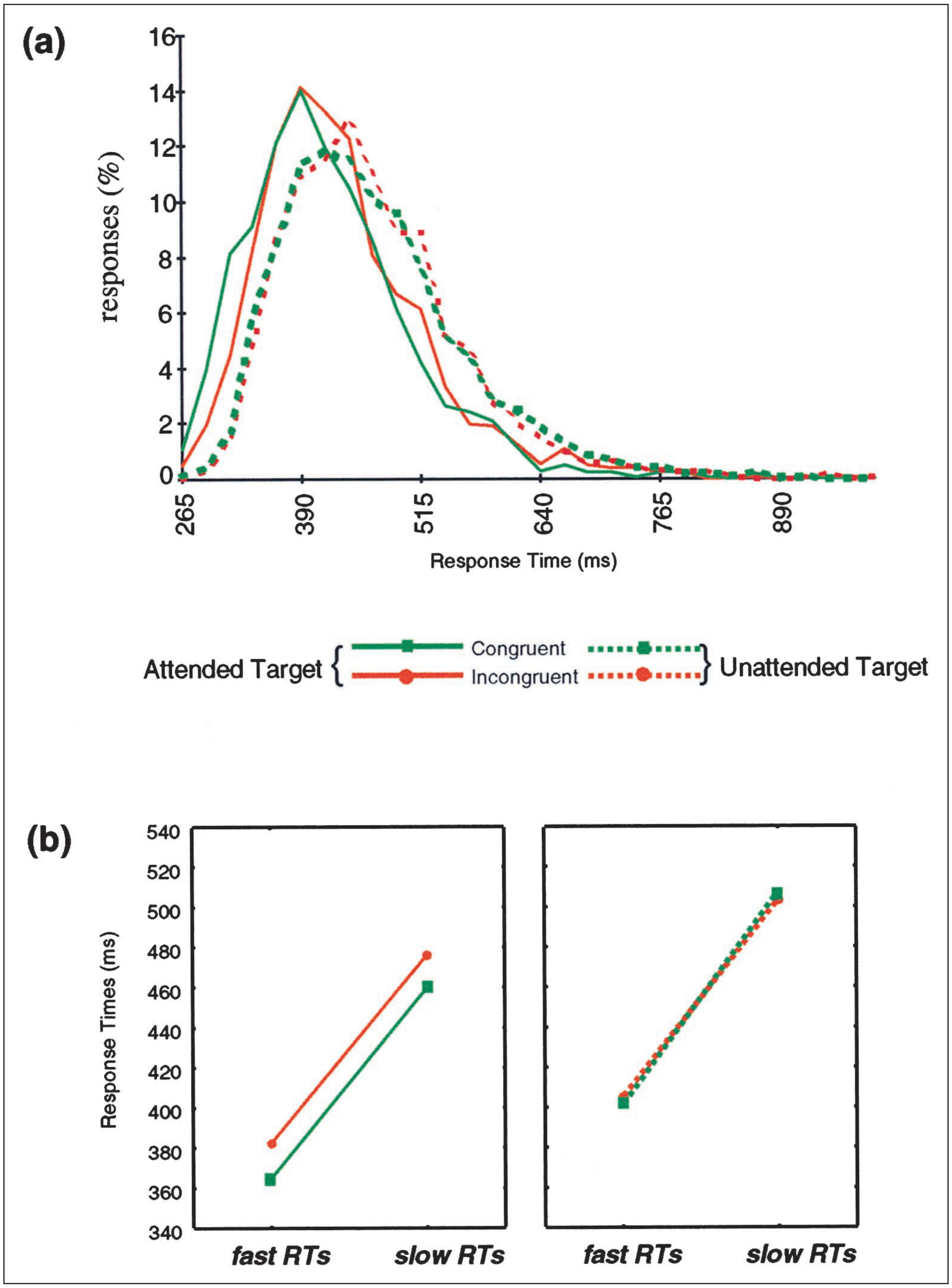

Fig. 5. Response time (RT) distributions (a) and stability of priming effects across slow and fast RTs (b). The graph in (a) shows the percentage of the total number of correct RTs that fell in each 25-ms RT bin, pooled across the three experiments. Results are shown separately for the congruent and incongruent attended and unattended conditions. The graphs in (b) plot the mean of RTs faster and slower than the median, respectively, in each of these four conditions.

TRACKING THE PROCESSING LEVEL AT WHICH ATTENTION OPERATES

Does inattention operate at an early stage, preventing even the perceptual processing of an unconscious prime? Or are unattended primes still processed up to visual or even semantic levels of representation, but without reaching the motor response level? In previous work (Koechlin, Naccache, Block, & Dehaene, 1999; Naccache & Dehaene, 2001a), we reported that the congruity priming effect results from the combination of two priming effects reflecting different levels of processing of the masked primes: (a) a repetition priming effect observed by contrasting RTs from repeated trials (e.g., prime and target are both 1) with those from congruent nonrepeated trials (e.g., prime is 4, target is 1) and (b) a motor priming effect observed by contrasting RTs from congruent nonrepeated trials with those from incongruent trials. To specify the locus of action of the attentional effect, we analyzed these two effects separately (see Fig. 6). Both repetition priming and motor priming were significant in the attended condition, $F(1, 33) = 4.2$, $p = .05$, effect size = 7.6 ms, and $F(1, 33) = 9.4$, $p = .004$, effect size = 11.1 ms, respectively, but vanished in the unattended condition, $F(1, 33) = 2.1$, $p = .15$, and $F < 1$, respectively. This resulted in a significant interaction of both forms of priming with attention, $F(1, 33) = 5.6$, $p = .02$, and $F(1, 33) = 5.5$, $p = .02$, respectively. None of these effects interacted with the type of experiment. Thus, when attention was oriented away from prime onset, even repetition priming vanished. This suggests that attention can modulate unconscious processing at an early processing stage.

ASSESSMENT OF PRIME AWARENESS

In each of the three experiments, prime awareness was evaluated through both subjective and objective measures. Subjectively, none of the 36 subjects reported having seen any of the primes. In order to obtain an objective measure of prime visibility, we then engaged them in a control experiment in which they viewed the very same trials as in the main experiment but had to explicitly compare the primes with 5. In each of the three experiments, the mean success rate was not significantly different from the chance level of 50% (all *p*s > .2). The mean d' values also did not differ from zero (−0.04, −0.07, and +0.09, respectively; all *p*s > .5). This remained true when only the cued trials were analyzed (−0.07, +0.07, and −0.005, respectively; all *p*s > .5).

DISCUSSION

In this work, we examined the influence of temporal attention on unconscious cognitive processing in three experiments in which the very same trials were presented within various temporal contexts. In Experiment 1, the predictability of target occurrence was manipulated. Subjects responded faster to targets occurring at predictable rather than unpredictable moments in time, and reliable priming was found only when target onset was predictable. In Experiment 2, exogenous cues signaled the temporal onset of one third of the targets. Subjects responded faster to cued trials than to uncued trials, and unconscious priming occurred only on cued trials. Finally, in Experiment 3, endogenous verbal cues were used to signal target onset, and cue validity was systematically manipulated. Again, unconscious priming occurred exclusively on validly cued trials. Further analyses demonstrated that this effect could not be imputed solely to the slower RTs on unattended trials, and that inattention even prevented the occurrence of physical repetition priming. Finally, in all the experiments, subjective and objective measures of prime awareness confirmed the absence of conscious perception of the masked primes, even on cued trials.

Response-congruity and repetition priming effects are highly reliable and have been observed with a broad variety of tasks, stimuli, and experimental procedures (Abrams & Greenwald, 2000; Damian, 2001; Klinger, Burton, & Pitts, 2000; Wentura, 2000). Nevertheless, most of those paradigms did not manipulate temporal attention and used regular timing of prime and target presentation, thus allowing subjects to focus their temporal attention. Our study suggests that it would be premature to interpret those effects as indicating an automatic, attention-independent processing of masked primes. Rather, it is possible that those effects were largely dependent on temporal attention and would vanish under conditions of temporal inattention. Note, however, that our results do not specify the level up to which unattended masked primes can be processed. Our behavioral results leave open the possibility that the earliest stages of visual processing proceed independently of attention, a possibility that could be evaluated with brain-imaging methods (Dehaene, Naccache, et al., 1998; Dehaene et al., 2001).

What is the mechanism by which attention modulates priming? We propose that when subjects focus their attention on the predicted time of appearance of the target, they open a temporal window of attention for a few hundreds of milliseconds. This temporal attention then benefits a prime that is presented temporally close to the target. Which of the three attentional systems (Posner & Raichle, 1994) is the source of this effect remains open to future investigation. Nonspecific temporal alerting is probably involved, but it could act in concert with the attention-orienting network, to selectively amplify information coming from the stimulated location at an early stage, and with the executive attention system, which specifies an appropriate series of processing stages.

Our finding that unattended primes fail to elicit priming effects may appear to conflict with other studies that have revealed elaborate processing of stimuli that were not attended. In the *inattentional blindness* paradigm, words projected at unattended locations elicited semantic priming although subjects could not report them (Mack & Rock, 1998). Likewise, patients with unilateral neglect may show evidence for high-level perceptual processes in their neglected visual hemifield (for a review, see McGlinchey-Berroth, 1997), as is also the case in some blindsight patients (Weiskrantz, 1990). Paradigms that manipulate temporal rather than spatial attention may also appear to conflict with our results. Luck, Vogel, and Shapiro (1996) demonstrated that in the attentional blink situation, words presented outside the focus of temporal attention may elicit semantic processing as indexed by the N400 component of event-related potentials. Even in the restricted field of subliminal perception, two studies using a parafoveal masking procedure reported priming effects for spatially unattended words in a lexical decision task (Fuentes, Carmona, & Agis, 1994), and for tem-

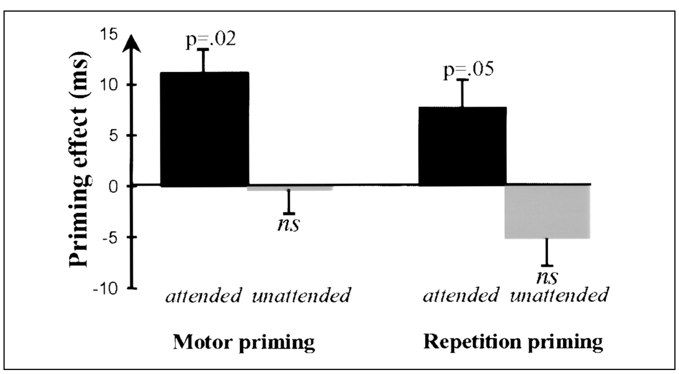

Fig. 6. Repetition priming and motor priming effects. Priming effects are expressed as response time differences in milliseconds for congruent nonrepeated minus repeated trials (repetition priming) and incongruent minus congruent nonrepeated trials (motor priming). The error bars show the standard errors of the means.

porally unpredictable masked words in a social perception task (Bargh & Pietromonaco, 1982). Therefore, the total disappearance of priming effects in our unattended conditions seems specific to our paradigm. It is plausible that stimuli presented under highly degraded conditions, as in our visual masking procedure, require a minimal amplification by attention, without which they are simply not processed at all. Less degraded stimuli, as used in most of the other paradigms just mentioned, may elicit detectable processing even when they fall away from the focus of attention, although we would still expect their modulation by attention.

Our finding that temporal attention can amplify unconscious processes without making them available to conscious report is consistent with two recent studies showing similar effects for spatial attention. Kentridge, Heywood, and Weiskrantz (1999) tested the efficacy of several visual cues on the forced detection of targets in the hemianopic scotoma of blindsight patient G.Y. They found that a central, consciously perceived arrow pointing toward the region of the scotoma where the target would appear could enhance G.Y.'s performance, although this target remained inaccessible to conscious report. Using a visual masking procedure close to ours, Lachter, Forster, and Ruthruff (2000) recently found that in normal subjects, unconscious repetition priming in a lexical decision task occurred only if the masked primes appeared at spatially attended locations.

To our knowledge, only a single study may have demonstrated a similar effect in the temporal domain. Smith, Besner, and Miyoshi (1994) showed that semantic priming with briefly presented prime words in a lexical decision task was observed at a short prime-to-target SOA (498 ms) only if trials were presented in blocks at this fixed SOA. When such trials were mixed with trials at longer prime-to-target SOAs (604 ms with a prime duration of 280 ms), semantic priming for brief-SOA trials disappeared, although repetition priming was observed in both contexts. This finding is close to our results from Experiment 1: In our mixed condition (variable target, fixed prime), because subjects could not easily predict target occurrence, they might have paid less attention to the early primes than in the fixed-target conditions, thus reducing semantic priming at the short SOA. Repetition priming might have been preserved because the primes were consciously perceptible and explicitly attended.

Our results on temporal attention are consistent with many other demonstrations of the sensitivity of priming effects to experimental context. Modifying the instructions, the nature of surrounding trials, or the list of stimuli can cause large changes in priming explainable only in terms of top-down influences (see Stolz & Besner, 1997, for a comprehensive survey, and Neely & Kahan, 2001, for a cautionary analysis of these findings). In most studies demonstrating such effects, the primes were consciously perceptible, and therefore one could not completely rule out the possibility that the effects were due to strategic processing. Recently, however, experimental context was observed to affect the processing of unconscious masked primes. Using an affective decision task, Abrams and Greenwald (2000) demonstrated that unconsciously perceived masked prime words elicited priming only inasmuch as some of their letter fragments matched those of a word from the target list. This result implies that arbitrary stimulus-response chains, once consciously established through instructions and practice, can affect the processing of unconsciously perceived stimuli. Likewise, in a recent study by Bodner and Masson (in press), the size of the masked repetition priming effect varied with the proportion of repeated trials. It should be pointed out, however, that Bodner and Masson used relatively long prime durations (45 or 65 ms), and did not evaluate perception of the primes with objective forced-choice tests. Thus, subjects might have consciously recognized some of the repeated trials and might have developed different strategies as a function of the proportion of such trials.

The fact that response-congruity and repetition priming effects can be influenced by attention, instructions, or task context is inconsistent with automatic spreading activation theory (Neely, 1991), which claims that unconscious access to abstract representational levels of processing is passive and automatic (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). One of the key criteria for automaticity is independence from top-down influences. However, our data suggest that, by this criterion, masked priming effects cannot be considered automatic. We propose that the definition of automaticity may have to be refined in order to separate the source of conscious strategic control from its effects. Processing of masked primes is automatic inasmuch as it cannot serve as a source of information for the subsequent definition of an explicit strategy (see, e.g., Merikle, Joordens, & Stolz, 1995). However, this does not imply that it is impermeable to the effects of top-down strategic control, originating from another source of information such as instructions and task context.

The distinction between sources and effects of conscious control follows from the hypothesis of a global neuronal workspace underlying conscious effort (Dehaene, Kerszberg, & Changeux, 1998; Dehaene & Naccache, 2001). According to this view, at any given time many modular cerebral networks are active in parallel and process information in an unconscious manner. Information becomes conscious, however, if the corresponding neural population is mobilized by top-down attentional amplification into a self-sustained brain-scale state of coherent activity. Applied to visual masking, this mechanism predicts that once a stream of processing is prepared consciously by the instructions and context, an unconscious prime may benefit from this conscious setting, and therefore show attentional amplification. However, an unseen prime cannot itself be used as a source of control to modify the choice of processing steps (Dehaene & Naccache, 2001, Fig. 2).

Finally, the present study also speaks to the debated links between attention and consciousness. Although several paradigms, like inattentional blindness (Mack & Rock, 1998) or the attentional blink (Raymond, Shapiro, & Arnell, 1992), suggest that conscious perception cannot occur without attention (Posner, 1994), our findings indicate that attention also has a determining impact on unconscious processing. Hence, attention cannot be identified with consciousness.

Acknowledgments—We thank Liz Spelke, Gifford Weary, Michele Nathan, and three anonymous reviewers for helpful remarks. Lionel Naccache and Stanislas Dehaene are supported by the Institut National de la Santé et de la Recherche Médicale.

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(RECEIVED 5/23/01; REVISION ACCEPTED 12/18/01)