How the Self Controls Its “Automatic Pilot” when Processing Subliminal Information

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Abstract

Human performance may be primed by information not consciously available. Can such priming become so overwhelming that observers cannot help but act accordingly? In the present study, well-visible stimuli were preceded by whole series of unidentifiable stimuli. These series had strong, additive priming effects on behavior. However, their effect depended on the frequency with which they provided information conflicting to the visible main stimuli. Thus, effects of subliminal priming are under observers’ strategic control, with the criterion presumably set as a function of the openly observable error frequency. Electrical brain potentials show that this criterion acts simultaneously at the level of visual discrimination of the primes and at motor activation evoked by the primes, thereby shielding observers from unwanted information.

INTRODUCTION

Numerous studies have shown that stimuli that are not consciously detected or recognized may nevertheless affect observers’ behavior. This phenomenon has been called subliminal priming. For instance, exposure to a word (a “prime”) fully prevented from accessing conscious perception by a subsequent “masking” stimulus makes the processing of the next visible word faster and more accurate if both words are semantically related (e.g., Dehaene et al., 1998; Greenwald, Sousa, & Gross, 1996). There is also evidence that subliminal processing proceeds automatically and as such is not controlled voluntarily. For example, Merikle and Joordens (1997a, 1997b) showed that participants could not use unconscious information to change their response strategy, in contrast to when primes were visible. Usually subliminal primes exert only weak effects on performance; but a paradigm is conceivable where these effects would be amplified by presentation of a series of subliminal primes. Assuming that every prime automatically activates a response tendency, an intriguing question arises. Is it possible to accumulate activation by repetitive presentation of primes to such a level that the wrong response will be executed inevitably? To answer this question, we modified a paradigm in which the effects of masked stimuli on responses times and errors have been repeatedly demonstrated (Ansorge & Neumann, submitted; Jaśkowski et al., 2002; Klotz & Neumann, 1999). In this task, two well-visible shapes are presented left and right from fixation. One of these shapes is defined as the target, requiring a left or right keypress depending on its side of presentation. In earlier work (Ansorge & Neumann, submitted; Jaśkowski et al., 2002; Klotz & Neumann, 1999), this pair of “main” figures was preceded by one pair of priming figures. The priming figures were small replicas of those used in the main pair and were completely masked by the main figures through meta-contrast (Enns & Di Lollo, 2000). Although primes were not identifiable, responses to the target figure in the main stimuli were speeded by compatible and delayed by incompatible primes, that is, it did matter whether the small copy of the target in the priming figure was on the same or on the other side as the target in the ensuing main stimulus. The primes activate their related cortical motor area (Jaśkowski et al., 2002; Eimer & Schlaghecken, 1998; Leuthold & Kopp, 1998); therefore these findings might be accounted for by Milner and Goodale’s (1995) interpretation of the two paths that start in the primary visual cortex. The dorsal path that projects to the posterior parietal cortex controls motor guidance, for example, of aiming movements. Because conscious perception is not necessary to guide this motor behavior, this system has been called “automatic pilot” (Pisella et al., 2000). To be consciously experienced, visual stimuli rather have to be analyzed on the ventral path that projects to the inferior temporal cortex.

We extended the described paradigm by presenting several primes in series. Each stimulus consisted of a pair of square outlines located left and right from

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fixation (Figure 1). The nontarget square had an intact outline, whereas the target was formed by removing a small part of the outline on both vertical sides. In each trial, five squares, each consisting of two squares, were presented one after another. The squares in every next stimulus were slightly larger copies of the previous ones. Prime duration was 11.8 msec. Main stimuli lasted 106 msec, always consisted of one target and one nontarget, and required a keypress on the side of the target.

**RESULTS**

**Experiment 1: Effect of Temporal Distance on Subliminal Priming**

Possibly persisting relatively briefly only (Hu & Goodale, 2000; Goodale, Jakobson, & Keillor, 1994; Gnadt, Bracewell, & Andersen, 1991), motor activation might not accumulate over multiple primes but expire before the next prime will exert its effect. Thus, we first checked how the priming effect depends on temporal distance from the main stimulus. We displayed sequences of four primes where only one prime contained the copy of the target, thereby varying the interval between this figure and the main stimulus. This copy of the target could be on the same side as the target in the main stimulus (compatible) or not (incompatible). Responses were faster in compatible than in incompatible trials, $F(1,9) = 93.6, p < .001$ (Figure 2a), for each position in the sequence, even for the most distant Position 1, although the compatibility effect was largest for Positions 2 and 3 (Tukey test, $p < .01$), amounting to about 100 msec. Similarly, participants committed many more errors in incompatible than in compatible trials, $F(1,9) = 21.9, p < .01$. Although most errors occurred for Position 2 (ca. 15% of trials), the interaction between compatibility and position remained...
insignificant, $F(3, 27) = 1.4, p > .05$. Thus, reflected both by response times and by error rates, targets placed in any one of the four positions in the priming sequence did contribute to activation of the response required to the main stimulus.

It is disputable whether the interaction between compatibility and position is due to manipulation of temporal distance or prime size as these two variables changed together; that is, the smaller the temporal distance between the prime pair containing the target figure and main stimulus, the larger were the priming figures. Thus, one can argue that a larger prime can exert larger effect than a smaller one. To reduce this possible effect, the gap in each square, which was the relevant feature necessary for target identification, was equal independent of figure size. However, this cannot wholly exclude the contamination of figure size. Nevertheless, the purpose of this experiment was to check if each target figure in the prime sequence has “a chance” to contribute to the compatibility effect and the answer is “yes.” The answer to the question why the compatibility effect varied with the temporal position of the target figure in the prime sequence remains open.

**Experiment 2: Additive Effect of Several Primes**

Based on these results, we expected that activation would indeed accumulate when elicited by a whole series of target shapes in the priming sequence, all priming the same response (either compatible or incompatible), and that this should lead to a massive further increase of the effect on RT and to many premature and wrong responses. Indeed (see Figure 2b) the effect of compatibility on RT depended on the number of target copies in the priming sequence, $F(3, 24) = 4.9, p < .01$, being largest when all four primes contained these shapes. Likewise, the more target copies were in the priming sequence, the more errors the participants made in incompatible trials, $F(3, 24) = 4.3, p < .05$. These results indicate that motor activation evoked by a series of primes does accumulate, facilitating or inhibiting motor responses to the target. This is in accordance with our predictions. However, compatibility effects were not larger in this experiment than in the previous one. For instance, the maximum compatibility effect obtained with four target copies in the priming sequence, about 100 msec and 13% error rate, did not differ substantially from the maximum compatibility effect obtained with only one target copy in the previous experiment. In other words, more primes were more efficient than one prime when compared within the second experiment, but not when compared between both experiments. This is true although from the participants’ point of view both experiments looked identical: The main stimuli were equal and required the same responses, and participants had no knowledge about the content of priming stimulation.

Apparently, the power exerted by automatic priming on response execution was somehow constrained in the experiment with several target copies in the priming sequence. Probably this was related to the overall slower speed of responses in this than in the previous experiment, $F(1, 17) = 14.8, p < .001$. Therefore, we assumed that participants used a more conservative strategy in selecting their responses, being aware that otherwise they would commit too many errors (although they did not perceive the reason of these errors).

**Experiment 3: Strategic Self-control on Processing of Subliminal Information**

To verify this hypothesis, the chances of committing errors should be manipulated selectively for incompatible trials without changing too much the overall error rate. To achieve this goal, we varied the proportions of compatible and incompatible trials. Wrong responses are certainly more likely if the subliminal primes almost always call for the wrong answer, thus when the proportion of incompatible trials is high. In such a situation, the independence of the automatic pilot should be constrained by strategic adaptations. Conversely, the likelihood of errors will be smaller when primes almost always facilitate the correct response, i.e., when the proportion of compatible trials is overwhelming. In such a situation, there is little need to constrain the “automatic pilot,” which should lead to many errors and marked response delays when priming is incompatible. Indeed, the compatibility effect was as small as 55 msec and the error rate for incompatible trials was only 7% when the proportion of incompatible trials was high (80% incompatible, 20% compatible). Both values were less than in the previous experiments, reflecting the need to use a conservative criterion for response selection because else the many incompatible trials would lead to many errors. In contrast, when only 20% incompatible trials were presented, error rate increased to 30% in these trials, and the compatibility effect for response times in correct trials increased to 130 msec, $F(1, 8) = 61.0, p < .01$ for the interaction of Proportion $\times$ Compatibility (Figure 2c), providing an estimate of the actual power of the unconstrained automatic pilot to control behavior.

**Experiment 4: Possible Loci of Strategic Control**

What might be the mechanisms by which the automatic pilot is prevented from getting access to behavior? At least three stages within the chain of information processing appear suitable to be modified by strategically set criteria. First, the threshold of activation within motor areas needed for executing responses might be varied (Mordkoff & Grosjean, 2001). Second, somewhat more “upstream,” the perceptual input provided by the targetlike shape in the primes might be blocked.

Jaśkowski, Skalska, and Verleger 913
from reaching access to motor areas (Praamstra & Plat, 2001; Wascher, Schatz, Kuder, & Verleger, 2001). Third, even more upstream, the amount of priming information processed within perceptual areas might be reduced. The second alternative fits best to the distinction of dorsal and ventral pathway as discussed above: Participants might prevent the fast activation provided by the dorsal pathway from getting access to motor areas, relying instead on the slower course of information via the ventral pathway. The third alternative fits well to recent reports of brain activation showing that subliminal primes may affect attentional processes (Jaśkowski et al., 2002) and visual processing (Dehaene et al., 2001); thus it is also conceivable that these processes might be modified under strategic control, fitting conceptions of action-dependent perceptual processes (Hommel, Müsseler, Aschersleben, & Prinz, 2001).

To decide among these alternatives, we replicated Experiment 3, additionally measuring event-related EEG potentials, thereby investigating how the proportion of compatible priming modifies effects of the primes on cortical activation. Left-right differences of EEG potentials were recorded between symmetrical scalp sites, contra- minus ipsilateral to the side of the target in the main stimulus (i.e., left minus right for right targets, right minus left for left ones). These differences were expected to provide evidence about specific processing of target information given by the main stimulus and the preceding primes: If these contra-minus ipsilateral differences were significant, this must be due to specific processing of target information. In previous work, these differences have indeed been shown to be sensitive to prime effects (Jaśkowski et al., 2002; Dehaene et al., 1998; Eimer & Schlaghecken, 1998; Leuthold & Kopp, 1998). Because differences were formed with respect to target side in the main stimulus, targets in compatible primes should have effects with the same polarity as in the main stimulus, and targets in incompatible primes should have effects with the opposite polarity. Thus, effects of primes should show up as effects that diverge to different polarities for compatible and incompatible trials. Indeed, three such epochs of prime effects were found in these difference potentials as visible in the displayed waveshapes (Figure 3, differences between bold and thin lines) and confirmed by analyses of variance (ANOVs) on successive 25-msec epochs: 155–175, 205–325, and 355–475 msec after prime onset, confirmed by effects of compatibility, F(1,10), or Compatibility×Recording, F(7,70): F(7,70) = 3.8, p = .035 for the 155- to 175-msec epoch; F ≥ 7.0 and ≤ 46.1 (p ≥ 0.24 and < .0001) for the five 25-msec epochs of the 205- to 325-msec epoch; F ≥ 4.9 and ≤ 11.7 (p ≥ .05 and < .0001) for the five 25-msec epochs of the 355- to 475-msec epoch. Having obtained these three epochs of prime effects, we went on to test whether these effects were modulated by the frequency of compatible versus incompatible primes. The first epoch, 155–175 msec at posterior sites, is probably an exogenous effect because of the asymmetry of the first pair of primes (Valle-Inclán, 1996). This effect of compatibility was not affected by the proportion of compatible trials within the block. The second epoch, 205–325 msec after prime onset, occurs as a distinct peak at posterior sites (‘‘N2pc’’: Wauschkuhn et al., 1998) reflecting the shift of attention towards the targetlike shape in the prime (Jaśkowski et al., 2002). The simultaneous activity at central sites might reflect priming either of motor activity (‘‘lateralized readiness potential’’: Coles, 1989) or of attention-related activity in the premotor cortex (Oostenveld, Praamstra, Stegeman, & van Oosterom, 2001) and has been reliably found with nonconsciously

![Figure 3. Event-related lateralizations. Contralateral–ipsilateral differences in the EEG responses evoked by prime and main stimuli were investigated in Experiment 4, averaged (for illustrative purposes) across the 11 participants, separately for trials with compatible (bold) and incompatible (thin) primes and separately for the 80% compatible/20% incompatible block (black) and the 20% compatible/80% incompatible block (gray). Contra- and ipsilateral are defined with respect to the side of the target in the main stimulus (=side of the responding hand), with contralateral negativity plotted upward. As in Experiment 3, in each trial, all primes contained a targetlike shape on the same side, thus were uniformly either compatible or incompatible with the target in the main stimulus. The x axis shows milliseconds from onset of the prime sequence, primes being presented at 0, 40, 80, 120 msec and the main stimulus at 160 msec. Stimulus onsets are denoted by arrows. Depicted are the contra–ipsilateral differences at the posterior pair P7 and P8 and at the central pair C3 and C4. Three epochs of prime compatibility effects were found and are visible in the displayed waveshapes (differences between bold and thin lines): 155–175, 205–325, and 355–475 msec after prime onset. These effects were found to be modulated by proportion of compatible trials (differences between black and gray lines) at posterior and central sites in the second and third epoch.](image-url)
processed primes (Jaśkowski et al., 2002; Dehaene et al., 1998; Eimer & Schlaghecken, 1998; Leuthold & Kopp, 1998). This compound of posterior and central effects of the primes was reduced in the 20% compatibility condition (difference between black and gray lines in Figure 3), Condition × Compatibility being significant in four consecutive 25-msec periods (230–325 msec), $F(1,10) \geq 5.8$ and $\leq 9.8$ ($p \leq .037$ and $\geq .01$). When tested separately, this reduction occurred both for compatible and for incompatible primes: For compatible primes, condition had significant effects in three periods from 255 to 325 msec, $F(1,10) \geq 5.0$ and $\leq 7.1$, $p \leq .049$ and $\geq .024$, for incompatible primes in three periods from 230 to 300 msec, $F(1,10) \geq 5.1$ and $\leq 9.2$, $p \leq .048$ and $\geq .013$. The third epoch, visible 355–475 msec after prime onset at posterior sites, that is, 195–315 msec after main-stimulus onset, reflects the shift of attention (N2pc) towards the target in the main stimulus in case of incompatible primes, not occurring after compatible primes because these primes already primed attention on the correct side (Jaśkowski et al., 2002). This effect appeared to be moderated by condition in its later part, Condition × Compatibility × Recording site being significant in three consecutive 25-msec periods (405–475 msec), $F(7,70) \geq 3.5$ and $\leq 4.9$ ($p \leq .006$ and $\geq .001$). However, this moderation might be response related, because responses started during this period and were particularly delayed with incompatible primes in the 80% compatibility condition.

To relate the contra–ipsilateral differences more explicitly to EEG potentials as usually reported, Figure 4 shows these EEG potentials re-referenced to a common reference (placed at the nose), averaged across trials irrespective of target side and averaged across left and right recording sites. The epochs in which primes had significant effects on the contra–ipsilateral differences (depicted in Figure 3) are marked. As Figure 4 shows, the first epoch of contra–ipsilateral differences (155–175 msec) coincides with the peak of N1 evoked by onset of the first prime, the second epoch (205–325 msec) coincides with a broad, slowly decreasing negativity (which might be composed of N1 components evoked by the four stimuli following the first prime), and the third epoch (355–475 msec) coincides with the N2-type component evoked by those main stimuli that are incompatible with the preceding primes. One should, however, be cautious in identifying the contra–ipsilateral differences as asymmetries of these very components because, for example, the contra–ipsilateral difference in the third epoch occurs at posterior recording sites only, whereas the simultaneous N2 component occurs at anterior sites as well. Anyway, it is evident that potentials are not generally smaller in the 20/80 versus the 80/20 condition; that is, an unspecified effect of generally reduced amplitudes in the 20/80 condition can be ruled out.

**DISCUSSION**

We devised a new paradigm to investigate dynamics of subliminal priming. Series of primes were presented in such a way that every next stimulus, being slightly larger than the previous one, masked its preceding stimulus by metacontrast. Although participants were not able to identify the primes, speed and errors of reactions to the main stimuli were remarkably affected by prime identity even for the most remote primes in the series. With this paradigm, we checked if the priming effect on performance could accumulate, leading to automatic response triggering against participants’ will in the extreme case. We indeed found accumulation of priming effects: The more targetlike shapes there were in the priming sequence, the larger was the RT difference between compatible and incompatible trials and the more errors were made by participants. But we further showed in Experiments 3 and 4 that this accumulation was limited strategically. When 80% of trials had incompatible primes, the priming effect was smaller than when only 20% trials were incompatible. This happened, in our view, because observers set a criterion for the processing of subliminal information, depending on average error rate and response delays they were willing to tolerate, and thus responded more cautiously when 80% of trials had incompatible primes and less cautiously when 80% had compatible primes.
Our results might appear to contradict those reported by Merikle and Joordens (1997a, 1997b). They investigated the effect of prime visibility on the priming effect in a Stroop-type task where primes contained information compatible or incompatible with the target. In one condition, primes were only briefly presented (33 msec) and could not be recognized. In the other condition, primes lasted longer (167 msec) making their contents available to awareness. In both conditions, primes were incompatible in 75% of trials. Only when primes were unrecognizable did a typical Stroop effect occur; that is, responses were faster for compatible than incompatible trials. The reversed effect was found in the above-threshold condition, because in this condition participants have the possibility to “capitalize on the predictive information provided by the primes” (Merikle & Joordens, 1997b, p. 220).

In apparent contradiction, we found strategic control over performance with unrecognizable primes. However, we do not argue that participants made direct use of the prime information for adapting their strategies. Under subliminal conditions, any conscious disclosing of the relation between information provided by primes and imperative stimuli is indeed impossible. But what is open to conscious access are the effects induced by the primes on performance (cf. Katkin, Wiens, & Öhman, 2001) who demonstrated that changes of heartbeat induced by masked conditioned stimuli might be used by participants to predict that these stimuli were followed by aversive stimuli. Thus, it is reasonable to assume that participants evaluated their general performance, trying to keep error rate on a low level. The critical assumption is that on the basis of this evaluation, participants could modulate the impact of primes in an unspecified way, that is, irrespective of the identity of the primes. This might have as well happened in Merikle and Joordens’ studies, because in their studies the differences of RT and error rate between the congruent and incongruent trials were rather small (e.g., in Merikle & Joordens, 1997b, approximately 10 msec for RT and 1.1% for error rate). Like in our condition of 80% incompatible primes, this might have been achieved by strategic reduction of the general impact of primes. Alternatively, that effect might have been so small from the very beginning. In this case, participants had no chance to notice it and thus to modulate their behavior. A way to decide between these two alternatives in their study would have been to use also a condition with reversed probabilities, that is, 25% incompatible trials. If the small size of the effect was due to strategic setting, it should become larger in this condition. Either way, the present data and conclusions are not in conflict with Merikle and Joordens (1997b) results. In fact, they extend and supplement their findings showing that when subliminal influences deteriorate participants’ performance too much some control mechanisms are activated, which try to prevent these influences from getting access to behavioral control. In other words, the amount to which human observers are affected by subliminally presented information might be considerable but may be modified to a large extent by strategic settings.

Our findings provide converging evidence to recently published studies on word priming. Bodner and Masson (2001) had items in a word/nonword decision task primed by masked items, with masked and visible items being identical in either 80% or 20% of trials. Very similar to the present findings, they found consistently larger priming effects in the 80% condition. Their use of words as stimuli allowed them to investigate effects of further moderating factors such as item frequency and variability of difficulty of target processing. Although these factors cannot be studied with the present homogeneous abstract stimuli, the homogeneity of our stimuli has the advantages of allowing more rigorous control on participants’ detection performance and of leading to neurophysiologically measurable consequences that could elucidate the mechanisms of control exerted by the strategic settings.

How do these settings affect processing? We considered three possibilities: (i) that the threshold of activation is modulated within motor areas (Mordkoff & Grosjean, 2001); (ii) that the extent is modulated by which the perceptual input provided by the targetlike shape in the primes is passed through to motor areas (Praamstra & Plat, 2001; Wascher et al., 2001); and (iii) that the amount of priming information processed within perceptual areas might be enhanced or reduced. Electrical brain potentials recorded in our Experiment 4 indicated three temporal epochs of prime effects. The lack of an effect of the proportion manipulation on the first epoch (155–175 msec) suggests that it is not early stages of visual perception that were altered by strategy changes. There was an effect of the proportion variation on the third epoch, 355–475 msec after prime onset. However, this effect was too late to provide unambiguous clues on the locus of the strategic effect, being an on-line window on processing of the main stimuli rather than on prime processing. Furthermore, the effect might simply be due to components related to thekeypress, which was delayed in incompatible trials of the 80% compatibility condition. However, the effects on the second epoch, around 250 msec after prime onset, did provide this window on prime processing: The reduction of the posterior N2pc evoked by primes suggests that processing the meaning of the primes was weakened in the 20% compatibility block. There is some evidence to assume that N2pc is generated by activity of the ventral visual pathway, either V4 or, less probable, TO (Oostenveld et al., 2001; Luck, Girelli, McDermott, & Ford, 1997). Simultaneously, activation evoked by the primes was reduced over central areas, possibly reflecting activation of premotor areas (Oostenveld et al., 2001; Verleger, Vollmer, Wauschkuhn, Van der Lubbe, & Wascher, 2000) as parts of dorsal visuomotor pathways.
(Rizzolatti, Luppino, & Matelli, 1998). Thus, the locus of effect of the strategic settings was not at the earliest stages of visual processing because there was definitely one early epoch of prime compatibility effects (155–175 msec) that was unaffected by these settings. Rather, the effect was simultaneously visible somewhat later, probably in the two branches of visual processing as far as can be concluded on the basis of the limited topographical resolution of the present method. Possibly, both simultaneous processes might be due to the impact of some third controlling center within the frontal lobes. Indeed, evidence for prefrontal modulation of extrastriate visual processing has been shown in patient studies (Barceló, Suwazono, & Knight, 2000) and has been further suggested by high-resolution spatio-temporal recordings (Foxe & Simpson, 2002). Thus, the reductions of N2pc at posterior sites and of activity at central sites possibly reflect top-down regulation of the degree to which visual nonconscious information gets access to behavioral control.

**METHOD**

**Apparatus**

All stimuli were presented on a 17-in. monitor (85 Hz in Experiments 1–3 and 75 Hz in Experiment 4) driven by Presentation software (Neurobehavioral Systems). The observation distance was 50 cm (120 cm in Experiment 4). Two kinds of squares were used as stimuli (see inset of Figure 1): Nontarget shapes had intact outlines, whereas in the target shape, a small part of both vertical sides was removed from the square outline. Stimuli consisted of two squares placed to the left and right of the fixation cross. In every trial, five stimuli were presented one after another. The squares in every next stimulus were slightly larger copies of the previous ones (except the cut-off parts that were identical in all squares), masking them by metacontrast. Squares of the first stimulus subtended 1.21° × 1.21°, increasing to 2.36° × 2.36° in the last stimulus. The center of each square was placed 1.6° to the left or right of fixation. The first four stimuli (primes) were each presented for 11.8 msec (13.3 msec in Experiment 4; duration of one monitor frame), the last (main) stimulus for 106 msec (120 msec in Experiment 4). Onset asynchrony between these five presentations was 35 msec (40 msec in Experiment 4). Main stimuli always consisted of one target and one nontarget.

**Experimental Procedure**

Participants had to make speeded responses with their left or right hand depending on the side of the target in the main stimulus. The number of targets and nontargets in the priming sequence as well as their distribution depended on the particular experiment. Trials started with a warning signal, serving as fixation aid: Four points appeared 5° above, below, left, and right of the screen center, moved inwards for 0.9 sec, and then “crystallized” as a fixation cross that remained on during the trial. The sequence of primes started 35 msec afterwards (40 msec in Experiment 4), giving way to the main stimulus after 140 msec (160 msec in Experiment 4). Time from response to onset of the fixation aid of the next trial was set to 800 msec; thus with response times of 400 msec the interval between onset of the prime stimuli in two successive trials was 2250 msec. In Experiments 1 and 2, a session consisted of two identical blocks of trials with 200 trials each. In Experiment 3, one block (80/20) had 160 compatible and 40 incompatible trials, the other (20/80) 40 compatible and 160 incompatible trials. Order of blocks alternated between participants. In Experiment 4, four blocks of 250 trials were performed. There were two 80/20 blocks with 200 compatible and 50 incompatible trials each, and two 20/80 blocks with 50 compatible and 200 incompatible trials. These four blocks alternated in ABAB or BABA order, alternating between subjects.

**Prime Identification Performance**

How to ascertain whether the primes used are truly subliminal has been a subject of fierce discussion (e.g., Kunimoto, Miller, & Pashler, 2001; Klotz & Neumann, 1999; Miller, 1991; Holender, 1986; Eriksen, 1960). To eliminate the possibility as far as possible that the effects found in this study were due to supraliminality of the primes in some fraction of trials, we employed the following procedure and analysis.

Identifiability of primes in the priming sequence was checked in a separate part of each session. Before the beginning of this part, the priming sequence was presented in slow motion to show participants how the priming sequence looks like and what kind of stimuli they should identify. Participants had to make their rating after every second trial: Two trials were presented, with targetlike shapes inserted in the priming sequence in one trial, none in the other, and participants had to indicate whether the targetlike shapes were present in the first or the second trial. The fixation aid “crystallized” for 900 msec before the first trial of a pair only and the fixation cross then remained on until response to the second trial of the pair. Time within pairs (from offset of the main stimulus of the first trial to onset of the primes of the second trial) was set to 1000 msec. Feedback information was provided after every response indicating correctness of the guess. Participants worked through 320 trial pairs, with a break after 160 trial pairs.

The forced-choice part was always conducted after the RT part. This order was deliberately chosen for the following reasons. Although participants were aware of the “presence” of primes, perceiving the stimulation
sequence as expansion of the left and right squares, they were not informed about the “composition” of these primes, that is, that there might be some gap already in the outline of the primes. Subjects did not spontaneously report any awareness of the contents of the priming sequence and, when shown the actual priming sequence in slow motion before the forced-choice part, stated that they had not noticed this feature before. We were afraid that with reversed order, although subjects could be less fatigued, some learning might occur, increasing discriminability of the primes in the RT sessions. There is indeed some evidence that masking becomes less effective with practice (Jaśkowski and Janik, unpublished data; Schubö, Schlaghecken, & Meinecke, 2001; Ventura, 1980).

Therefore, when the forced-choice part would be administrated first, participants might identify the primes in the subsequent RT part in a significant fraction of trials, whereas \( d' \) calculated from the first part could be close to zero indicating no awareness. With the forced-choice part always administrated second, possible practice effects would overestimate \( d' \) making our criteria of exclusion from the further analysis even more strict. Further, this choice of task sequence was validated by Klitz and Neumann (1999) using a similar task: In that study, several orders and combinations of the RT priming and the prime identification parts were tried and found not to change the principal pattern of results.

Discrimination accuracy (\( d' \)) could thus be calculated for each position in the priming sequence (Experiment 1) and for any number of primes containing target figures (Experiment 2). Participants who had too many hits in one of these single conditions of Experiments 1 and 2 (\( d' > 0.35 \)) or an average \( d' > 0.25 \) (in Experiments 1 to 4) were excluded from further analysis. (These criteria were redundant, i.e., participants who had \( d' > 0.55 \) in one condition of Experiments 1 and 2 also had average \( d' > 0.25 \), and vice versa). Using these criteria, 3 of 13 original participants of Experiment 1, 3 of 12 participants of Experiment 2, 1 of 10 participants of Experiment 3, and 3 of 14 participants of Experiment 4 were excluded. For the remaining participants, mean \( d' \) for detecting targetlike shapes did not differ significantly from zero (\( d' \geq -0.12 \) and \( \leq 0.10; p \geq .12 \)) for any position (Experiment 1) or number (Experiment 2) of primes in the priming sequence and was independent of prime position, Experiment 1: \( F(3,27) = 1.03, p = .38 \), or number of primes, Experiment 2: \( F(3,24) = 2.31, p = .11 \).

Moreover, we checked the correlation between participants’ individual \( d' \) scores with the corresponding size of their compatibility effects obtained in the RT part (i.e., the difference between RT for compatible and incompatible trials) (Damian, 2001). In all experiments, correlation coefficients were not significant, both when calculated for all conditions taken together and when calculated separately for individual conditions (\( r \geq -.41 \) and \( \leq +.39, p \geq .26 \), two-sided).

**Statistical Analysis**

Repeated measures ANOVAs were performed on RTs and error rates for two factors. One factor was in all experiments compatibility between primes and main stimulus (compatible vs. incompatible). The second factor was target position in the priming sequence (1, 2, 3, or 4) in Experiment 1, number of targets in the priming sequence (1, 2, 3, or 4) in Experiment 2, and relative number of compatible trials (20% compatible/80% incompatible vs. 80% compatible/20% incompatible) in Experiments 3 and 4. When appropriate, Huynh–Feldt adjustments to the degrees of freedom were performed.

**EEG Recording**

In Experiment 4, brain electrical activity was recorded from Ag/AgCl electrodes placed at 19 scalp sites (F3, Fz, F4, FC3, FC4, C3, C1, Cz, C2, C4, P7, P3, Pz, P4, P8, P7, P07, P08, O1, O2) referenced to the nose tip. For identifying ocular potentials in the EEG, the vertical electrooculogram (EOG) was measured with two electrodes above and beneath the left eye, and the horizontal EOG with two electrodes placed at the outer canthi of both eyes. Voltages were amplified within 0.03 to 35 Hz and stored on disk with a sampling rate of 200 Hz (one data point every 5 msec). Off-line, trials were excluded when there were zero lines, out-of-scale values, slow drifts larger than 60 \( \mu \)V, or fast shifts larger than 100 \( \mu \)V/500 msec. Transmission of ocular potentials was corrected from the EEG by linear regression.

The differences between the EEGs contralateral and ipsilateral to the target shape in the main stimulus were determined for each symmetrical pair of electrodes (F3–F4, FC3–FC4, C1–C2, C3–C4, P3–P4, P7–P8, PO7–PO8, O1–O2) in correctly responded artifact-free trials. Separate averages were calculated for trials with the target shape on the left and trials with the target shape on the right, and these averages were then averaged together, separately for compatible and incompatible primes and separately for the 80/20 and the 20/80 condition. These individually averaged contralateral–ipsilateral differences were averaged for illustrative purposes across the 11 participants (Figure 3). Statistical analysis was done on mean amplitudes over successive 25-msec windows (five data points each), starting with the 5- to 25-msec and ending with the 480- to 500-msec window. Each window was submitted to an ANOVA (procedure GLM in SPSS 9.0) with the repeated-measurement factors condition (80/20 vs. 20/80 proportion of compatible/incompatible trials), prime compatibility (compatible vs. incompatible), and pair of recording sites (eight levels). Effects of recording site were corrected by Huynh–Feldt’s \( \epsilon \).
In addition to contra-ipsilateral differences, EEG potentials were averaged as recorded (with the nose as common reference) irrespectively of the side of the target shape. For illustrative purposes, these individual averages were averaged across the 11 participants and across symmetrical recording sites (Figure 4).

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