

THE POWER OF UNCONSCIOUS SEMANTIC PROCESSING: THE EFFECT OF SEMANTIC RELATEDNESS BETWEEN PRIME AND TARGET ON SUBLIMINAL PRIMING

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Recent studies have shown that subliminal priming effects can be of a semantic nature. However, the question remains how strong this kind of priming will prove to be. In the present study we investigated whether truly semantic unconscious priming only occurs for prime-target pairs that are strongly semantically related (e.g., cat-DOG) or whether priming effects can also be observed for pairs that are less semantically related (e.g., ant-DOG). A typical masked priming paradigm, with word primes and picture targets, was used and the relatedness between prime and target was manipulated. The results showed that prime-target relatedness significantly moderated the effects. A priming effect was only found for the strongly related prime-target pairs. This indicates that semantic subliminal priming requires a sufficient amount of semantic relatedness between prime and target, rendering it as sensitive to this semantic factor as supraliminal priming.

Key words: masked priming, semantic priming, semantic relatedness

Introduction

A masked or subliminal prime can enhance the categorization of a subsequent target when prime and target evoke the same response and disturb the categorization when they do not (see for example Dehaene et al., 1998; see Van den Bussche, Van den Noortgate & Reynvoet, 2009b for a meta-analysis on masked priming effects). It has often been assumed that these subliminal priming effects are caused by a non-semantic process, where links are created

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automatically between stimuli and their adequate responses (i.e., S-R links). According to Damian (2001) a direct S-R link can be formed for masked primes to which participants have to overtly respond during the task. These direct S-R mappings can lead to the emergence of priming effects. However, this S-R account predicts that for masked primes never requiring a response, the formation of S-R mappings cannot be established and no priming effects are expected. According to Kunde, Kiesel and Hoffmann (2003), participants will prepare action triggers for the stimuli they might receive in the experiment during the task instructions. These action triggers create automatic associations between all expected stimuli and their appropriate responses. Kunde et al. (2003) showed that priming effects are indeed observed for the prepared set of stimuli. However, when the primes fell outside the expected stimulus range or when they were presented in an unexpected format, no priming was observed. Thus, this action-trigger account predicts that participants will only be able to form action triggers for expected stimuli. If the (expected) format of the targets differs from the (not expected) format of the primes, no action triggers will be formed for these primes and consequently they will be unable to elicit priming.

Based on these two non-semantic accounts, we can hypothesize that S-R links should only be formed for stimuli that a participant overtly receives (Damian, 2001) or expects to receive (Kunde et al., 2003) during a task. This would imply that, if unconscious stimuli can only be processed non-semanticly, subliminal priming should not be observed when the primes are not expected by the participants, since no S-R links will be formed for them which eliminates their possibility to influence the target categorization.

However, at least two studies have shown that even when unconscious primes are completely unexpected, by presenting them in a different format as the targets, subliminal priming can still be observed. Both Dell'Acqua and Grainger (1999) and Van den Bussche, Notebaert and Reynvoet (2009a) asked participants to categorize target words which were preceded by subliminal picture primes. These studies reported significant priming effects, even though the primes were presented in an unexpected format which prohibited the formation of automatic S-R links. Thus, these effects could only be explained by a semantic analysis of the primes, indicating that unconscious information can also be processed up to a high semantic level, as is the case for conscious information.

Now that the evidence in favour of truly semantic unconscious processing (i.e., when eliminating all possible S-R effects) is accumulating, we can investigate its power. What has not yet been studied hitherto is what the possibilities of this unconscious semantic processing are. Will a semantic analysis of subliminal primes always have the potential to cause noticeable priming effects (once possible S-R effects have been eliminated) or does this depend

on moderating factors? The present experiment aimed to shed a first light on this issue. Our goal was to study whether the semantic relatedness between prime and target moderates unconscious semantic processing. More specifically, we wondered whether subliminal priming only occurs for prime-target pairs that are very closely semantically related (e.g., cat-DOG) or whether priming effects also emerge for pairs that are less semantically related (e.g., ant-DOG). Within the unmasked priming domain, this issue has already received some attention. A study from McRae and Boisvert (1998) showed that the magnitude of the obtained unmasked priming effect was dependent on the degree of semantic similarity between prime and target. In one of their experiments, a target (e.g., jar) was paired with both a highly similar (e.g., bottle) and a less similar prime (e.g., plate). They found significant priming for the highly similar primes, while priming for the less similar primes was only significant when the Stimulus-Onset Asynchrony (SOA) was rather long. Likewise, Abad, Noguera and Ortells (2003) only observed priming effects when the categorically related prime-target combinations were also highly associated (e.g., tiger-lion). No such priming effect was obtained when prime and target were only weakly associated (e.g., lion-cow). In other words, stemming from the same semantic category as the target was not sufficient for a prime to elicit priming. These results in the field of unmasked priming suggest that prime-target semantic relatedness may be a potential moderator of masked priming effects as well.

In order to investigate this, we first of all needed to eliminate the influence of S-R effects. As in the studies of Dell'Acqua and Grainger (1999) and Van den Bussche et al. (2009a) we used a typical masked priming paradigm where primes and targets were presented in different modalities. However, contrary to these previous studies where primes were presented as pictures and targets as words, we now used the reversed approach and presented primes as words and targets as pictures. It has been argued that pictures and words are processed in a different way. For example, Smith and Magee (1980) suggested that for words, information about pronunciation is more readily available than semantic information, whereas for pictures, accessing the verbal name code occurs relatively late compared to access of meaning. It might therefore be worthwhile to check whether switching the prime and target modalities has an impact on the observed priming effects. Furthermore, the relatedness between prime and target was manipulated. For each target, a strongly related, a weakly related and two unrelated primes were selected. Based on the unmasked priming results we hypothesized that this factor would moderate semantic subliminal priming effects and stronger priming should emerge for strongly related prime-target pairs. If primes are truly semantically processed, it is indeed likely that there is a potential effect of semantic factors such as the degree of semantic relatedness between prime and target. However, if

unconscious processing is less sensitive to manipulations at the semantic level than conscious processing, then this manipulation will have no influence and a similar priming effect will be observed, regardless of the relatedness between prime and target.

Experiment 1: Masked Condition

Method

Participants. Twenty-three psychology students participated as partial fulfilment of a course requirement. All of them were Dutch native speakers. None of the participants made more than 20% errors, but one participant was omitted because she was substantially (+2.5SD) slower. The final sample consisted of twenty-two participants. Twenty of them were female and the mean age was 19.4 years ($SD = 1.8$, range = 18-25 years).

Procedure. Figure 1 depicts the sequence of a trial. First, a forward mask (#####) was shown for 480ms, followed by a word prime presented for 27ms. These primes, ranging from 1.3cm to 3.2cm in width and 0.7cm in height, were presented as black lowercase letters on a white background. The prime was followed by a backward mask (#####) for 13ms. Finally, a picture target was presented until the participants' response was registered. The dimensions of the picture targets ranged from 2cm to 5.5cm in width and 2cm to 5.5cm in height. The inter-trial interval was 1000ms. All presentations were synchronized with the vertical refresh cycle of the screen (13.3ms). Participants were told that they would see pictures, which needed to be classified as animals or objects by pressing one of two buttons. Response assignment was varied across participants. Participants were instructed to respond as quickly as possible and to avoid mistakes.

Stimuli. The picture targets consisted of line drawings of four objects and four animals taken from the greyscale shaded images set of the "Snodgrass and Vanderwart-like" objects^[1] (Rossion & Pourtois, 2004). Word primes were selected based on their relatedness to the picture targets. The relatedness between the primes and targets was based on the empirically derived semantic feature norms collected by McRae, Cree, Seidenberg and McNorgan (2005)^[2]. They asked 725 participants to list the features of 541 living (e.g., dog) and nonliving (e.g., chair) basic-level concepts. A total of 2526 features was extracted. To calculate the similarities between the 541 concepts, a 541-

1. See <http://titan.cog.brown.edu:8080/TarrLab/stimuli/objects/svlo.zip/view>

2. See <http://www.psychonomic.org/archive>

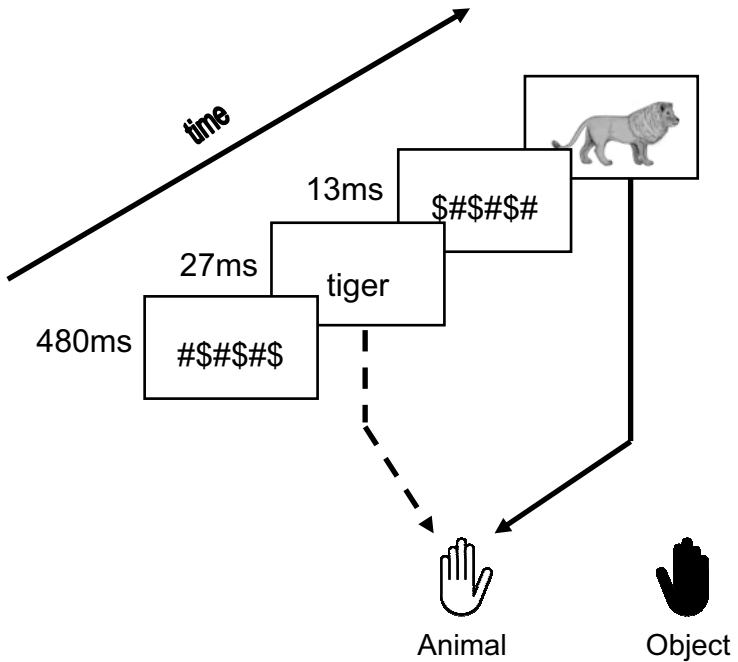


Figure 1
Example of a strongly related trial

by-541 matrix of cosines between concept pairs was constructed. In order to compute this matrix, the authors used the full matrix with 541 rows (one for each concept) and 2526 columns (one for each feature) and calculated the cosine between each pair of concepts. The cosine is calculated as the dot product between two concept vectors, divided by the product of their lengths. The resulting 541-by-541 matrix contains these cosines, with the main diagonal equal to 1.0 (the cosine between a concept and itself) and the remaining cosines ranging from -1 (opposite concepts) to 1 (identical concepts), with 0 indicating independent concepts. Based on this relatedness matrix, we selected four Dutch word primes for each of our picture targets. Two of these primes were congruent (i.e., prime and target belonged to the same semantic category): one congruent prime which was strongly related (cosine > .30) to the target (e.g., cat-dog), one congruent prime which was weakly related (.05 < cosine < 0.12) to the target (e.g., bull-dog); the other two primes were incongruent (i.e., prime and target belonged to different semantic categories) and unrelated (cosine = 0) to the target (e.g., bottle-dog and door-dog). All primes consisted of three to five letters. Log frequencies for the primes were calculated using the WordGen program of Duyck, Desmet, Verbeke and

Brysbaert (2004). All primes were medium to high frequency words (log frequencies ranging from 0.60 to 2.59) and frequencies did not differ between the strongly related, the weakly related and the two unrelated conditions (mean log frequencies respectively 1.32, 1.53, 1.28, 1.54; $F(3,28) = 0.37$, $p = .78$). In total, this led to 32 trials (8 targets x 4 primes) which were presented three times, leading to a total of 96 randomly presented trials in the experiment. In Appendix an overview of all prime-target combinations and the relatedness indices for each related prime-target pair can be found.

Prime visibility. Prime visibility was assessed using an objective visibility test. After the experiment, participants were informed about the presence of the primes and were asked to participate in a post-test. They received the same trials, which led to a total of 96 trials. Participants were instructed to apply the same instructions as before, but now to the word primes instead of to the picture targets. If they were unable to categorize the primes, they were forced to guess.

Results

RT and error analyses. Median RTs from correct responses and mean error rates were submitted to a repeated measures analysis with relatedness (strong, weak or unrelated) as within-subject factor. Inaccurate responses (on average 3.8%) were discarded from the RT analyses. The main effect of relatedness was significant ($F(2,20) = 3.62$, $p = .045$). The mean median RT for strongly related trials was 429ms ($SD = 40.0$); the mean median RT for weakly related trials was 438ms ($SD = 43.1$); the mean median RT for unrelated trials was 440ms ($SD = 46.0$). Simple contrasts indicated that the RTs for unrelated trials differed significantly from the RTs for strongly related trials ($F(1,21) = 6.91$, $p = .016$), but not from the RTs for weakly related trials ($F(1,21) = 0.12$, $p = .74$). The RTs for weakly related trials also did not significantly differ from the RTs for strongly related trials ($F(1,21) = 3.11$, $p = .092$), although a trend was visible. The same repeated measures analysis performed on error rates revealed no significant effects.

Prime visibility. Analyses of the post-test revealed that participants, on average, could only classify 52% of the primes correctly. The visibility of the strongly related primes did not significantly differ from the visibility of the weakly related primes ($t(21) = 1.33$, $p = .20$). A direct measure of prime visibility (d') was calculated for each participant. The measures are obtained by treating one level of the response category (i.e., animal) as signal and the other level (i.e., object) as noise. The overall mean d' value was 0.08. A t -test against the null mean indicated that this d' value was not significantly differ-

ent from 0 ($t(21) = 1.04, p = .31$), indicating that the unconscious nature of the primes was guaranteed.

Experiment 2: Unmasked Condition

In order to rule out that the semantic relatedness between primes and targets in our weakly related condition was in fact no different from the unrelated condition, which could explain the absence of a priming effect for the weakly related primes, we conducted the experiment again. In this second experiment, however, the primes were presented for a longer duration and were not masked, making them clearly visible. If the semantic relatedness in the weakly related condition is stronger than in the unrelated condition, then the weakly related primes should be able to elicit semantic priming under these circumstances.

Method

Participants. Sixteen psychology students participated as partial fulfilment of a course requirement. All of them were Dutch native speakers. None of the participants were omitted since none of them made more than 20% errors or were substantially ($+2.5SD$) slower. Fifteen of them were female and the mean age was 18.6 years ($SD = 0.7$, range = 18-20 years).

Procedure, stimuli and prime visibility. The procedure, stimuli and the assessment of prime visibility were identical to experiment 1, except that the prime was shown for 107ms and no backward mask was presented (based on Van den Bussche, Hughes, Van Humbeeck & Reynvoet, 2010).

Results

RT and error analyses. Median RTs from correct responses and mean error rates were submitted to a repeated measures analysis with relatedness (strong, weak or unrelated) as within-subject factor. Inaccurate responses (on average 4.0%) were discarded from the RT analyses. The main effect of relatedness was significant ($F(2,14) = 4.65, p = .028$). The mean median RT for strongly related trials was 513ms ($SD = 71.9$); the mean median RT for weakly related trials was 528ms ($SD = 93.4$); the mean median RT for unrelated trials was 542ms ($SD = 99.6$). Simple contrasts indicated that the RTs for unrelated trials differed significantly from the RTs for strongly related trials ($F(1,15) = 5.50, p = .033$), and from the RTs for weakly related trials ($F(1,15) = 7.30, p = .016$). The RTs for weakly related trials did not significantly differ from the RTs for strongly related trials ($F(1,15) = 1.76, p = .20$), although a magnitude difference of 15ms was observed between the two conditions. The same

repeated measures analysis performed on error rates revealed no significant effects.

Prime visibility. Analyses of the post-test revealed that participants, on average, could classify 94% of the primes correctly. The visibility of the strongly related primes did not significantly differ from the visibility of the weakly related primes ($t(15) = -0.20, p = .84$).

Discussion

It is becoming increasingly more clear that subliminal priming effects can be of a semantic nature (e.g., Van den Bussche et al., 2009a). It has already been suggested that unconscious processing involves a series of stages, similar to those involved in conscious processing, which include a semantic process (Dehaene et al., 1998). It remains to be studied whether the semantic processing of unconscious information can be as flexible and sensitive as conscious processing. Previous research using the unmasked priming paradigm has shown that the semantic relatedness between prime and target moderates the amount of priming observed. The aim of the present study was to unravel whether this factor also played a significant role in a masked priming context.

The results were straightforward: the semantic relatedness between prime and target significantly moderated the participants' reaction times. Participants responded significantly faster to strongly related prime-target pairs compared to unrelated pairs, leading to a significant priming effect in this condition. Weakly related prime-target pairs were not responded to faster than unrelated pairs and thus no priming effect was observed for these pairs. Although not significant, a trend indicated that participants also responded faster to strongly related pairs compared to weakly related pairs. This implies that belonging to the same semantic category as the target is not always sufficient. In both the strongly and the weakly related pairs primes and targets belonged to the same category. Still, only in the strongly related condition priming was observed. Thus, masked semantic priming seems to depend on the strength of the relatedness between the prime and the target. Our second experiment, where the primes were presented clearly visible, excluded the possibility that these results were caused by the fact that the semantic relatedness between primes and targets was similar in the weakly related condition and the unrelated condition. In an unmasked context, the weakly related primes were able to elicit significant priming.

Both the S-R account (Damian, 2001) and the action-trigger account (Kunde et al., 2003) fail to explain the priming effects we observed. Crucially, the modality of the primes and targets differed in our experiment: primes were presented as words and targets as pictures. This ensured that pos-

sible S-R effects were eliminated and therefore could not attribute to the observed effects (see also Van den Bussche et al., 2009a). Consequently, the observed priming effect could solely stem from a semantic analysis of the primes. Furthermore, as semantic relatedness is a factor that clearly could only exert an influence when the processing of the primes occurs semantically, this again provides us with strong evidence for the fact that subliminal information can be genuinely semantically processed.

However, this semantic processing also seems to have its limits. Dehaene et al. (1998) suggested that masked priming effects are caused by the fact that participants will also unconsciously apply the task instructions to the masked primes: participants will respond faster to congruent trials where prime and target trigger the same response than to incongruent trials where they trigger different responses. However, if this would be the case, then this priming effect should be observed regardless of the strength of the prime-target relatedness. Indeed, regardless of whether the target "dog" is followed by the prime "cat" (strongly related) or the prime "bull" (weakly related), in both cases prime and target elicit the same response which should speed up responses. Still, our results indicate that congruency alone is not sufficient for a masked prime to elicit priming. Higher order factors, such as prime-target relatedness, seem to moderate whether a priming effect will occur.

We also note that reversing the modalities of the primes and targets did not seem to influence the possibility to observe significant priming effects: priming has been reported when primes were presented as pictures and targets as words (Dell'Acqua & Grainger, 1999; Van den Bussche et al., 2009a) and when primes were presented as words and targets as pictures (the present study).

Semantic relatedness proved to be a significant moderator of masked priming (see the present study) and unmasked priming (Abad et al., 2003; McRae & Boisvert, 1998; and a hint of an effect in the present study). The fact that semantic relatedness is able to moderate priming effects in both masked and unmasked conditions, suggests that both semantic subliminal and supraliminal priming require a sufficient amount of semantic relatedness between prime and target. This seems to indicate that unconscious processing is as susceptible and sensitive to the influence of certain semantic factors as conscious processing and that it operates in a similar way. Recently, such findings indicating that unconscious processing can reach sophisticated cognitive levels has led researchers to question whether unconscious processing has limits and whether consciousness has a special function at all (Dehaene, 2008; Lau, in press).

The present study also has implications for future research. The potential influence of the semantic relation between prime and target has been largely overlooked in the masked priming literature. This might also imply that the

failure of certain studies to obtain semantic subliminal priming effects was not due to the fact that subliminal primes cannot be semantically processed, but rather that primes and targets were presumably not sufficiently semantically similar to produce significant priming effects. For example, Abrams (2008) observed no priming when excluding S-R effects and eliminating orthographic overlap (e.g., cat-cow) between primes and targets. This led him to conclude that truly semantic unconscious priming is an unreliable phenomenon. However, when taking into account the degree of semantic relatedness between the primes and targets in Abrams' stimulus set, it becomes clear that this factor might have obscured the results. Based on the 28 prime-target pairs for which the semantic relatedness could be computed using the semantic feature norms of McRae et al. (2005) (ambiguous stimuli such as "tick" and "fly" are not represented in the matrix), the average cosine in Abrams' low-overlap condition was 0.21. Only six of these pairs had a cosine above .30, which we defined as "strongly related" in the present study and eight pairs had a cosine lower than .12 which we defined as "weakly related". Although speculative, this stimulus set where primes and targets were not very strongly semantically related, might have alternatively caused the lack of a priming effect. In any case, based on the present results, it becomes clear that it is important to carefully manipulate semantic relatedness in terms of shared common features in order to be able to observe semantic priming effects.

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Appendix

Primes (and their English translations) and targets and the prime-target relatedness for the related prime-target pairs

Table 1

Picture targets		Word primes			
		Strong	Weak	Unrelated	
Animal	dog	kat (cat) 0,602	stier (bull) 0,118	fles (bottle)	deur (door)
	ant	vlo (flea) 0,475	paard (horse) 0,056	tang (pliers)	lamp (lamp)
	duck	gans (goose) 0,626	muis (mouse) 0,057	boog (bow)	glas (glass)
	lion	tijger (tiger) 0,607	haan (rooster) 0,115	brief (letter)	boek (book)
Object	chair	tafel (table) 0,425	mand (basket) 0,088	slak (snail)	zwaan (swan)
	fork	lepel (spoon) 0,546	kraan (faucet) 0,089	geit (goat)	rund (ox)
	axe	hamer (hammer) 0,329	steen (rock) 0,060	spin (spider)	pauw (peacock)
	piano	viool (violin) 0,445	boot (boat) 0,082	hert (deer)	ezel (donkey)

Note. Strong = prime strongly related to target; Weak = prime weakly related to target; Unrelated = prime unrelated to target; All strongly and weakly related primes were congruent primes, whereas all unrelated primes were incongruent primes. The relatedness between the targets and the unrelated primes was always 0.

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