Consciousness and Cognition 19 (2010) 999–1006

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Unconscious task application

Filip Van Opstal [a,*], Wim Gevers [b], Magda Osman [c], Tom Verguts [a]

[a] Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Gent, Belgium
[b] Unescog, Université Libre de Bruxelles, Avenue Fr. Roosevelt 50, B-1050 Bruxelles, Belgium
[c] Department of Psychology, University College London, Gower Street, London WC1E 6BT, UK

ARTICLE INFO

Article history:
Received 20 January 2010
Available online 26 May 2010

Keywords:
Subliminal priming
Consciousness

ABSTRACT

The nature of unconscious information processing is a heavily debated issue in cognitive science (e.g., Kouider & Dehaene, 2007), and neuroscience (e.g., Crick & Koch, 1998). Traditionally, it has been thought that unconscious cognitive processing is restricted to knowledge that is strongly prepared by conscious processes (e.g., Dehaene et al., 1998). In three experiments, we show that the task that is performed consciously can also be applied unconsciously to items outside the current task set. We found that a same–different judgment of two target stimuli was also performed on two subliminally presented prime stimuli. This was true for target and prime stimuli from entirely different categories, as well as for prime and target stimuli at different levels of abstraction. These results reveal that unconscious processing can generalize more widely than previously accepted.

1. Introduction

An important issue in consciousness research is to what extent unconscious information can affect human behavior. One long-standing issue of debate has been whether it is possible to process semantic information that is subliminally presented. Subliminal perception refers to the behavioral influence of a stimulus that is presented below the threshold for conscious perception. Recent studies reviewing (Kouider & Dehaene, 2007) or meta-analyzing (Van den Bussche, Van den Noortgate, & Reynvoet, 2009) past research on visual masking now unequivocally support this possibility. Although this already broadens the scope of unconscious processing, it is still generally believed that unconscious processes are limited. The processing of a subliminally presented stimulus is, for example, believed to be limited to activating existing memory traces (or stimulus–response links; S–R links). This limitation of unconscious processes to learned associations is in line with the view that automatic processes, processes that require little thought and conscious awareness, are limited to existing memory traces (Logan, 1988). However, it has been acknowledged that subliminal priming is possible for very recently learned S–R associations (e.g., Abrams & Greenwald, 2000), for example for associations learned during the experimental task (e.g., Kunde, Kiesel, & Hofmann, 2003). According to the Action Trigger Account (Kunde et al., 2003) even the expectancy of the participants for certain stimuli (e.g., following task instructions) can create S–R links that can cause a subliminal priming effect. Taken together, this would mean that subliminal priming is possible either for memory traces from long-term memory, or for traces established in short term memory in the course of, or prior to, an experiment. In other words, stimuli without existing or consciously prepared memory traces cannot be processed without awareness.

The present study aimed at directly testing this limitation of subliminal processing. We investigate whether the processing of subliminally presented stimuli is indeed restricted to stimuli that are consciously prepared or to stimuli that have existing memory traces in memory. To achieve this, there are two key conditions of the design: (1) prime and target stimuli

* Corresponding author. Fax: +32 (0)9 264 64 09.
E-mail address: filip.vanopstal@ugent.be (F.V. Opstal).

1053-8100/$ - see front matter
doi:10.1016/j.concog.2010.05.002

are from two distinct stimulus sets and (2) no previous stimulus–response mappings exist for the prime stimuli. Importantly, because of (1), stimulus–response mappings for the prime stimuli cannot develop during the course of the experiment because they are not consciously perceived. In three experiments participants were instructed to judge whether two stimuli appearing after a series of flashes on the screen were the same or different. To ensure that the primes were not processed consciously, we employed rigorous checks that probed participants' knowledge of the primes.

2. Experiment 1

To satisfy the first condition of the design, the prime and target stimuli in this experiment belonged to different categories, namely numbers and colored patches, respectively. To satisfy the second condition, we employed a same–different task. In this task participants have to judge the similarity of two simultaneously presented stimuli by pressing the corresponding response keys "Same" or "Different". For this task it can reasonably be assumed that no existing S–R links exist. For example, it is unclear why an association between 3, 7, and "different" would be stored in long-term memory and activated while judging color patches when one is not even aware that numbers are presented. If the task that is applied to the targets is also applied unconsciously to the primes, a congruency effect can be expected: For two same prime stimuli, reaction times (RTs) will be faster when two same target stimuli are presented compared to when two different target stimuli are presented because in the former case the primes elicit the same response (namely, "Same") as the targets. In contrast, for two different prime stimuli, RTs will be faster when two different target stimuli are presented compared to when two same target stimuli are presented because the former will elicit the same response (namely, "Different"). The presence of a congruency effect in this case would indicate that the task is also performed on stimuli that are outside the consciously prepared task set.

2.1. Method

2.1.1. Participants

Twenty-two university students (2 male, aged between 18 and 32) participated in this experiment for course credits. None of the participants was aware of the purpose of the experiment.

2.1.2. Apparatus and stimuli

A 60 Hz monitor was used and stimulus presentation was synchronized with the refresh rate (16.7 ms). Key presses were registered with a response box. Primes were numbers with colored patches as targets. To be able to investigate robustness of our results, we created two different Prime Sets of number stimuli (odd: 1, 3, 5, 7; even: 2, 4, 6, 8). Four different colored patches were used as targets (yellow, red, green, blue; Fig. 1A). Primes and targets were 6 mm high and 4 mm wide. The two prime or target stimuli were separated by a distance of 8 mm. If the task that is performed to the conscious (non-symbolic) targets would also be performed to the unconscious (symbolic) primes, this would provide strong evidence for the unconscious processing of stimuli that have no pre-existing memory trace or that are not consciously prepared during the experiment.

2.1.3. Procedure

Before the experiment, participants were told that on each trial they would see a brief series of flashes ending with two stimuli (the target display; in this case two colored patches). Their task was to judge whether the two stimuli from the target display were the same or not, by pressing the corresponding key. Unknown to the participants, the series of flashes consisted of a prime display sandwiched between two mask displays. The prime display also contained two stimuli that could be either

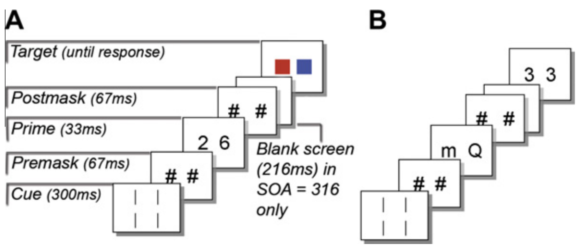

Fig. 1. The experimental design was the same in all three experiments. After the presentation of a cue (300 ms), a mask, consisting of two hash marks, appeared for 67 ms. This was immediately followed by a prime for 33 ms. The prime consisted of two stimuli appearing on the same locations as the hash masks. After the prime, a postmask was presented for 67 ms. In the SOA = 100 condition, the target was presented immediately after the mask. In the SOA = 316 condition a blank screen was presented for 216 ms before target onset. In Experiment 1 (A), the primes were numbers and the targets were colored patches (red, green, yellow, and green). In Experiments 2 and 3 (B), the primes were always letters, and the targets numbers. The primes consisted of one small letter and one capital letter. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the same or different. Before or during the experimental task, participants were not told about the two prime stimuli. The interstimulus interval between presentation of the postmask and the target could be either 0 ms or 216 ms, and was varied between blocks (the time between prime and target onset (SOA) was thus 100 or 316 ms). We used two SOAs because we were unsure about the exact timing of unconscious task application. Response hands, stimulus sets, and SOA were counterbalanced between participants. The experiment consisted of 1152 trials (576 trials for each SOA). Congruent trials are defined as trials in which the relation between the prime stimuli and the target stimuli is identical (i.e., primes and targets both Same, or primes and targets both Different). In incongruent trials, the relation between prime and target differed (primes Same, targets Different; or primes Different, targets Same). Note, though, that the sameness relation is only defined within primes or within targets, as prime and target stimuli were numbers and colors, respectively. A congruency effect would thus indicate that the task applied to the targets can also be applied to subliminally presented primes. There were equal numbers of Same and Different primes, and Same and Different targets. These factors were systematically crossed, so there was also an equal number of congruent and incongruent trials.

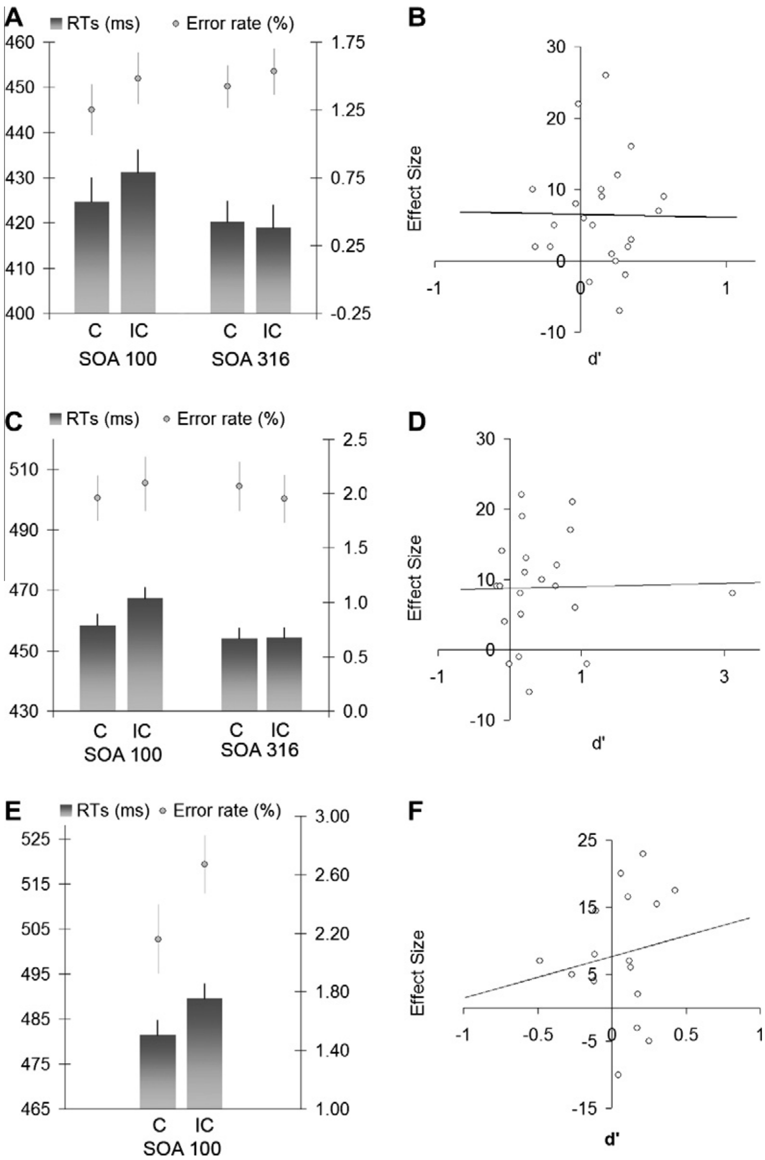

Fig. 2. Results of the RT and error analyses and of the forced choice post-experiment awareness test. Analyses of the median RTs for the congruent and incongruent trials show a congruency effect in the short SOA (100 ms) condition, but not in the long SOA (316 ms) condition in (A) Experiment 1, and (C) Experiment 2. In (E) Experiment 3 only the short SOA was presented. Error bars denote 95% confidence intervals (Masson & Loftus, 2003). A regression analysis on the d' measures with the congruency effect size as predictor for each participant revealed that at $d' = 0$ there was still a significant congruency effect in all three experiments (B, D, and F). Each dot represents a participant. C = Congruent; IC = Incongruent. Removal of the outlier with a high d' in Experiment 2 did not affect the results.

2.2. Results

A 2 (Congruency: Congruent/Incongruent) × 2 (SOA: 100, or 316) × 2 (Prime Set: 1, 3, 5, 7 or 2, 4, 6, 8) ANOVA on the mean correct RTs revealed a significant congruency effect, $F(1, 20) = 4.84$, $p < .05$, $MSE = 31$, and a significant interaction between congruency and SOA, $F(1, 20) = 7.92$, $p < .01$, $MSE = 42$. The congruency effect was significant in the SOA = 100 condition (6 ms; $t(21) = 3.91$, $p < .001$), but not in the SOA = 316 condition ($t < 1$). The same analysis on the error rates showed a significant effect of congruency (0.23%, $F(1, 20) = 5.02$, $p < .05$, $MSE = 2.02$) (Fig. 2A).

To exclude the possibility that the priming effect was caused by S–R links that were created in the course of the experiment, we investigated the time course of the priming effect. We therefore divided the SOA = 100 ms condition in six blocks of 96 trials and looked at the congruency effect in all six blocks: If S–R links were created in the course of the experiment a change in the congruency priming effect between blocks should be observed. A 2 (Congruency) × 6 (Blocks) ANOVA with block and congruency as within-participants factors revealed only a main effect of congruency, $F(1, 21) = 25.30$, $p < .0001$, $MSE = 156$. The absence of an interaction with block ($p = .98$) indicates that the congruency effect was not significantly different between blocks (see Table 1). This suggests that the congruency priming effect was present from the start of the experiment and could therefore not be caused by the creation of SR-links in the course of the experiment.

2.3. Prime awareness

After every experiment, prime awareness was extensively tested. First, subjective awareness was measured by asking participants after the main experiment to name any symbol that they saw on the screen before the presentation of the target stimulus. None of the participants could name an actual prime symbol, and only mentioned the hash masks. Second, participants were informed about the prime stimuli, and objective awareness was measured using a forced-choice test identical to the main experimental task, i.e. with both primes and targets presented. Here, participants were instructed to judge the similarity of the primes rather than the targets (e.g., Dehaene et al., 1998). After each trial in the forced-choice test, they gave confidence ratings on a scale ranging from 1 (absolutely not confident) to 9 (absolutely confident). The prime awareness test consisted of 144 trials for each SOA. Because priming effects were only found in the short SOA condition we report prime visibility results of this condition only. Average prime visibility (d') was 0.14, and was significantly different from 0, $t(21) = 2.51$, $p = .017$ but extremely small (52% correct answers). A regression analysis on the d' measures (Greenwald, Draine, & Abrams, 1996) of the short SOA condition was performed to investigate the reliability of the priming effect. This revealed a significant intercept (6.55 ms, $t(20) = 3.35$, $p < .005$), indicating that at zero d', the point where there is absolutely no awareness of the primes, there is still a significant congruency effect (Fig. 2B). The presence of a congruency effect is therefore not related to the visibility of the primes. Furthermore, the certainty ratings were very low (average 1.74), further demonstrating that participants lacked any awareness of the primes.

The results of this experiment clearly show that a task that is consciously performed on the target stimuli can also be performed on prime stimuli that are presented below the threshold of conscious perception. Importantly, in contrast to what is generally believed, the experiment reveals that the task execution is not limited to stimuli that are consciously prepared (Greenwald, Abrams, Naccache, & Dehaene, 2003; Kunde et al., 2003). Because the conscious task was only performed on colored patches and numbers were never consciously perceived, it is clear that numbers were no part of a consciously prepared task set in this experiment. Still these unconsciously presented numbers were processed.

Because colored patches and Arabic digits are perceptually very dissimilar these results furthermore indicate that the observed congruency effect does not derive from low-level perceptual overlap between prime and target categories. In the following experiment we further investigated the possibility that the same/different judgment on the primes is not only based on perceptual matching.

3. Experiment 2

In Experiment 1 the Prime Set consisted of Arabic digits. This means that Same pairs were pairs composed of two identical Arabic digits. It is therefore possible that the same/different judgment on the prime stimuli was based on perceptual features

Table 1
Average RTs on incongruent (Incon) and congruent (Con) trials for every block in the SOA = 100 ms condition for Experiments 1, 2, and 3. No differences between the blocks were observed, indicating that no change in the congruency priming effect occurred in the course of the experiment.

Block	Experiment					
	1		2		3	
	Incon (ms)	Con (ms)	Incon (ms)	Con (ms)	Incon (ms)	Con (ms)
1	431	425	462	460	493	490
2	430	423	476	466	491	486
3	434	428	477	461	498	483
4	429	421	468	458	479	476
5	434	426	458	455	490	480
6	434	424	464	450	494	488

of the digits rather than on their numerical value. The primes could thus have been processed without accessing their semantics; the same/different judgment could have been based on comparing perceptual features. In Experiment 2 we wanted to exclude perceptually based prime processing by presenting two letters as primes: One letter in upper case and one in lower case. A same/different judgment would then only be successful if the abstract identity of the prime letters is processed. A congruency effect would thus indicate that the primes are not compared based on perceptual features only (e.g., press ‘same’ if both stimuli have a horizontal line).

3.1. Method

3.1.1. Participants

Twenty-one university students (aged between 18 and 25, 4 male) were rewarded 10 Euros for participation. None of the participants took part in Experiment 1 or was aware of the purpose of the experiment.

3.1.2. Apparatus and stimuli

Primes were letters; to decrease the probability that the effects were caused by a specific stimulus set, we used two letter sets (ADEG and LMQR). The targets were numbers (i.e., the same sets used as primes in Experiment 1). The prime letters always consisted of one letter presented in lower case and the other letter in upper case (e.g., aA; Fig. 1B). Using Boles and Clifford’s (1989) similarity ratings, the letter sets were chosen such that the physical similarity between upper and lower case letters was minimized.

3.1.3. Procedure

Identical to Experiment 1.

3.2. Results

A 2 (Congruency) × 2 (SOA) × 2 (Prime Set: ADEG or LMQR) repeated measures ANOVA on the mean correct RTs with Prime Set as a between-participants factor revealed a significant congruency effect, $F(1, 19) = 15.83$, $p < .001$, $MSE = 28$, and a significant interaction between congruency and SOA, $F(1, 19) = 10.63$, $p < .005$, $MSE = 35$. As in Experiment 1, the congruency effect was significant in the SOA = 100 condition (9 ms; $t(20) = 5.35$, $p < .001$), but not in the SOA = 316 condition ($t < 1$). Analysis of the error rates revealed no significant effects (Fig. 2C).

As in Experiment 1, we investigated the time course of the congruency effect. A 2 (congruency) × block (6 blocks) repeated measures ANOVA with block and congruency as within-participants factors revealed a main effect of block, $F(5, 100) = 3.09$, $p < .05$, $MSE = 499$, and a main effect of congruency, $F(1, 20) = 23.81$, $p < .001$, $MSE = 216$. Again, no interaction between block and congruency ($p = .36$) was observed, indicating that the congruency effect did not change during the course of the experiment (see Table 1).

3.3. Prime awareness

To control for prime visibility, a prime awareness test was performed after the experiment. Identical to Experiment 1, subjective and objectives measures of prime awareness were taken from the participants. Participants only reported having seen hash marks. None of the participants was aware of the presentation of letters during the experiment. Objective prime visibility (d') was calculated for the SOA = 100 condition and was significantly different from 0 (0.46; $t(20) = 2.93$, $p < .01$; 58% correct answers). However, regression analysis on the d' measures revealed a significant intercept (8.75 ms, $t(19) = 4.31$, $p < .001$) indicating a significant priming effect at zero prime visibility (Fig. 2D). The certainty of the responses were rated 1.94 on average, supporting the suggestion that participants had no awareness of the primes.

The presence of a congruency priming effect in this experiment demonstrates that abstract identities of the prime letters are being accessed and compared. However, because of the higher prime visibility compared with Experiment 1, we replicated the experiment to investigate its robustness.

4. Experiment 3

4.1. Method

4.1.1. Participants

Sixteen university students (aged between 18 and 21, 3 male) participated in this experiment. None took part in an earlier experiment or was aware of the task purpose.

4.1.2. Procedure

The same as in Experiment 1. However, because the two previous experiments only showed an effect in the short SOA condition, we only used this SOA (100 ms) here.

4.1.3. Apparatus and stimuli

The same as in Experiment 2.

4.2. Results

A repeated measures ANOVA with congruency as within-participants factor and Prime Set as between-participants factor only revealed a main effect of congruency, 8 ms, $F(1, 14) = 14.25$, $p < .005$, MSE = 41. The same analysis was also performed on the error rates. Contrary to Experiment 2, a significant effect of congruency was now also present in the error rates 0.51%, $F(1, 14) = 5.21$, $p < .05$, $MSE = .33$ (see Fig. 2E).

As in the previous experiments, we also investigated the time course of the priming effect to see if the effect was caused by the creation of action triggers in the course of the experiment. We therefore divided the experiment in six blocks of 96 trials and looked at the congruency effect in all six blocks by applying a 2 (congruency) × 6 (blocks) ANOVA with block and congruency as within-participants factors. This revealed only a main effect of congruency, $F(1, 15) = 10.15$, $p < .01$, $MSE = 228$. The absence of an interaction with block indicates that the congruency effect was not significantly different between blocks (see Table 1).

These results replicate the results of Experiment 2, and provide clear evidence for unconscious processing of the abstract identities of letters without conscious preparation. Although we took all possible measures to use letter primes for which the between-case same-letter and different-letter pairs were as closely matched as possible, this could not be equalized exactly (according to Boles and Clifford's ratings, the average physical similarities for same-letter and different-letter pairs were 247/500 and 160/500 respectively; lower values indicate less similarity: minimum value = 100, maximum value = 500; Boles & Clifford, 1989). To further investigate this, we looked at the differential contributions of same/different primes and same/different targets. This revealed that the congruency priming effect was mostly driven by different-letter different-number prime–target pairs in Experiment 2 (see Table 2). In Experiment 3, however, the priming pattern reveals that the effect is driven mostly by same-letter same-number prime–target pairs (see Table 2). This indicates that the effect is due to same-letter primes priming a "same" response; but if physical similarity is relevant, it is unclear how overall dissimilar prime pairs (247/500) could prime a "same" response.

In sum, we do not deny a possible influence of physical similarity, but from this, we can conclude that the observed congruency effects can not be entirely guided by it. More information, i.e. the abstract identity of the letters, is needed to respond correctly.

4.3. Prime awareness

None of the participants reported having seen anything else than hash marks. None was aware of the presentation of letters during the experiment. In contrast to the previous experiments, this time prime visibility (d') measures were very low and not different from 0 (0.06; $t(15) = .99$, $p = .34$; 51% correct responses). Regression analyses showed a significant intercept at zero prime visibility (7.65 ms, $t(14) = 3.10$, $p < .01$). Again certainty ratings were very low (1.92 on average).

5. General discussion

Overall, the findings are consistent with much of the research that demonstrates the influence of unconscious processes on human behavior (see Kouider and Dehaene (2007) for a recent review). However, contrary to what is generally agreed on, the present study provides clear evidence that unconscious processing can go beyond activating memory representations and the associated responses in memory. Our demonstration that a task can be performed on stimuli outside the consciously prepared task set challenges the view that unconscious processing is limited to existing memory traces or to stimuli that are consciously prepared.

According to the Action Trigger Account proposed by Kunde et al. (2003) action triggers that are created during the experiment or during the presentation of the instructions are responsible for subliminal priming. Following this line of reasoning, it could be argued that participants prepared action triggers in a very broad way when they were told they had to perform same–different judgments; action triggers for stimuli outside the task set could have also been prepared. In our experiments this would mean that participants would prepare action triggers for numerical stimuli when they were told to judge colors

Table 2
Differential mean RTs for same/different primes and same/different targets for Experiments 2, and 3. *p*-Values were obtained from simple paired *t*-tests.

Experiment	*Prime*					
	Same			Different		
	Target					
	Same	Different	Difference (*p*-value)	Same	Different	Difference (*p*-value)
2	458	464	.45	471	459	.07
3	478	487	.14	490	487	.61

(Experiment 1), or that participants who were told to compare numbers would also prepare action triggers for letters (Experiments 2 and 3). If this would be the case, we would have to make the implausible assumption that participants prepared action triggers for all possible non-symbolic or symbolic stimuli. Ultimately, this would imply the preparation of an extremely large number of action triggers. Another option would be that these action triggers already existed in memory. Indeed, we do not deny that participants have prior experience with judging numbers or letters as same or different. We do, however, question the existence of solid memory traces for every particular instance of a same/different judgment. It could be that single numbers have strong associations to their attributes (e.g., number '2' with 'even' and 'small'), but we find it highly unlikely that each pair of (different) numbers or each pair of (different) letters has a strong association to the response 'different'. Another possibility would be that participants were able to see the primes on some occasions and constructed S–R links in the course of the experiment. Our results, however, show that this is very unlikely. First, objective and subjective prime awareness tests demonstrated that none of the participants was aware of the primes. Second, analysis of the time course of the congruency priming effect showed that the effect did not differ between blocks, suggesting that the effect was present from the start of the experiment and did not change. A different view would be that generalization of task execution occurred across symbolic and non-symbolic categories (Experiment 1), and across different levels of abstraction (Experiments 2 and 3). Indeed, this study demonstrates for the first time that subliminal priming can be obtained when prime and target stimuli are from completely distinct categories. Although previous studies have used different category sets for primes and targets (different sets of Arabic digits, Naccache & Dehaene, 2001, or different formats (verbal/Arabic numbers, Kunde et al., 2003; Van Opstal, Reynvoet, & Verguts, 2005a; pictures and words with the same semantic content, Dell'Acqua & Grainger, 1999), a priming effect across completely unrelated stimulus categories has not previously been demonstrated.

Furthermore, to our knowledge this is the first demonstration that more than one prime can be processed at the same time without awareness. Previous research on unconscious processing only used a single prime (e.g., one word, one Arabic digit, one face). Because two primes are presented simultaneously, and because the response can only be acquired by comparing these primes on a trial by trial basis, this provides strong evidence against the view that unconscious priming is limited to activating single stimulus–response associations.

We found no priming for the long SOA condition. In retrospect, this is not so surprising for two reasons. First, given the fast decay rate of the iconic memory buffer (Sperling, 1960), waiting (approximately) 300 ms for the target after the prime has disappeared could have been sufficient to wipe out much of the prime information, in which case it could no longer be processed when the task is performed on the target stimuli. Second, rather than just increasing the SOA, the masking conditions were also changed in the long SOA condition. The postmask in the SOA = 316 ms condition not only consisted of a hash mask, but also of a blank white screen that could function as an extra mask or even clear iconic memory (Sligte, Scholte, & Lamme, 2008).

The results of this study are at odds with previous research that limited the possibilities of subliminal processing. One possible explanation for this difference could be the use of different masking parameters between the studies. As we have shown in a previous discussion (Kunde, Kiesel, & Hoffmann, 2005; Kunde et al., 2003; Van Opstal et al., 2005a; Van Opstal, Reynvoet, & Verguts, 2005b) the use of different masks can obscure possible priming effects. The masks used in the present study (hash masks) were shown to be very good masks in the sense that they sufficiently mask the primes to make them invisible for the participants but do not completely disrupt the prime information.

In conclusion, the results from this study demonstrate that subliminal processing is not restricted to stimuli from the same task set that is consciously prepared (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Kunde et al., 2003), and that subliminal priming is not limited to the execution of existing stimulus–response links (Kunde et al., 2003). In contrast, our results suggest that algorithms can be computed without awareness. Indeed, they support the view that many mental computations can be performed outside the scope of consciousness (Jackendoff, 1987; Koch, 2004), and could add to the debate of the function of consciousness (Crick & Koch, 1998; Dehaene, 2008; Lau, 2009).

Acknowledgments

F.V.O. is a Postdoctoral Fellow of the Research Foundation–Flanders (FWO-Vlaanderen). The support of the ESRC Research Center for Economic Learning and Human Evolution is gratefully acknowledged. The authors would like to thank Leslie Renous for collecting the data of the third experiment.

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