



# The semantic origin of unconscious priming: Behavioral and event-related potential evidence during category congruency priming from strongly and weakly related masked words



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## ABSTRACT

The mechanisms underlying masked congruency priming, semantic mechanisms such as semantic activation or non-semantic mechanisms, for example response activation, remain a matter of debate. In order to decide between these alternatives, reaction times (RTs) and event-related potentials (ERPs) were recorded in the present study, while participants performed a semantic categorization task on visible word targets that were preceded either 167 ms (Experiment 1) or 34 ms before (Experiment 2) by briefly presented (33 ms) novel (unpracticed) masked prime words. The primes and targets belonged to different categories (unrelated), or they were either strongly or weakly semantically related category co-exemplars. Behavioral (RT) and electrophysiological masked congruency priming effects were significantly greater for strongly related pairs than for weakly related pairs, indicating a semantic origin of effects. Priming in the latter condition was not statistically reliable. Furthermore, priming effects modulated the N400 event-related potential (ERP) component, an electrophysiological index of semantic processing, but not ERPs in the time range of the N200 component, associated with response conflict and visuo-motor response priming. The present results demonstrate that masked congruency priming from novel prime words also depends on semantic processing of the primes and is not exclusively driven by non-semantic mechanisms such as response activation.

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## 1. Introduction

Masked congruency priming has become a well-established method to investigate the impact of unconsciously processed words on overt decisions and responses (e.g., Dehaene et al., 1998; Greenwald, Klinger, & Schuh, 1995; Kiefer, 2002; Klauer, Eder, Greenwald, & Abrams, 2007; for reviews, see Kouider & Dehaene, 2007; Van den Bussche, Van den Noortgate, & Reynvoet, 2009). In this paradigm, participants are asked to categorize visible targets words (for example, referring to an animal vs. a body part) that are preceded by briefly flashed, visually masked primes whose category (and/or response) is either congruent or incongruent with the target. The masks, typically visual patterns (e.g. random letter strings) presented before and/or after the prime word, prevent its conscious identification (e.g., Breitmeyer & Ögmen, 2006). A

congruency priming effect occurs when target categorization on congruent trials (e.g., lion-dog) is faster and/or more accurate than on incongruent trials (hand-dog). Such priming has been described as unconscious in nature when subjects are phenomenally unaware of the masked primes and/or they cannot identify them in a separate test of prime visibility. Evidence for reproducible unconscious congruency priming has been accumulated across a variety of categorization tasks, such as positive vs. negative valence judgments (De Houwer, Hermans, Rothermund, & Wentura, 2002; Kiefer, Sim, & Wentura, 2015; Klauer et al., 2007; Naccache et al., 2005), number classification (Dehaene et al., 1998; Naccache & Dehaene, 2001a, 2001b), size discrimination (Kiesel, Kunde, Pohl, & Hoffmann, 2006), gender classification (Greenwald & Abrams, 2002; Klauer et al., 2007), and category classification (Forster, Mohan, & Hector, 2003; Ortells, Daza, & Fox, 2003; Ortells, Frings, & Plaza-Ayllón, 2012; Ortells, Vellido, Daza, & Noguera, 2006; Van den Bussche & Reynvoet, 2007).

Recently, however, the mechanisms underlying unconscious congruency priming from words have attracted considerable

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interest and debate (Kang, Blake, & Woodman, 2011; Kouider & Dehaene, 2007; Van den Bussche et al., 2009). One of the most straightforward ways to explain masked priming effects is that they reflect unconscious access to the meaning of the prime and automatic preactivation of the semantic target representation (e.g., Kiefer, 2002; Kiefer & Martens, 2010; Masson, 1995; Naccache et al., 2005). In addition to semantic preactivation, congruency priming might be based on the implicit application of task-control representations ('task sets') (Ansorge, Kunde, & Kiefer, 2014; Kiefer et al., 2015; Klauer et al., 2007; Neumann, 1990) to the prime, whether consciously presented or subliminally, although it is not required by the task. According to this view, participants establish a task set on the grounds of the experimental instruction (e.g., "press left key in response to an animal, press right key in response to a body part"). If the prime matches this prepared task set, the task set is executed and the corresponding response is activated. Similar to the semantic activation account, the task set execution account of subliminal priming predicts priming also for unfamiliar, novel primes, which are not presented as targets. Unfamiliar primes can lead to task set execution, as long as they are sufficiently similar to the information specified in the task set. This includes at least a coarse semantic analysis of the prime stimulus, e.g. with regard to its category, in order to determine whether it is suited to execute the task set (Kiefer et al., 2015). Furthermore, the task set execution account of subliminal priming opens the room for attentional influences such as stimulus expectations or task sets, which determine whether an unfamiliar prime is able to elicit priming effects (Kiefer, Adams, & Zovko, 2012; Kiefer & Martens, 2010; Kiefer et al., 2015).

In contrast to these semantic accounts of priming, several findings have indicated that masked congruency priming effects could be caused rather by non-semantic processes such as direct stimulus-response associations (e.g., Klinger, Burton, & Pitts, 2000; see also De Houwer et al., 2002). Such non-semantic accounts, which have dominated research on category congruency priming for the last decade, are supported by several lines of evidence (for a discussion see Van den Bussche et al., 2009): On the one hand, many prior demonstrations of unconscious congruency priming have used a reduced stimulus-set with the undesirable consequence that the critical masked primes reappear as classified visible (conscious) targets in different trials (e.g., Dehaene et al., 1998; Draine & Greenwald, 1998; Greenwald, Draine, & Abrams, 1996). This repetition of items may allow the primes to be partially identified. Identification of isolated prime features (e.g., word fragments of one or more letters), could then aid the retrieval of its identity without accessing semantic information. Furthermore, the unconscious primes may activate the stimulus-response (S-R) links that were mapped and practiced with the conscious target stimuli (e.g., Damian, 2001; Neumann & Klotz, 1994), or even activate the practiced links between targets and a more abstract response-related representation, such as its response category (e.g., Abrams, Klinger, & Greenwald, 2002), curtailing the need for semantic processing of unconscious primes.

Another non-semantic account of unconscious congruency priming has been developed by Kunde, Kiesel, and Hoffmann (2003). These authors assume that following task instructions, participants intentionally prepare *action triggers* for the stimuli they expect to receive during the experiment. These action triggers create automatic associations between all expected stimuli and their appropriate responses. When a prime stimulus is included in the prepared action trigger set, it can automatically trigger the adequate response and evoke priming without the need of undergoing semantic processing. Note that action triggers would be more readily applied when a small stimulus set and/or category (e.g., months; farm animals) is used. However, albeit that such a mechanism is reliant on the sustained expectancy of a number of

individual instances, it seems unlikely (as acknowledged by Kunde et al., 2003) that subjects are able to form action triggers for all possible members of *large* task categories that usually include many perceptually dissimilar members (e.g., positive vs. negative words; animals vs. non-animals).

To decide between semantic and non-semantic interpretations, it should be considered whether subliminal stimuli that are never presented as targets (i.e., novel or unpracticed primes) induce reliable congruency priming. If unpracticed primes remain ineffective despite their fit to the current task instructions, congruency priming would be restricted to acquired S-R mappings. By using *pictures* as prime stimuli, several prior studies (e.g., Dell'Acqua & Grainger, 1999; Van den Bussche et al., 2009; see also Pohl, Kiesel, Kunde, & Hoffmann, 2010) have reported reliable semantic congruity effects from subliminal primes that were part of a large stimulus set and never appeared as targets during the experiment. These findings provide a clear-cut demonstration of unconscious congruency priming at the semantic level, as they cannot be explained in terms of prime-target orthographic overlap, action triggers or stimulus-response mappings. But as suggested by Kouider and Dehaene (2007; see also Kang et al., 2011), it remains possible that picture stimuli could have a more direct access to meaning representations, thus leading to stronger semantic effects under subliminal conditions as opposed to word stimuli.

Nevertheless, when prime stimuli consist of symbolic carriers instead, such as words, the evidence of unconscious congruency priming with novel primes has been elusive thus far. An exception is the single category of number words, for which a convincing set of reports demonstrated unconscious semantic processing, including generalization to novel primes. For example, by using a number comparison task in which participants had to decide whether a visible target number (preceded by another invisible prime number) was larger or smaller than 5, Naccache and Dehaene (2001a) showed reliable response priming effects (i.e., faster responses when prime and target fell on the same side of 5 -congruent- than when they did not -incongruent trials-) even for *novel* prime stimuli that were never seen consciously, and for which no stimulus-response learning could conceivably occur. They also found an effect of semantic distance between prime and target, such that responses on congruent trials were gradually faster as the numerical distance between prime and target was smaller. In another study by Naccache and Dehaene (2001b), it was shown that subliminal number primes modulated fMRI activation in parietal areas known to be involved in semantic quantity processing, thus providing an even stronger empirical basis for unconscious semantic processing of numbers. It has been argued, however, that nonconscious access to quantity, the main semantic attribute of numbers, could be the single exception to a general principle stating that semantic representations are necessarily conscious (cf. Naccache et al., 2005, pp. 7713).

In clear contrast to the findings with number words, when unpracticed *nonnumeric words from large categories* are used as prime stimuli, unconscious congruency effects have often been weak and difficult to replicate (Abrams, 2008; Kiefer et al., 2015), with the observed priming effects being highly sensitive to minor procedural differences (e.g., target frequency, prime-target orthographic overlap, test power, type of masking or prime duration). Contradictory results have even been reported under very similar task demands and stimulus presentation conditions (see, for example, the opposite pattern of results reported by Forster et al., 2003, and Van den Bussche & Reynvoet, 2007, both using animal targets).

A difference between masked congruency priming and the more conventional semantic priming paradigm within lexical decision or naming tasks (e.g., Neely, 1991), which could be relevant here, concerns semantic similarity or association strength between prime and target words. *Semantic similarity* (e.g., McRae & Boisvert,

1998) reflects the similarity in meaning or the overlap in feature descriptions of two words (e.g., *whale-dolphin*). *Association strength* is a normative description of the probability that one word will call to mind a second word (e.g., Postman & Keppel, 1970). Although the degree of semantic similarity and associative strength between two words do not necessarily covary together, highly associated items tend to share more or stronger semantic relations than weakly associated members (e.g., Hutchison, 2003; Hutchison, Balota, Cortese, & Watson, 2008; McNamara, 2005; but see Coane & Balota, 2011). Accordingly, the term *semantic relatedness* has frequently been used in a wide sense to refer to category co-exemplars that are both strongly associated and highly similar in semantic overlap.

This is the case in a standard semantic priming procedure, in which the semantically related trials usually consist of strongly associated and semantically similar word pairs. It is well documented that highly associated words from the same semantic category that also share a large semantic feature overlap (e.g., *cat-dog*; *bread-butter*) reliably prime each other in lexical decision, naming, and categorization tasks (Hutchison et al., 2008; McNamara, 2005). But the evidence for associative priming in the absence of semantic similarity is weaker by comparison (Lucas, 2000; but see Coane & Balota, 2011). Likewise, the evidence for “pure” semantic priming (i.e., defined only in terms of category co-membership) in the absence of associative relation is also weak (e.g., Abad, Noguera, & Ortells, 2003; Hutchison, 2003), and it is likely to mainly reflect task-dependent strategic processes such as the expectation of individual category members similar to the action triggers described earlier (Kunde et al., 2003). Consequently, *automatic* semantic priming (not modulated by strategies) seems to be due to both association strength and semantic feature overlap. But the very fact of being members of the same category does not seem to be enough to observe reliable automatic priming (Hutchison, 2003; see also McRae & Boisvert, 1998). It is quite possible that for pure category priming without semantic association, semantic distance between prime and target is too large (e.g. *trout-elephant*) despite shared category membership (e.g. animal).

In clear contrast to the semantic priming literature, congruency priming is normally manipulated by selecting primes and targets that share the same category, (congruent) or those that do not (incongruent), making it irrelevant whether these pairs are more or less associatively and/or semantically related. This practice implicitly assumes that a congruency priming effect mainly results from a competition between the prime and target categories, thus reflecting category or response congruity instead of semantic priming in the classic sense of spreading activation theories (e.g., Collins & Loftus, 1975). But in a vast majority of masked congruency priming studies, the pairs presented on congruent trials consist of a random mixture of more (e.g., *eagle-hawk*) and less related items in terms of associative norms and/or semantic feature overlap (e.g., *bull-fly*; *shark-donkey*; *ape-cat*; see, e.g., Van den Bussche & Reynvoet, 2007, Appendix B, p. 235).

Presenting either more or less closely related category members on congruent trials in a congruency priming experiment might not be an issue when a *reduced stimulus set* is presented repeatedly, or even with unpracticed primes from *small* categories (e.g., months, numbers, or farm animals). Yet prime-target semantic relatedness could be *critical* when using a large set of unrepeatable prime words from broader categories (e.g., animals).

Thus it remains possible that prior congruency priming studies reporting null or inconsistent results with unpracticed prime words (i.e., not presented as targets), have used category exemplars that were not sufficiently strongly related (in terms of association strength and/or semantic similarity) to produce robust priming effects. In support of this argument, some recent studies have consistently demonstrated that stemming from the same

semantic category as the target is not sufficient for a masked prime word to elicit reliable congruency priming effects (e.g., Ortells, Marí-Beffa, & Plaza-Ayllón, 2013; Van den Bussche, Smets, Sasanguie, & Reynvoet, 2012). For example, by using a masked congruency priming task Ortells et al. (2013) found reliable priming effects from unpracticed prime words, only when they were followed by strongly related, but not by weakly related targets. These findings are difficult to explain in terms other than a semantic processing of masked words, as both strongly and weakly related pairs did not differ in terms of either prime-target orthographic overlap, response congruency (e.g., Wentura, 2000), stimulus–response mappings, or action-triggers for semantic categories (Kiesel et al., 2006). In contrast, if priming were based on response activation bypassing semantic prime processing, equal priming for strongly and weakly related pairs would be expected.

It should be noted, however, that in the experiments by Ortells et al. (2013) prime-target semantic relatedness was manipulated across different block of trials. We consider it important to replicate the findings of Ortells et al. by using a congruency priming task in which strong and weakly related pairs varied randomly from trial-to-trial within the experimental session. This was the first main goal of the present research.

A second main goal was to investigate whether semantic relatedness between prime and target words would significantly modulate not only behavioral effects (i.e., RTs) but also electrophysiological correlates (e.g., event-related potentials, ERPs) of nonconscious semantic processing. The major strength of the ERP method is the on-line analysis of brain processes during task performance with a temporal resolution in the range of milliseconds. ERPs have been applied to examine semantic processing in numerous studies.

The N400 ERP component, a negative potential deflection between 300 and 500 ms that peaks at about 400 ms after stimulus presentation at centroparietal electrode sites, has been widely used as an electrophysiological index of semantic processing at both the sentence and word level (Kutas & Hillyard, 1984; see Kutas & Federmeier, 2011 for a recent review). In semantic priming paradigms, N400 amplitude to targets is attenuated (i.e., less negative) for semantically related (congruent) prime-target combinations compared with unrelated or incongruent pairings. There is now compelling evidence that the N400 amplitude is modulated by both consciously and unconsciously perceived masked words (e.g., Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002; Kiefer & Brendel, 2006; Kiefer & Martens, 2010; Kiefer & Spitzer, 2000; Küper & Heil, 2009; Rohaut et al., 2015). Although the negative deflection often temporally overlaps with a large positive component (late-positive complex) and does not necessarily appear as a negative potential in absolute terms, this phenomenon is known as the *N400 priming effect* (Bentin, McCarthy, & Wood, 1985; Kiefer, 2005; Kiefer, Weisbrod, Kern, Maier, & Spitzer, 1998). Intracranial ERP recordings (Nobre & McCarthy, 1995) and source analyses of scalp potentials (Kiefer, Schuch, Schenck, & Fiedler, 2007) have implicated a region in the anterior-medial temporal lobe in generating the N400 ERP component.

The use of ERPs in the present experiments also allows us to investigate whether congruency priming effects could at least partly reflect response congruency (i.e., visuo-motor priming or action triggering). The processing of the response congruency relation between prime and target has been previously associated with the N200 ERP component, a negative deflection with a fronto-central distribution that peaks around 250–350 ms after stimulus presentation (e.g., Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). The amplitude of the N200 component has been found to be more negative in incongruent (or incompatible) trials compared to congruent (or compatible) trials (e.g., Clayson & Larson, 2011; Wendt & Luna-Rodríguez, 2009; see also

Panadero, Castellanos, & Tudela, 2015). Furthermore, unconscious response priming has been shown to modulate occipito-parietal ERPs in the N200 time range, consistent with the notion of a rapid activation of visuo-motor representation within the dorsal visual pathway (e.g., Jaśkowski, Skalska, & Verleger, 2003; Martens, Ansoorge, & Kiefer, 2011; Zovko & Kiefer, 2013). To the extent that unconscious congruency effects in our research would depend on response priming by-passing semantic analysis, we expected to find a similar modulation of ERPs in the time range of the N200 for both strongly related and weakly related conditions (as compared to the unrelated trials), as both conditions would be response-congruent and hence, activate the same response type. By contrast, if the N400 priming effect can be an electrophysiological reflection of automatic activation in semantic networks, we then expected larger N400 priming effects to word targets preceded by strongly semantically related masked primes than to targets preceded by weakly related masked primes.

## 2. Experiment 1

Participants were asked to perform a semantic categorization task (animal vs. body part) on visible target words that were preceded by briefly presented (33 ms) prime words about which participants were not informed. The primes were preceded by a 100 ms pattern mask and also immediately followed by another 167 ms mask, thus resulting in a prime-target stimulus onset asynchrony (SOA) of 200 ms. The prime and target words belonged to different categories on 50% of trials (incongruent or unrelated trials), they were strongly semantically related members from the same category on 25% of trials (strongly related trials), and were weakly related co-exemplars on the remaining 25% (weakly related trials). This procedure is very similar to that used by Ortells et al. (2003, Experiment 3) but with two differences: First, prime-target semantic relatedness was manipulated in a within-participant design, such that strongly related, weakly related and unrelated prime-target pairs varied randomly from trial to trial. By adopting this procedure, we tried to prevent participants from using separate strategies for processing the strongly and weakly related word pairs. Second, whereas in the study by Ortells et al. (2013) only backward masking was used to render the prime words unidentifiable, in the present experiment the prime words were both preceded and followed by pattern masks, in an attempt to make prime masking more effective and to prevent all tested participants from consciously perceiving the primes. Note on this respect that the overall discrimination scores (i.e.,  $d'$ ) for masked primes in a prime visibility test were clearly above chance performance in all the experiments by Ortells et al. (2013).

### 2.1. Method

#### 2.1.1. Participants

Twenty-six healthy, right-handed, native Spanish speakers with normal or corrected-to-normal vision participated in the experiment. Data of four participants were excluded due to excessive EEG artifacts (> 60% of artifact trials; a minimum of 50% of artifact-free trials per condition was considered necessary for inclusion into the Grand Average), leaving 22 subjects for behavioral and ERP analysis (mean age 25.6; range 18–42; 15 females). All participants signed a written consent after the nature and the consequences of the experiment had been explained. The experiment was conducted in accordance with the Declaration of Helsinki.

#### 2.1.2. Materials

Stimulus delivery and response recordings were controlled by E-prime software (Psychology Software Tools Inc; www.pstnet.com/

eprime). All stimuli were presented at the center of a cathode ray tube screen at a viewing distance of approximately 60 cm, and were displayed in white font against a black background on a computer monitor synchronous with the screen refresh rate (16.67 ms). Primes and targets words were, on average, five letters long (range 4–6) and subtended a visual angle of about 2.21° wide and 0.49° high. Random strings of seven white capital letters (e.g., MDGTKSN), subtending a visual angle of about 2.46° horizontally and 0.49° vertically, were used as forward and backward pattern-masks. Within each trial, different letter strings were used for the forward and backward masks.

The stimulus set was similar to that recently used by Ortells et al. (2013; Experiments 2–4). It consisted of 32 concrete and familiar Spanish nouns of 4–6 letters length (16 animals and 16 body-parts) selected from the intra-categorical associative norms published by Callejas, Correa, Lupiáñez, and Tudela (2003). From that 32-word set, 16 were presented only as masked primes and the remaining 16 were presented only as visible targets (a different word set was presented during practice trials).

Primes and targets from each category were matched on *familiarity* (how often participants encountered instances or thought about a given concept; 1 = very unfamiliar; 5 = very familiar); *typicality* (how representative of its category participants thought an exemplar was; 1 = least typical; 5 = most typical), *lexical frequency* derived from Internet search hits (natural logarithm; min. = 2.83; max. = 17.31), *number of letters* and *syllables* in each word according to Spanish phonological rules. A summary of these variables for words from each semantic category (which were obtained from the Spanish norms published by Moreno-Martínez, Montoro, & Rodríguez-Rojo, 2014) is presented in Appendix A. Appendix B presents summary statistics (mean and standard deviation) for all the aforementioned variables for each animal and body part word.

The 16 prime-target pairs (8 from each category) presented on strongly-semantically related trials appeared as highly associated category members (i.e., the first ranked exemplar on forward direction) in the norms of Callejas et al. The 16 weakly related word pairs were created re-pairing the strongly related prime-target pairs within each category, such that the new pairs were semantically dissimilar members of the category (e.g., DOG-cow; HAND-head) and they did not appear as associatively related co-exemplars in the norms of Callejas et al. The 32 unrelated word pairs were created re-pairing the former prime and target words in a pseudorandom way, such that the 8 prime words from each semantic category were followed by two different target words belonging to the other semantic category. To minimize orthographic overlap between prime and target stimuli, neither related (strong or weak), nor unrelated trials contained any target word that shared a first letter or a first (or last) syllable with their corresponding prime word (see Appendix C).

In the intra-categorical norms published by Callejas et al. (2003) participants received a set of words belonging to different semantic categories, being asked to generate the first word from the *same category* that came to mind after reading each of the items. Given these task instructions, it is very likely that associative strength in that study could also reflect semantic similarity in terms of feature overlap. In particular, category co-exemplars that were more strongly associated could also share a higher number of semantic features. To test this possibility and provide an additional objective dissociation between strong and weakly related items, both the related and unrelated word pairs were screened in a further similarity rating study. All the 64 prime-target pairs used in the experiment (16 strongly related and 16 weakly related co-exemplars, and 32 unrelated pairs from the different categories) were presented to a separate group of 100 participants, which rated the similarity of each prime-target pair (In terms of features in common, how similar are the things that these words refer to?) on a

7-point scale (1 = not at all similar; 7 = highly similar). As predicted, strongly related pairs from each category showed much higher similarity ratings than weakly related pairs (see Appendix C). Overall mean ratings were reliably larger [ $F(1, 14) = 354.1$ ] for strongly related pairs ( $M = 6.21$ ,  $SD = 0.28$ ) than for weakly related ones ( $M = 2.71$ ,  $SD = 0.62$ ), and also reliably larger [ $F(1, 14) = 85.9$ ] for weakly related pairs than for unrelated word pairs belonging to different categories ( $M = 1.48$ ,  $SD = 0.23$ ). Planned comparisons showed a similar pattern of differential ratings for strongly and weakly related pairs of the two semantic categories: *Animals* (strong:  $M = 6.12$ ,  $SD = 0.22$ ; weak:  $M = 2.46$ ,  $SD = 0.61$ ;  $F(1, 7) = 232.8$ ); and *body-parts* (strong:  $M = 6.30$ ,  $SD = 0.32$ ; weak:  $M = 2.96$ ,  $SD = 0.55$ ;  $F(1, 7) = 778.4$ ).

### 2.1.3. Procedure

General task instructions were displayed on the monitor and also orally delivered. The timing of the events was as follows (see Fig. 1): (1) blank screen presented for either 1600 ms or 2000 ms, with both durations varying randomly within the experiment; (2) fixation display (+), presented for 500 ms; (3) forward mask (a random string of seven consonants) presented for 100 ms; (4) prime word, in uppercase, presented for 33.5 ms; (5) backward mask (a different random string of seven consonants), presented for 166.5 ms; (6) target word, in lowercase, presented until response.

Participants were told to decide as fast and as accurately as possible the semantic category (animal vs. body part) of the target word by pressing one of two backside buttons of a gamepad with their left and right index fingers, with the mapping between categories and response keys being counterbalanced across participants. Participants were not informed of the presence of the prime word between the masks.

Participants took part in a single session (lasting about 25 min) consisting of 32 practice trials followed by 256 experimental trials divided into 4 consecutive blocks of 64 trials each. Half of the trials within each block were unrelated (incongruent) trials, in which the prime and target words belonged to different semantic categories. The remaining trials were related (congruent) trials, in which the prime and target belonged to the same semantic category. Within the latter related trial-set, the prime-target pairs were strongly semantically related category members (e.g., COW-bull; HAND-finger) on 50% of trials, whereas they were weakly related co-exemplars (e.g., COW-frog; HAND-head) on the remaining 50% of trials. Within each block of 64 trials, each prime (and target) word from each category was thus presented four times: Once on strongly-semantically related trials, once on weakly related trials, and twice on unrelated trials. Trials of the different relatedness conditions (strongly related, weakly related, unrelated) within each block were presented in a randomized order. Prime words were never presented as visible targets.

After completing the priming task, participants were questioned about subjective awareness of the prime words between the masks. This was achieved by means of a Likert-style scale ranging from 1 (prime fully unconscious on all the priming trials) to 7 (prime fully conscious on all the trials; see Ruz, Madrid, Lupiáñez, & Tudela, 2003, for a similar procedure). None of 22 participants reported subjective awareness of the primes (mean awareness rating = 1.32; range = 1–2). To obtain an objective measure of prime identification, participants performed thereafter a test on prime visibility that began with 16 practice trials followed by 128 experimental trials. Timing of events was identical to that of the priming task, with the only difference that participants were now instructed to categorize the masked prime (rather than the target). Instructions stressed accuracy over response speed. Participants were informed that the prime word could be either an animal or a body-part with an identical probability (.50). If they were unable

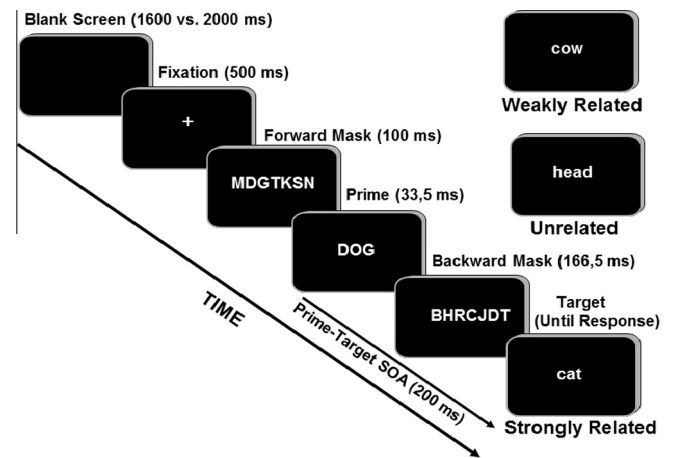


Fig. 1. Sequence of events in Experiment 1. The word stimuli shown here for related and unrelated trials have been translated from Spanish to English. Stimuli are not drawn to scale.

to categorize the prime, they were forced to make the best guess (forced choice) without time limit.

### 2.1.4. EEG recording and analysis

Participants were seated in a comfortable chair in a dimly lit, electrically shielded room. Scalp voltages were continuously recorded from 29 active electrodes mounted in a cap (actiCAP, Brain Products, Munich, Germany) arranged according to the international 10–10 system. An electrode between Fpz and Fz was connected to the ground, and an electrode between Fz and Cz was used as recording reference. Vertical eye movements were monitored with supra and infraorbital electrodes. Two additional electrodes were attached over the left and right mastoids so that the ERP data could be off-line re-referenced to averaged mastoids. All EEG electrode impedances were maintained below 5 k $\Omega$ . Brain electrical signals were digitized with a sampling rate of 250 Hz (0.1–70 Hz band-pass, 50 Hz notch filter) by an AC-coupled amplifier (Brain Amp, Brain Products, Munich, Germany), digitally band-pass filtered (high cutoff: 25 Hz, 24 dB/octave attenuation; low cutoff: .2 Hz, 12 dB/octave attenuation), and segmented from 450 ms pre-target onset (150 ms before the forward mask onset) to 800 ms posttarget onset.

The EEG was corrected for ocular/blink artifacts using independent component analysis (ICA; Makeig, Bell, Jung, Ghahremani, & Sejnowski, 1997). Remaining ocular and muscular artifacts were rejected off-line in any EEG channel (maximum amplitude in the recording epoch  $\pm 100$   $\mu$ V; maximum difference between two consecutive sampling points 50  $\mu$ V; maximum difference of two values in the epoch 200  $\mu$ V; lowest allowed activity-change 0.5  $\mu$ V in successive intervals of 100 ms) and were excluded from averaging. EEG data were corrected to a 150 ms baseline prior to the onset of the forward mask (i.e., the last 150 ms of the fixation screen). Finally, electrodes were re-referenced off-line to averaged mastoids. Artifact free EEG segments to trials with correct responses were averaged separately for the three prime-target relatedness conditions (with the mean percentage of EEG analyzable epochs per condition given in parentheses): strongly related (94.6%), weakly related (94.4%), and unrelated (94.3%). Fifteen electrodes of fronto-central and centro-parietal scalp regions, in which the N400 ERP component was usually largest (Kutas & Hillyard, 1984; see also Kiefer, 2002; Kiefer & Spitzer, 2000), were selected for statistical analyses (electrode sites: F3/F4, FC1/FC2, Fz, FCz, Cz, Pz, Oz, C3/C4, CP1/CP2, P3/P4).

Mean amplitudes in two time windows, 250–350 ms posttarget onset for the N200, and 350–500 ms posttarget onset for the N400, were computed for each of those electrodes. Repeated measures  $3 \times 3 \times 5$  ANOVAs were performed on each time window, treating Prime-Target Relatedness (strongly related, weakly related, unrelated), Laterality (left, mid, right) and Caudality (frontal, fronto-central, central, centro-parietal, parietal) as within-participant factors ( $p$  level of .05). The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom, when appropriate. In order to quantify the time-course of priming effects for strongly and weakly related prime-target pairs in more detail, mean amplitudes in ten successive 50 ms epochs starting at target onset (0 ms) and running through the end of the typical N400 window (500 ms) were also analyzed.

## 2.2. Results

### 2.2.1. Behavioral results

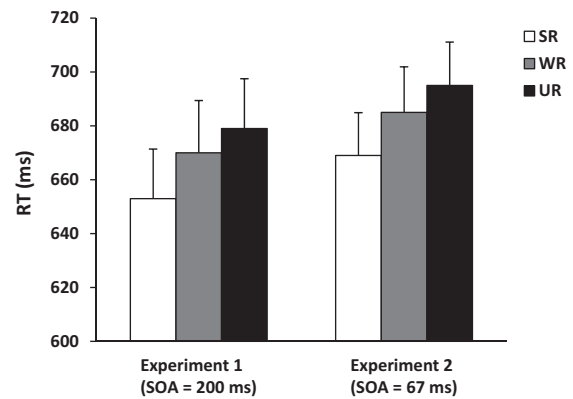
**2.2.1.1. Priming task.** Trials containing an incorrect response (2.4% of trials) or those with RTs falling more than 2.5 standard deviations from the overall mean RT (2.1% of trials) were removed from analyses. By-subject and by-item analyses of variance (ANOVAs) were performed on the trimmed data, with Trial Block (Blocks 1–4), and Prime-Target Relatedness (strongly related, weakly related, unrelated) as factors.<sup>2</sup>

The analysis on RTs revealed a significant main effect of Trial Block ( $F_s(3,63) = 7.98, p = 0.02, \eta^2 = 0.27; F_i(3,45) = 22.05, p < 0.001, \eta^2 = 0.59$ ), such that RTs were gradually faster across the block of trials (665, 633, 628, and 616 ms for Blocks 1 to 4, respectively). There was also a significant main effect of Prime-Target Semantic Relatedness ( $F_s(2,42) = 5.89, p = 0.006, \eta^2 = 0.22; F_i(2,30) = 17.61, p < 0.001, \eta^2 = 0.54$ ), which did not interact with the Block factor. In fact, the main effect of Prime-Target Relatedness reached significance from the first Trial Block ( $F_s(2,42) = 3.62, p = 0.036, \eta^2 = 0.15; F_i(2,30) = 6.79, p = 0.006, \eta^2 = 0.31$ ), thus suggesting that the observed priming effects were not compromised by stimulus repetition.

Further contrasts indicated that the RTs to strongly related trials were significantly faster than RTs to unrelated trials (15 ms;  $F_s(1,21) = 9.75, p = 0.005, \eta^2 = 0.30; F_i(1,15) = 33.96, p < 0.001, \eta^2 = 0.69$ ), and they were also faster than RTs to weakly related trials, with the difference between strong and weak associates being only marginally significant in the subject analysis ( $F_s(1,21) = 4.14, p = 0.055, \eta^2 = 0.17$ ), but statistically significant in the item analysis ( $F_i(1,15) = 16.30, p = 0.001, \eta^2 = 0.52$ ). By contrast, the RTs to weakly related trials were not statistically different from RTs to unrelated trials (7 ms;  $F_s(1,21) = 2.5, p > 0.13; F_i < 1$ ) (see Fig. 2, left panel).

There was also a reliable correlation across participants between priming effects produced by strongly related and weakly related prime-target pairs ( $r = 0.59, p = 0.004$ ), thus indicating a high consistency in congruency priming effects across participants. The same repeated-measures analysis performed on error rates revealed no significant effects (strongly related = 2.1%; weakly related = 2.7%; unrelated = 2.3%).

**2.2.1.2. Prime visibility test.** Although all participants consistently claimed to be unaware of identity of the masked prime words in the priming task (i.e., a subjective measure of conscious awareness), we also obtained an objective measure of prime awareness



**Fig. 2.** Mean reaction times to strongly related (SR), weakly related (WR) and unrelated (UR) prime-target pairs for Experiment 1 (prime-target SOA = 200 ms;  $n = 22$ ) and Experiment 2 (prime-target SOA = 67 ms;  $n = 22$ ). The vertical lines depict the standard error of means for each condition. Priming effects were statistically significant only for strongly, but not for weakly related prime-target pairs in the two Experiments.

(i.e., the observer's inability to discriminate between alternative stimulus states), by computing the signal detection measure  $d'$  for each participant in the prime visibility test. This was done treating one level of the prime category (e.g., animal) as signal and the other level (e.g., body part) as noise. Overall  $d'$  for discrimination for masked primes was .05 (mean hit rate = 50%, false alarm rate = 48%), which did not reliably deviate from zero ( $t(21) = 1.6, p > 0.11$ ), thus suggesting that the masked primes were below both subjective and objective threshold for conscious awareness. In addition, the individual averaged  $d'$  values and the size of the priming effects did not correlate with each other (Strongly-related:  $r = -.14, p = .52$ ; Weakly-related:  $r = -.17, p = 0.43$ ), which suggests that the congruency priming effects observed in the priming task were not the result of participants' awareness of masked primes (this issue will be further discussed in Experiment 2).

### 2.2.2. Electrophysiological results

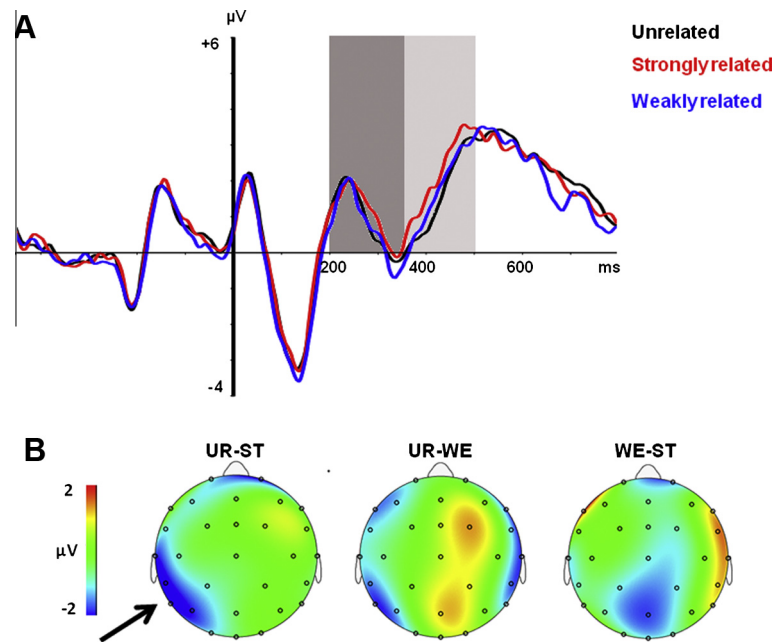
Plotted in Fig. 3 are the averaged ERPs, time locked to the target onset for the strongly related, weakly related and unrelated conditions. As can be seen in the figure, through the early post-target time interval (0 to approximately 250 ms) the waveforms are remarkably similar for the related and unrelated conditions. In fact, no evidence of EEG priming effects (i.e., reliable differences in mean amplitudes between the unrelated and related conditions) was found on the 50–250 posttarget epoch in neither this nor the next experiment.

**2.2.2.1. 250–350 ms posttarget epoch (N200).** There were significant main effects for Laterality ( $F(2,42) = 24.5, p < 0.001, \eta^2 = 0.54$ ), and Caudality ( $F(4,84) = 4.66, p = 0.03, \eta^2 = 0.18$ ). The main effect of Prime-Target Semantic Relatedness did not reach statistical significance ( $F(2,42) = 1.70, p > 0.20$ ) and this factor did not interact with any of the others.

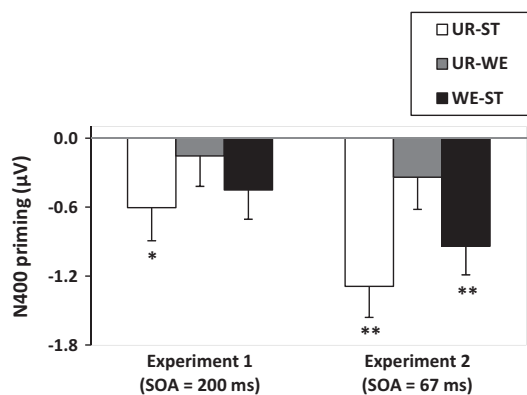
**2.2.2.2. 350–500 ms posttarget epoch (N400).** There were significant main effects for Laterality ( $F(2,42) = 19.06, p < 0.001, \eta^2 = 0.48$ ), and Caudality ( $F(4,84) = 7.76, p = 0.004, \eta^2 = 0.27$ ). The main effect of Prime-Target Semantic Relatedness was marginally significant ( $F(2,42) = 2.96, p = 0.056, \eta^2 = 0.12$ ), while this latter factor did not interact with either Laterality or Caudality.

Further contrasts (see Fig. 4) revealed a reliable N400 priming effect for strongly related targets ( $F(1,21) = 5.37, p = 0.031, \eta^2 = 0.20$ ), which produced a larger positivity (mean = 2.184  $\mu$ V,  $SD = \pm 3.34$ ) than unrelated targets (mean = 1.578  $\mu$ V,  $SD = \pm 2.78$ ;

<sup>2</sup> In both Experiments 1 and 2, we also conducted a previous by-item ANOVA including Target Category (animal vs. body part) as a factor. Given this factor did not appear as a main effect or in a reliable interaction with any other variable in either Experiment 1 or Experiment 2, the data were averaged across the categories for further analyses.



**Fig. 3.** Experiment 1. (A) Grand-averaged voltage data as function of prime-target semantic relatedness (strongly related, weakly related, unrelated). As statistical analyses did not yield significant effects of the factors laterality and caudality, voltages were collapsed across fronto-central and centro-parietal electrode sites. In this and the upcoming figures, the analyzed epoch lasted from 450 before the onset of the target to 800 ms after target onset. Negative potentials are plotted downwards. Vertical gray shadings above the X-axes indicate the 200–350 ms (N200) and 350–500 ms (N400) time windows used for statistical analysis in this and the other ERP figures. (B) Topographic voltage maps across the 29 electrode sites, displaying the N400 priming effects, coded in color, averaged in the time window between 350 ms and 500 ms, in each relatedness condition. The small arrowhead towards the back of the voltage map highlights the posterior topography of the N400 effect. UR–ST, Unrelated minus strongly related conditions; UR–WE, Unrelated minus weakly related conditions; WE–ST, weakly related minus strongly related conditions.



**Fig. 4.** Magnitude of the N400 ERP priming effects in each relatedness condition for Experiments 1 and 2. Voltages were collapsed across fronto-central and centro-parietal electrode sites. Significant contrasts are highlighted by asterisks (\* =  $p < .05$ ; \*\* =  $p < .01$ ). UR–ST, Unrelated minus strongly related conditions; UR–WE, Unrelated minus weakly related conditions; WE–ST, weakly related minus strongly related conditions.

see Fig. 3), although the ERP differences between strongly and weakly related targets did not reach statistical significance ( $F(1,21) = 2.74, p > 0.11, \eta^2 = 0.11$ ). By contrast, ERPs to unrelated targets did not statistically differ from those to weakly related targets (mean =  $1.732 \mu\text{V}$ ,  $SD = \pm 3.33$ ;  $F < 1$ ; see Kutas, 1993, for a similar modulation by prime-target semantic relatedness on the N400 priming effects from consciously perceived prime words). Lastly, there was a significant correlation between N400 priming effects by strongly and weakly related pairs ( $r = .568, p = .006$ ), again indicating a high consistency in ERP (N400) priming effects across participants.

**2.2.2.3. Time-course analyses.** To better characterize the temporal profile of the above effects, we also performed a series of time course analyses on the ERP data in ten consecutive latency bins starting at target onset and going until 500 ms for both strongly related and weakly related word pairs. Because statistical analyses yield that Prime-Target Relatedness did not interact with either Laterality or Caudality, voltages were collapsed across the fifteen fronto-central and centro-parietal electrode sites. As can be seen in Table 1, the effects of priming for strongly related pairs were significant at 350–400 ms and 400–450 ms epochs and marginally significant at 450–500 ms epoch, with weakly related words yielding no reliable ERP priming effect at any epoch. The voltage differences between strongly related and weakly related words were only marginally significant at 350–400 ms and 400–450 ms epochs.

## 2.3. Discussion

There were two main findings in the present experiment. First, our behavioral results replicate those recently reported by Ortells et al. (2013) in showing reliable unconscious congruency priming for strongly, but not for weakly semantically related prime-target pairs. But unlike Ortells et al., the different relatedness conditions were randomly mixed within a session rather than blocked across sessions. Consequently, the different priming effects observed for strong and weakly related co-exemplars could not reflect different processing strategies for the different conditions. If congruency priming in our task would mainly arise from response congruency between prime and target words, as predicted by a response priming account of congruency priming (e.g., Forster, 2004; Wentura, 2000), then there should not be any difference between strongly related and weakly related pairs, as both conditions are identical in terms of S–R category congruency. But in contrast, priming for strongly related pairs was significantly greater than for weakly

**Table 1**  
Time-course analyses of the ERP priming (unrelated minus related) effects for consecutive 50 ms time windows in Experiments 1 (prime-target SOA = 200 ms) and 2 (prime-target SOA = 67 ms).

	0–50	50–100	100–150	150–200	200–250
<i>Experiment 1</i>					
Weak–unrelated	ns	ns	ns	ns	ns
Strong–unrelated	ns	ns	ns	ns	ns
Strong–weak	ns	ns	ns	ns	ns
	250–300	300–350	350–400	400–450	450–500
Weak–unrelated	ns	ns	ns	ns	ns
Strong–unrelated	ns	ns	*	*	(*)
Strong–weak	ns	ns	(*)	ns	(*)
<i>Experiment 2</i>					
Weak–unrelated	ns	ns	ns	ns	ns
Strong–unrelated	ns	ns	ns	ns	ns
Strong–weak	ns	ns	ns	ns	ns
	250–300	300–350	350–400	400–450	450–500
Weak–unrelated	ns	ns	ns	ns	ns
Strong–unrelated	ns	ns	*	**	**
Strong–weak	ns	ns	*	**	**

ns =  $p > .1$ ; (\*) =  $p < .1$ .

\*  $p < .05$ .

\*\*  $p < .01$ .

related pairs, a finding difficult to explain in terms other than a semantic processing of masked prime words.

We also found that behavioral priming effects did not reliably correlate with participants' performance in the prime visibility task. The lack of relation between both measures is common in the unconscious priming literature (e.g., Damian, 2001; Kiefer, 2002; Kiesel et al., 2006; Van den Bussche & Reynvoet, 2007). Such a finding could partly reflect small reliability in either task due to, for example, high individual differences in baseline RTs (e.g., Hutchison et al., 2008). Some researchers have even suggested that semantic priming effects under automatic conditions (e.g., prime masking; short prime-target SOA) could be noisy and variable, perhaps reflecting inherently uncoordinated, rather than coherent, activity in participants' semantic memory (e.g., Stolz, Besner, & Carr, 2005). But this does not appear to be the case in our study, because there was a reliable correlation across participants between unconscious priming effects produced by strongly related and weakly related words ( $r = 0.59$ ,  $p = 0.004$ ). The latter result demonstrates that there was indeed some predictable variability in unconscious congruency priming within each individual even under conditions promoting automatic processing of primes.

A second relevant finding in this experiment is that unconscious semantic brain activation, as indexed by the N400 ERP component, was also modulated by prime-target semantic relatedness. The N400 priming effect was mainly observed when the masked prime words were followed by strongly related word targets, which produced the most positive-going ERPs, with ERPs to weakly related targets being not reliably different from those to the unrelated targets. As congruency modulated the N400 ERP component, an index for semantic processing, and not ERPs in the time range of the N200 component, an index for response conflict and visuo-motor response priming (e.g., Jaśkowski et al., 2003; Martens et al., 2011; Ridderinkhof et al., 2004; Zovko & Kiefer, 2013), the present results indicate that congruency effects also depend on semantic processing and are not exclusively the result of response activation.

Nevertheless, the observed N400 priming effects with strongly related targets (i.e., unrelated minus strongly related targets =  $-0.66 \mu\text{V}$ ) were of a smaller size than those reported by some prior masked priming studies (e.g., Kiefer, 2002; Kiefer & Martens, 2010; Kiefer & Spitzer, 2000). In fact, the overall main effect of

Prime-Target Semantic Relatedness was only marginally significant, and that the ERPs to strongly related targets did not significantly differ from those to weakly related targets (see Fig. 4). Some previous ERP studies have demonstrated that obtaining reliable N400 unconscious priming depends critically on the use of very short prime-target SOAs (<100 ms). For example, by manipulating the prime-target SOA (67 ms vs. 200 ms) in a semantic priming task, Kiefer and Spitzer (2000) reported reliable behavioral priming effects from conscious and unconsciously perceived prime words at the two SOA intervals. Interestingly, a different time course of ERP effects was observed from conscious and unconscious priming: Visible primes produced a significant N400 priming effect that increased with the duration of SOA. By contrast, unconscious priming on the centro-parietal N400 ERP component decayed rapidly, with a significant N400 priming effect being observed at the shortest 67-ms SOA (see also Kiefer, 2002; Kiefer & Martens, 2010), but not at the longest 200-ms SOA. It remains thus possible that a prime-target SOA of 200 ms, which has traditionally been viewed as a relatively short interval in behavior priming research, could actually be a too long time interval to observe reliable and robust N400 ERP priming from unconsciously perceived prime words, particularly in the weakly related condition.

Furthermore, prior behavioral research addressing unconscious congruency priming has generally used prime-target SOA intervals that were shorter (i.e., 100 ms or less; see for example, Abrams, 2008; Kiefer et al., 2015; Klauer et al., 2007; Van den Bussche & Reynvoet, 2007; Van den Bussche et al., 2012) than the 200-ms SOA used in our Experiment. One could argue that priming effects from weakly related pairs could be more short-lived than those observed with strongly related ones, thus explaining why the unconscious behavioral priming effects from the former pairs at 200-ms SOA were much smaller than those found with strongly related co-exemplars. In order to address these issues we conducted a further experiment in which the prime-target SOA was reduced to 67 ms.

### 3. Experiment 2

In this experiment we used the same procedure as that in Experiment 1, the only difference being that the prime-target SOA was reduced from 200 ms to 67 ms.



### 3.1. Method

#### 3.1.1. Participants

Twenty-eight healthy, right-handed, native Spanish speakers with normal or corrected-to-normal vision participated in the experiment. Data of one participant were excluded from analysis because their identification rate clearly exceeded the confidence interval of chance performance in the masked prime visibility test (accuracy greater than 65%). Data from five further participants had to also be discarded due to an excessive amount of ERP artifacts (>60% of artifact trials), leaving 22 subjects for behavioral and ERP analysis (mean age 21.6; range 18–26; 12 females). All participants signed a written consent after the nature and the consequences of the experiment had been explained. The experiment was conducted in accordance with the Declaration of Helsinki.

#### 3.1.2. Materials and procedure

These were the same as in Experiment 1 except that the backward mask immediately following the prime offset was presented for 33.5 ms (rather than for 166.5 ms, as in Experiment 1), thus resulting in a prime-target SOA of 67 ms.

#### 3.1.3. EEG recording and analysis

These were similar to those in Experiment 1. The EEG was again corrected for ocular artifact/blink contributions using independent component analysis (ICA). Artifact free EEG segments to trials with correct responses were averaged separately for the three prime-target relatedness conditions (with the mean percentage of valid trials per condition given in parentheses): strongly related (87.8%), weakly related (87.9%), and unrelated (88.3%). Mean voltages in the N200 and N400 time windows (250–350 ms and 350–500 ms posttarget onset, respectively) were computed for each of the same fifteen electrode sites as in Experiment 1 (i.e., F3/F4, FC1/FC2, Fz, FCz, Cz, Pz, Oz, C3/C4, CP1/CP2, P3/P4). Repeated measures  $3 \times 3 \times 5$  ANOVAs were performed on each time window with Prime-Target Relatedness (strongly related, weakly related, unrelated), Laterality (left, mid, right) and Caudality (frontal, fronto-central, central, centro-parietal, parietal) as within-participant factors ( $p$  level of .05).

### 3.2. Results

#### 3.2.1. Behavioral results

**3.2.1.1. Priming task.** Trials containing an incorrect response (3.3% of trials) or those with RTs falling more than 2.5 standard deviations from the overall mean RT (3.1% of trials) were removed from analyses. By-subject and by-item ANOVAs were performed on the trimmed data, with Trial Block (Blocks 1–4), and Prime-Target Relatedness (strongly related, weakly related, unrelated) as factors. Mean RTs and mean error rates as a function of Prime-Target Relatedness are shown in Fig. 2.

No reliable effects were found in the analysis of error rates (strongly related = 3.1%; weakly related = 3.9%; unrelated = 3.9%). In the analysis of RTs, there was a significant main effect of Trial Block ( $F_s(3,63) = 3.42, p = 0.048, \eta^2 = 0.14; F_i(3,45) = 7.81, p < 0.001, \eta^2 = 0.34$ ), such that slower RTs were observed in the first Block (707 ms) as compared to RTs in Blocks 2 to 4 (670, 674 and 679 ms, respectively). There was also a significant main effect of Prime-Target Relatedness ( $F_s(2,42) = 15.53, p = 0.001, \eta^2 = 0.42; F_i(2,30) = 10.63, p = 0.001, \eta^2 = 0.41$ ), which did not interact with the Block factor. As in Experiment 1, the main effect of Prime-Target Relatedness was already significant in the first Trial Block ( $F_s(2,42) = 4.93, p = 0.016, \eta^2 = 0.19; F_i(2,30) = 3.9, p = 0.043, \eta^2 = 0.20$ ), again suggesting that obtaining reliable congruency priming in our task did not depend on stimulus repetition.

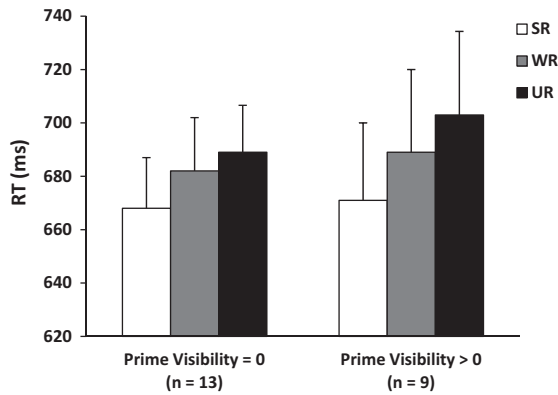
Further contrasts indicated that RTs to strongly related trials were significantly faster than RTs to both unrelated trials (25 ms;  $F_s(1,21) = 29.96, p = 0.001, \eta^2 = 0.59; F_i(1,15) = 27.37, p < 0.001, \eta^2 = 0.65$ ), and to weakly related trials ( $F_s(1,21) = 14.26, p = 0.001, \eta^2 = 0.40; F_i(1,15) = 14.46, p = 0.002, \eta^2 = 0.49$ ; see Fig. 2, right panel). By contrast, the RT differences between unrelated and weakly related trials were only marginally significant in the subject analysis (10 ms;  $F_s(1,21) = 3.99, p = 0.06, \eta^2 = 0.16$ ), but not in the item analysis ( $F_i < 1$ ). As in Experiment 1, there was a significant correlation between priming effects by strong and weakly related pairs ( $r = .645, p = .001$ ), again indicating a high consistency in congruency priming effects across participants.

**3.2.1.2. Prime visibility test.** Overall discrimination for primes was  $d' = .35$  (mean hit rate = 57%, false alarm rate = 43%) that significantly deviated from zero ( $t(21) = 3.11, p = .005$ ). Yet, this above-chance performance in the visibility test does not necessarily reveal conscious perception of the masked primes. As in Experiment 1, all participants reported subjective invisibility of the masked primes both within the main experiment and the visibility test. Additionally, the individual  $d'$  values and the magnitude of the priming effects from strong and weak associates did not reliably correlate with each other (strongly related:  $r = .32, p = .14$ ; weakly related:  $r = .02, p = 0.93$ ), indicating again that the observed priming effects were unrelated to participants' identification measures of the masked primes.

Despite the lack of a relation between priming effects and prime visibility measures, priming effects have frequently been regressed on prime visibility indexes in order to test whether the regression  $y$ -intercept is significantly larger than zero (e.g., Greenwald et al., 1996; Kiefer, 2002; Klauer et al., 2007; Naccache & Dehaene, 2001a; Van den Bussche & Reynvoet, 2007). A regression  $y$ -intercept larger than zero provides an estimate of priming at zero prime visibility ( $d' = 0$ ), i.e. when performance in the visibility test is at chance. The linear regression method has the advantage of not relying on the acceptance of the null hypothesis of zero prime visibility in testing for priming effects in the absence of prime awareness (e.g., Greenwald et al., 1996). Yet, the regression method is clearly valid when the direct ( $d'$ ) and indirect (priming) measures are related, but not when they are unrelated. In the absence of a reliable correlation between direct and indirect measures, the regression intercept index might simply reveal the overall mean sensitivity of the indirect measure (i.e., the mean priming effect; Doshier, 1998; Merikle & Reingold, 1998; Snodgrass & Shevrin, 2006). Despite these limitations due to a missing correlation between the magnitude of priming effects and visibility, we determined the regression intercepts and found an intercept significantly larger than zero only for strongly related primes.<sup>3</sup>

In order to further test whether residual prime visibility affected the results, we applied an alternative strategy of splitting observers into two different groups based on their performance in the prime visibility test (see Ortells et al., 2013, for a similar strategy). Participants with an overall null or negative  $d'$  score in the prime visibility test ( $n = 13$ ) were assigned to a “lower discrimination” group. The remaining participants ( $n = 9$ ) were assigned to a second “higher discrimination” group. Whereas the latter showed a  $d'$  mean of .80

<sup>3</sup> We also conducted regression analyses in which both behavioral (RT differences) and ERP (voltage differences) priming effects were regressed on the prime visibility index ( $d'$ ). A similar result pattern was found for both RT and ERP priming measures, with the regression  $y$ -intercept being significantly greater than zero for strongly related, but not for weakly related primes in both Experiment 1 [RT priming: strong = 15 ms;  $t(21) = 3.12, p = .005$ ; weak = 7 ms;  $t(21) = 1.7, p > .10$ ; ERP priming: strong =  $-.624 \mu\text{V}$ ;  $t(21) = 2.33, p = .05$ ; weak =  $-.197 \mu\text{V}$ ;  $t(21) < 1$ ], and Experiment 2 [RT priming: strong = 20 ms;  $t(21) = 3.80, p = .001$ ; weak = 9 ms;  $t(21) = 1.5, p > .13$ ; ERP priming: strong =  $-.897 \mu\text{V}$ ;  $t(21) = 2.74, p = .013$ ; weak =  $-.225 \mu\text{V}$ ;  $t(21) < 1$ ]. But as the correlations between the indirect (priming) and direct ( $d'$ ) measures were not significant in either Experiment, we did not include these data in the Results sections.



**Fig. 5.** Mean reaction times to strongly related (SR), weakly related (WR) and unrelated (UR) prime-target pairs in Experiment 2, for both participants performing at chance ( $n = 13$ ) and above chance ( $n = 9$ ) in the prime visibility test. The vertical lines depict the standard error of means for each condition. Priming effects were significant only for strongly related prime-target pairs but not for weakly related prime-target pairs in both participants subgroups.

that was reliably above chance ( $t(8) = 10.20, p = .04$ ), the former group showed a  $d'$  mean of .04 that did not reliably differ from zero ( $t(12) = 1.54, p = .15$ ). It is crucially significant that both groups showed a similar priming pattern (i.e., the interaction between visibility group and priming was not significant,  $F < 1$ ; see Fig. 5), namely, reliable priming effects were found for participants that performed above chance in the visibility test [strong = +31 ms;  $F_s(1,8) = 16.7, p = 0.003, \eta^2 = 0.68$ ;  $F_i(1,15) = 6.24, p = 0.025, \eta^2 = 0.29$ ; weak = +14 ms;  $F_s(1,8) = 3.64, p = 0.09, \eta^2 = 0.13$ ;  $F_i(1,15) = 1.15, p > 0.29$ ], and, more critical for our study, for those participants that did not discriminate the primes better than chance [strong = +21 ms;  $F_s(1,12) = 13.96, p = 0.003, \eta^2 = 0.54$ ;  $F_i(1,15) = 8.59, p = 0.010, \eta^2 = 0.36$ ; weak = +7 ms;  $F_s(1,12) = 1.05, p = 0.32$ ;  $F_i < 1$ ]. These latter results provide strong evidence that masked

priming effects in our experiment did not depend on potentially residual prime visibility.

### 3.2.2. Electrophysiological results

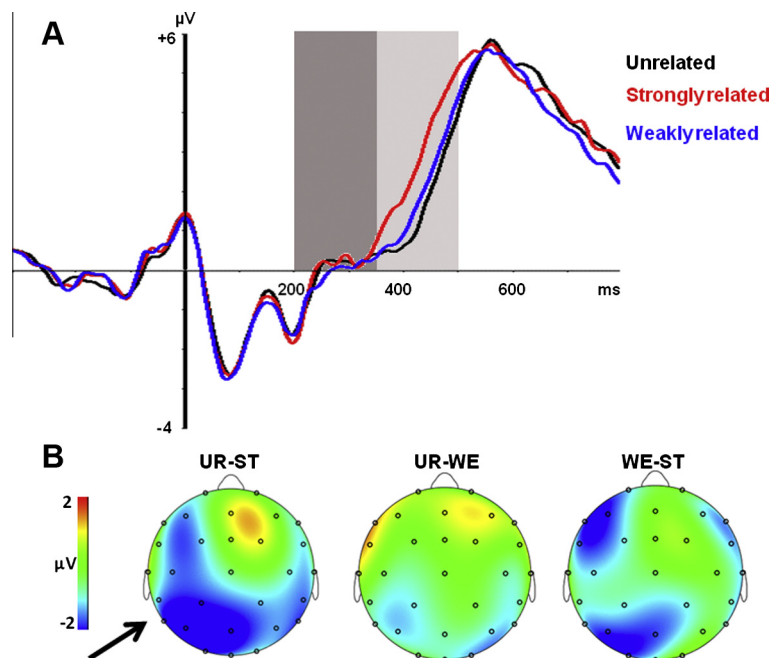
Plotted in Fig. 6 are the averaged ERPs (collapsed across the same fifteen fronto-central and centro-parietal electrode sites as those in Experiment 1), time locked to the target onset for the strongly related, weakly related, and unrelated conditions.

As can be seen in the figure, through the early post-target time interval (0 to approximately 250 ms) the waveforms are remarkably similar for the related and unrelated conditions.

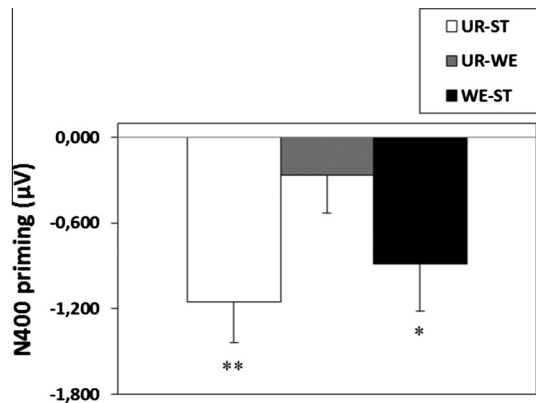
**3.2.2.1. 250–350 ms posttarget epoch (N200).** There was only a main effect for Laterality ( $F(2,42) = 12.61, p < 0.001, \eta^2 = 0.38$ ), with mean amplitudes to related targets being very similar to those to the unrelated targets (Prime-Target Relatedness =  $F < 1$ ).

**3.2.2.2. 350–500 ms posttarget epoch (N400).** There was a significant main effect for Caudality ( $F(4,84) = 13.8, p < 0.001, \eta^2 = 0.40$ ), and more relevant, for Prime-Target Semantic Relatedness ( $F(2,42) = 11.76, p < 0.001, \eta^2 = 0.36$ ). Further contrasts revealed a reliable N400 priming effect for strongly related targets ( $F(1,21) = 19.4, p < 0.001, \eta^2 = 0.48$ ), which elicited more positive ERPs (mean = 2.878  $\mu\text{V}$ ,  $\text{SD} = \pm 3.28$ ; see Fig. 6). The ERPs to strongly related targets were also significantly more positive ( $F(1,21) = 14.03, p < 0.001, \eta^2 = 0.40$ ) than ERPs to weakly related targets (mean = 1.934  $\mu\text{V}$ ,  $\text{SD} = \pm 3.70$ ). In contrast, ERPs to weakly related targets did not reliably differ from ERPs to unrelated targets ( $F(1,21) = 1.54, p > 0.23$ ). As in Experiment 1, there was a significant correlation between N400 priming effects by strong and weakly related pairs ( $r = .615, p = .002$ ), again indicating a high consistency in ERP (N400) priming effects across participants.

In order to provide further evidence for the unconscious nature of the N400 priming effects from masked words in this experiment, a further ANOVA was conducted on ERP data from those



**Fig. 6.** Experiment 2. (A) Grand-averaged voltage data as function of prime-target semantic relatedness (strongly related, weakly related, unrelated). As statistical analyses did not yield significant effects of the factors laterality and caudality, voltages were collapsed across selected electrode sites. (B) Topographic voltage maps across the 29 electrode sites, displaying the N400 priming effects, coded in color, averaged in the time window between 350 ms and 500 ms, in each relatedness condition. The small arrowhead towards the back of the voltage map highlights the posterior topography of the N400 effect. UR–ST, Unrelated minus strongly related conditions; UR–WE, Unrelated minus weakly related conditions; WE–ST, weakly related minus strongly related conditions.



**Fig. 7.** Experiment 2. Magnitude of the N400 ERP priming effects in each relatedness condition for participants performing at chance in the prime visibility test ( $n = 13$ ). Significant contrasts are highlighted by asterisks (\* =  $p < .05$ ; \*\* =  $p < .01$ ). UR–ST, Unrelated minus strongly related conditions; UR–WE, Unrelated minus weakly related conditions; WE–ST, weakly related minus strongly related conditions.

participants showing a chance performance ( $d' = 0$  or less) in the prime visibility test ( $n = 13$ ). The main effect of Prime-Target Relatedness was again significant ( $F(2, 24) = 8.29$ ,  $p = 0.002$ ,  $\eta^2 = 0.41$ ), with ERPs to the unrelated targets (mean =  $1.558 \mu\text{V}$ ,  $SD = \pm 3.05$ ) being significantly different from those to strongly related targets (mean =  $2.710 \mu\text{V}$ ,  $SD = \pm 2.74$ ;  $F(1, 12) = 15.9$ ,  $p = 0.002$ ,  $\eta^2 = 0.57$ ), but not from ERPs to weakly related targets (mean =  $1.826 \mu\text{V}$ ,  $SD = \pm 2.92$ ;  $F(1, 12) = 1.08$ ,  $p > 0.33$ ; see Fig. 7). The ERPs to strongly related targets again significantly differed from those to weakly related targets ( $F(1, 12) = 7.14$ ,  $p = 0.02$ ,  $\eta^2 = 0.37$ ). These results clearly demonstrate that behavioral and ERP (N400) priming effects from masked words in this experiment were truly subliminal, as occurred in Experiment 1.

**3.2.2.3. Time-course analyses.** As in Experiment 1, we performed time course analyses on the ERP data for both strongly related and weakly related word pairs (voltages were collapsed across the fifteen fronto-central and centro-parietal electrode sites). The time-course of priming effects was similar to that observed in Experiment 1 (see Table 1), namely, strongly related pairs produced reliable ERP priming effects in the 350–400 ms, 400–450 ms and 450–500 ms epochs, whereas no reliable ERP priming was found for weakly related primes. In addition, the ERP differences between strongly related and weakly related primes were also significant at 350–400 ms, 400–450 ms and 450–500 ms epochs.

### 3.2.3. Discussion

By shortening the prime-target SOA from 200 ms to 67 ms in the present experiment, we found again that semantic relatedness between prime and target words significantly modulated both behavioral and electrophysiological indices (i.e., N400) of unconscious semantic processing. Masked primes followed by strongly related targets again produced reliable behavioral priming effects. By contrast, the behavioral priming effects from weakly related words were significantly smaller and did not reach statistical significance, thus suggesting that priming effects from weakly related primes are not necessarily more short-lived than those from strongly related primes. In a similar vein, the electrophysiological results showed that targets preceded by strongly related primes produced the most positive-going ERPs (i.e., N400 priming effect), with ERPs to targets preceded by weakly related primes being not reliably different from those preceded by unrelated primes. As for the behavioral data, ERP priming was significantly smaller for weakly than for strongly related pairs. We also found that the

N400 priming effects for strongly related targets in the present experiment with a prime-target SOA of 67 ms were of a much larger magnitude (i.e.,  $-1.292 \mu\text{V}$ ) than those observed with an SOA of 200 ms in Experiment 1 (i.e.,  $-0.66 \mu\text{V}$ ; see Fig. 4). These results are consistent with those reported by some previous studies (e.g., Kiefer & Spitzer, 2000), which suggest that the use of very short prime-target SOA intervals (i.e., 67 ms) constitutes a critical variable to obtain robust N400 ERP priming from unconsciously perceived words.

The fact that both behavioral and electrophysiological masked priming effects remained substantial even for those participants performing at chance in the prime visibility test ( $n = 13$ ), provides further evidence for the unconscious nature of those effects.

Another relevant finding in the present experiment was that both behavioral responses (RTs) and ERPs to targets preceded by strongly related primes differed not only from responses to targets preceded by unrelated primes, but they were also significantly different from responses to targets preceded by weakly related primes. Thus, the effect of semantic relatedness in our study does not rely on the null effect of priming for weakly related pairs.<sup>4</sup>

## 4. General discussion

The results of the present research are clear-cut. Unconsciously perceived novel (unpracticed) words from large categories produced reliable and systematically larger priming effects when followed by semantically strongly related word targets than when they were followed by weakly related targets. Whereas similar behavioral results have been reported by some recent studies (e.g., Ortells et al., 2013; Van den Bussche et al., 2012), to our knowledge, this is the first time in demonstrating a reliable modulation by the degree of prime-target semantic relatedness on nonconscious semantic brain activation, as indexed by the N400 ERP component. In both Experiments 1 and 2, we found that word targets preceded by strongly related masked primes produced the most positive-going ERPs, as compared to both unrelated targets and weakly related targets, with ERPs to weakly related targets being not reliably different from those to the unrelated targets. The fact that our prime-target relatedness manipulation in the two experiments modulated the N400 ERP component, but not ERPs in the time range of the N200 component, indicative for response conflict and visuo-motor response priming (e.g., Jaśkowski et al., 2003; Martens et al., 2011; Zovko & Kiefer, 2013), suggests that our congruency effects mainly depended on semantic processing of unconsciously perceived primes, rather than being the result of response activation. Our findings are in line with previous evidence suggesting that the N400 modulation does not only reflect conscious (strategic) processes, but also unconscious (automatic) semantic processes (e.g., Deacon et al., 2000; Kiefer, 2002; Kiefer & Brendel, 2006; Kiefer & Spitzer, 2000; Küper & Heil, 2009; Rohaut et al., 2015).

The present N400 priming effects are highly informative regarding the mechanisms underlying category congruency priming because unlike naming and lexical decision tasks, categorization

<sup>4</sup> We conducted a further analysis in which, across each of the 16 prime-target pairs the relatedness scores for strongly-related, weakly-related, and unrelated prime-target pairs obtained in the rating similarity study were correlated with their corresponding RTs (item analyses) for both Experiments 1 and 2. Reliable negative correlations between relatedness scores and RTs we found for both Experiment 1 ( $r = -0.54$ ,  $p < 0.001$ ) and Experiment 2 ( $r = -0.57$ ,  $p < 0.001$ ), such that the prime-target pairs with higher relatedness rating scores (i.e., the strongly related ones) were associated with faster responses by participants in the two experiments. These results provide further positive evidence that the observed modulation by semantic relatedness on congruency priming effects does not only reflect a difference between strongly related and unrelated conditions, but also a difference between strong and weakly related conditions.

tasks usually confound response congruency with semantic relatedness (as defined by category co-membership), in that categorically related (congruent) pairs are associated with the same response, whereas unrelated (incongruent) primes are associated with different responses (e.g., Forster, 2004; Wentura, 2000). Thus, congruency priming effects could mainly reflect response congruency, semantic relatedness, or both.

However, if the unconscious priming effects observed in our experiments mainly reflected either the involvement of action-triggers for the semantic categories (Kiesel et al., 2006) and/or the mere congruency of prime and target stimulus–response mappings (a “response priming” hypothesis), then there should not be any difference between strongly and weakly related word pairs, as both conditions are identical in terms of either category co-membership or S–R category congruency. So, a response priming account of congruency priming would predict equal priming in strongly and weakly related pairs. In clear contrast, in both Experiments we found that strongly related prime–target pairs produced far larger behavioral and electrophysiological (N400) congruency effects compared with weakly related pairs, a finding difficult to explain in terms other than a true semantic processing of unconsciously perceived words.

The present findings are therefore difficult to reconcile with some non-semantic accounts of unconscious congruency priming. For instance, they cannot be explained by the pre-existence of established S–R mappings (Damian, 2001), as the unpracticed primes had never been presented as targets and thus mapped to a response before. Also, it is unlikely that our results emerge from subword processing of the primes (Abrams, 2008) resulting from orthographic overlap between prime and target words (see for example, Van den Bussche & Reynvoet, 2007; Experiment 1c), as such an orthographic overlap was minimal in our experiments (see also Klauer et al., 2007; Van den Bussche & Reynvoet, 2007; Experiments 2 and 3). Finally, the use of large categories (e.g., animals) makes it unlikely that our results emerge from the strategic activation of action triggers that create associations between all expected stimuli and their appropriate responses (Kunde et al., 2003). Of course, we do not exclude the possibility that non-semantic mechanisms such as S–R associations or action triggering also contribute to masked congruency priming (e.g., Kiefer et al., 2015), given that experimental conditions other than in the present experiments are realized (e.g., masked primes also presented as visible targets, small categories).

Kiesel et al. (2006) have recently extended the action trigger hypothesis to explain unconscious priming from novel words and large target sets. They suggest that when many targets from broad categories (e.g., animals) are presented, subjects could form an action trigger for the expected semantic categories, instead of for the individual expected stimuli. Accordingly, novel primes from large stimulus sets might elicit responding to the extent that they match these semantic categories, as would be the case when they belong to the target set’s category. It should be noted, however, that this explanation requires at least a semantic analysis in order to determine category membership of the unconsciously presented masked prime words. This modified action trigger hypothesis therefore resembles the task set execution account that assumes implicit application of activated task sets to unconscious primes after a coarse semantic analysis (Ansorge et al., 2014; Kiefer et al., 2015).

Note that the lack of reliable priming effects from weakly related masked primes in our study cannot be due to the involvement of different strategies to process strong and weakly related word pairs, as both kinds of related trials were randomized within participants. It also appears unlikely that priming effects from weak associates could be more short-lived than those observed

with strong associates, as these latter produced reliably greater behavioral and ERP (N400) priming effects than the former ones even when a very short prime–target SOA (67 ms) was used, as was the case in Experiment 2 (see Fig. 4).

As our strongly related pairs were both highly associated category members and highly semantically similar in terms of feature overlap (see Appendix C; see also Ortells et al., 2013), the present research cannot differentiate whether the observed priming effects from such items could be due to either associative relations (e.g., spreading activation; Collins & Loftus, 1975; Neely, 1991), semantic feature overlap (e.g., Masson, 1995), or even both (Hutchison et al., 2008). But the point to be stressed here is that our results undoubtedly demonstrate that the mere existence of a categorical or response-based relationship between two words is not enough to find robust unconscious (automatic) congruency priming from unpracticed prime words.

Some researchers have even suggested that semantic priming effects under automatic conditions (e.g., prime masking; short prime–target SOA) could be noisy and variable, perhaps reflecting inherently uncoordinated, rather than coherent, activity in participants’ semantic memory (e.g., Stolz et al., 2005). But this does not appear to be case in the present study, as a high and reliable correlation between behavioral priming effects produced by strongly related and weakly related words was found across participants in both Experiments 1 and 2. Such a kind of reliable correlation was also observed in the electrophysiological results (N400) of the two Experiments, thus indicating that there was indeed some predictable variability in congruency priming within each individual even under conditions promoting automatic processing of primes (e.g., a short prime–target SOA of 67 ms in Experiment 2).

## 5. Conclusions

The results of the present research clearly demonstrate that unconsciously perceived prime words that are never presented as visible targets can give rise to robust behavioral and electrophysiological (N400) priming effects, when they are followed by closely-semantically related, but not by weakly related word targets. The observation of differential priming effects for strongly and weakly related primes and the modulation of the N400 ERP component suggest that unconscious category congruency priming is mainly driven by semantic processes and to a lesser extent by pure response activation processes that bypass semantics.

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## Appendix A

Mean familiarity (Fam) and Typicality (Typ) rates, Lexical frequency (LF, natural logarithm), number of Letters and Syllables for animal and body-part words (and their English translations) presented as primes and targets in Experiments 1 and 2.

	Fam	Typ	LF	Letters	Syllables
<i>Primes</i>					
CABRA (GOAT)	3.23	4.22	14.43	5	2
CISNE (SWAN)	3.50	3.88	12.85	5	3
GORILA (GORILLA)	3.39	4.20	9.75	6	3
LEON (LION)	3.51	4.89	13.80	4	2
LIEBRE (HARE)	3.47	3.86	12.86	6	2
PERRO (DOG)	4.90	4.97	15.35	5	2
SAPO (TOAD)	3.12	3.63	13.88	4	3
TORO (BULL)	3.53	4.32	15.06	4	2
BOCA (MOUTH)	4.89	4.71	15.17	4	2
CARA (FACE)	4.92	4.68	15.67	4	2
CODO (ELBOW)	4.31	4.21	13.22	4	2
MANO (HAND)	4.97	4.89	16.52	4	2
MUELA (MOLAR)	4.49	3.22	13.43	5	2
MUSLO (THIGH)	4.30	3.98	12.27	5	2
NUCA (NAPE)	4.18	3.74	12.25	4	2
PELO (HAIR)	4.74	3.80	15.19	4	2
<i>Targets</i>					
CONEJO (RABBIT)	4.27	4.55	14.40	6	3
GATO (CAT)	4.63	5.00	9.77	4	2
MONO (MONKEY)	3.47	4.37	14.57	4	2
OVEJA (SHEEP)	3.80	4.50	13.60	5	3
PATO (DUCK)	4.18	4.28	14.20	4	2
RANA (FROG)	3.18	3.90	13.22	4	3
TIGRE (TIGER)	3.53	4.52	14.36	5	2
VACA (COW)	3.89	4.82	14.43	4	2
BRAZO (ARM)	4.69	4.82	13.97	5	2
CABEZA (HEAD)	4.97	4.90	15.29	6	3
CUELLO (NECK)	4.61	4.39	14.26	6	2
DEDOS (FINGER)	4.89	4.57	14.08	4	2
DIENTE (TOOTH)	4.68	3.88	13.80	6	2
LABIOS (LIPS)	4.59	4.11	12.84	5	2
OJOS (EYES)	4.77	4.89	14.78	3	2
PIERNA (LEG)	4.89	4.77	13.76	6	2

**Appendix B**

Summary statistics (Mean and standard deviation for all the variables) for animal and body-part words (and their English translations) presented as primes and targets in Experiments 1 and 2.

	Fam	Typ	LF (log)	Letters	Syllables
<i>Primes</i>					
Animals	3.58 (.55)	4.25 (.48)	13.50 (1.77)	4.88 (.83)	2.38 (.52)
Body parts	4.60 (.32)	4.15 (.58)	14.21 (1.63)	4.25 (.46)	2.00 (.00)
<i>Targets</i>					
Animals	3.87 (.48)	4.49 (.33)	13.57 (1.60)	4.50 (.76)	2.38 (.52)
Body parts	4.76 (.14)	4.54 (.39)	14.10 (.77)	5.13 (1.33)	2.13 (.35)

**Appendix C**

Mean (M) similarity rates and standard errors (SE) in the rating similarity study (min. = 1; max. = 7) for strongly related, weakly related, and unrelated prime-target pairs presented in Experiments 1 and 2. Associative strength (%AS) scores (in forward direction) for strongly related pairs from norms by Callejas et al. (2003) are also presented.

	Primes	Targets	M	SE	%AS
<i>Strongly related</i>					
CABRA (GOAT)		oveja (sheep)	6.19	.07	73.4
PERRO (DOG)		gato (cat)	5.84	.08	89.6
LEON (LION)		tigre (tiger)	6.15	.08	84.4
LIEBRE (HARE)		conejo (rabbit)	6.47	.07	89.2
SAPO (TOAD)		rana (frog)	6.51	.06	96.2
TORO (BULL)		vaca (cow)	6.32	.08	92.3
CISNE (SWAN)		pato (duck)	6.16	.08	86.3
GORILA (GORILLA)		mono (monkey)	6.42	.06	84.2
BOCA (MOUTH)		labios (lips)	6.71	.05	50.0
CARA (FACE)		ojos (eyes)	5.92	.08	38.2
CODO (ELBOW)		brazo (arm)	6.29	.08	66.7
MANO (HAND)		dedos (finger)	6.48	.07	58.3
MUSLO (THIGH)		pierna (leg)	6.50	.06	62.4
PELO (HAIR)		cabeza (head)	6.19	.07	60.0
MUELA (MOLAR)		diente (tooth)	6.76	.05	66.4
NUCA (NAPE)		cuello (neck)	6.38	.06	50.8
<i>Weakly related</i>					
CABRA (GOAT)		pato (duck)	2.44	.12	
PERRO (DOG)		vaca (cow)	2.48	.13	
LEON (LION)		oveja (sheep)	2.84	.14	
LIEBRE (HARE)		gato (cat)	3.55	.15	
SAPO (TOAD)		tigre (tiger)	1.66	.10	
TORO (BULL)		rana (frog)	1.87	.11	
CISNE (SWAN)		mono (monkey)	2.25	.12	
GORILA (GORILLA)		conejo (rabbit)	2.42	.12	
BOCA (MOUTH)		dedos (finger)	3.02	.14	
CARA (FACE)		diente (tooth)	3.71	.09	
CODO (ELBOW)		labios (lips)	2.66	.12	
MANO (HAND)		cabeza (head)	3.26	.12	
MUSLO (THIGH)		ojos (eyes)	2.47	.13	
PELO (HAIR)		brazo (arm)	3.29	.16	
MUELA (MOLAR)		cuello (neck)	2.29	.12	
NUCA (NAPE)		pierna (leg)	2.67	.14	
<i>Unrelated</i>					
CABRA (GOAT)		diente (tooth)	1.45	.08	
PERRO (DOG)		cabeza (head)	1.80	.10	
LEON (LION)		dedos (finger)	1.16	.05	
LIEBRE (HARE)		ojos (eyes)	1.68	.11	
SAPO (TOAD)		brazo (arm)	1.24	.06	
TORO (BULL)		cuello (neck)	1.70	.10	
CISNE (SWAN)		labios (lips)	1.12	.04	
GORILA (GORILLA)		pierna (leg)	1.68	.10	
BOCA (MOUTH)		mono (monkey)	1.67	.09	
CARA (FACE)		pato (duck)	1.53	.09	
CODO (ELBOW)		rana (frog)	1.13	.05	
MANO (HAND)		conejo (rabbit)	1.19	.05	
MUSLO (THIGH)		oveja (sheep)	1.39	.08	
PELO (HAIR)		vaca (cow)	1.82	.11	
MUELA (MOLAR)		gato (cat)	1.50	.09	
NUCA (NAPE)		tigre (tiger)	1.32	.07	
CABRA (GOAT)		ojos (eyes)	1.61	.09	
PERRO (DOG)		dedos (finger)	1.32	.07	
LEON (LION)		brazo (arm)	1.16	.05	
LIEBRE (HARE)		cabeza (head)	1.67	.10	
SAPO (TOAD)		pierna (leg)	1.19	.04	
TORO (BULL)		labios (lips)	1.16	.04	
CISNE (SWAN)		diente (tooth)	1.09	.03	
GORILA (GORILLA)		cuello (neck)	1.71	.09	
BOCA (MOUTH)		pato (duck)	1.46	.09	
CARA (FACE)		mono (monkey)	1.89	.10	

(continued on next page)

## Appendix C (continued)

Primes	Targets	M	SE	%AS
CODO (ELBOW)	vaca (cow)	1.33	.07	
MANO (HAND)	oveja (sheep)	1.20	.06	
MUSLO (THIGH)	tigre (tiger)	1.41	.08	
PELO (HAIR)	rana (frog)	1.26	.07	
MUELA (MOLAR)	conejo (rabbit)	1.27	.07	
NUCA (NAPE)	gato (cat)	1.38	.08	

## Appendix D. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.cognition.2015.09.012>.

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