

Unconscious semantic processing of polysemous words is not automatic

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Abstract

Semantic processing of visually presented words can be identified both on behavioral and neurophysiological evidence. One of the major discoveries of the last decades is the demonstration that these signatures of semantic processing, initially observed for consciously perceived words, can also be detected for masked words inaccessible to conscious reports. In this context, the distinction between conscious and unconscious verbal semantic processing constitutes a challenging scientific issue. A prominent view considered that while conscious representations are subject to executive control, unconscious ones would operate automatically in a modular way, independent from control and top-down influences. Recent findings challenged this view by revealing that endogenous attention and task-setting can have a strong influence on unconscious processing. However, one of the major arguments supporting the automaticity of unconscious semantic processing still stands, stemming from a seminal observation reported by Marcel in 1980 about polysemous words. In the present study we reexamined this evidence. We present a combination of behavioral and event-related-potentials (ERPs) results that refute this view by showing that the current conscious semantic context has a major and similar influence on the semantic processing of both visible and masked polysemous words. In a classical lexical decision task, a polysemous word was preceded by a word which defined the current semantic context. Crucially, this context was associated with only one of the two meanings of the polysemous word, and was followed by a word/pseudo-word target. Behavioral and electrophysiological evidence of semantic priming of target words by masked polysemous words was strongly dependent on the conscious context. Moreover, we describe a new type of influence related to the response-code used to answer for target words in the lexical decision task: unconscious semantic priming constrained by the conscious context was present both in behavior and ERPs exclusively when right-handed subjects were instructed to respond to words with their right hand. The strong and respective influences of conscious context and response-code on semantic processing of masked polysemous words demonstrate that unconscious verbal semantic representations are not automatic.

Key words: consciousness; unconscious processing; subliminal perception; semantic priming; polysemy; event-related potentials

Received: 9 September 2015; Revised: 8 June 2016. Accepted: 13 June 2016

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Introduction

During the last decades, the scope of unconscious cognitive processes has been dramatically enlarged (Kihlstrom, 1987; Dehaene and Naccache, 2001; Naccache, 2006; Van den Bussche et al., 2009; Dehaene, 2014). This major conceptual change, grounded on a rich set of original empirical findings collected in normal volunteers and in brain-damaged patients, concerns both the representational content of unconscious processes, and their relation to top-down executive control. Schematically, within this relatively short period the dominant view moved from a modular (Fodor, 1983), automatic (Schneider and Shiffrin, 1977) and “stupid” unconscious, to a heterogeneous unconscious which includes flexible (Naccache, 2008; Van den Bussche et al., 2008) and high-level cognitive processes (Naccache and Dehaene, 2001; Naccache et al., 2005; Kouider and Dehaene, 2007) sensitive to various influences including: endogenous spatio-temporal attention (Kentridge et al. 1999; Naccache et al., 2002; Kentridge et al., 2008), conscious consideration of task instructions and stimuli sets (Greenwald et al., 2003; Van Opstal et al., 2010), and executive control (van Gaal et al., 2008; van Gaal et al., 2009; Reuss et al., 2014; Schoupe et al. 2014).

This recent conceptual evolution culminated in empirical reports showing that semantic attributes of recent symbolic stimuli (such as written words and numbers) can be processed unconsciously and can be sensitive to executive control [for a short review see Naccache (2008)]. However, a few influential findings still advocate for the uncontrollable nature of unconscious processes. One of such findings relates to a seminal publication of Marcel that we decided to revisit, more than 30 years later, in the present work (Marcel, 1980). In this set of experiments, Marcel used the word priming paradigm initially designed by Meyer and Schvaneveldt (1971). More specifically, Marcel exploited an important result previously found by these two authors (Schvaneveldt and Meyer, 1976) in a lexical decision task (LDT): they used a three-word trial structure beginning with a context word (W1), followed by a prime word (W2) and then by a target stimulus which could be a word or a pseudo-word. Crucially, W2 was a polysemous word (e.g.: BANK conveying at least two distinct semantic representations). They showed that the contextual word W1 (e.g.: SAVE) had a radical impact on W2 priming effects on the target word. Only the semantic representation congruent with the context defined by W1 (e.g.: SAVE-BANK) primed a semantically related target word (e.g.: MONEY). In sharp contrast, the meaning incongruent with the context did not prime semantically related target words (e.g.: RIVER-BANK-MONEY). This result demonstrated the strong influence of conscious context on conscious priming effects (priming for unmasked primes). Since this pioneering article, several studies replicated and refined the influences of context on meaning selection (Swinney et al., 1979; Tanenhaus et al., 1979; Simpson, 1981; Simpson and Krueger, 1991; Paul et al., 1992; Tabossi and Zardon, 1993; Chen and Boland, 2008). For reviews, see Spinelli and Alario (2002) and Lupker (2007). A recent study extended this effect by reporting an event-related-potential (ERP) effect (N400) for targets related to the noncontextualized meaning of polysemous words (Kotchoubey and El-Khoury, 2014).

Inspired by this work, and driven by his ongoing studies on masked semantic priming (Marcel, 1983), Marcel used the triple-word paradigm designed by Schvaneveldt and Meyer to compare the performance between unmasked and masked polysemous W2 words. Whenever W2 was unmasked, Marcel

replicated the original finding that only the contextualized meaning of W2 has a priming effect. Crucially, Marcel discovered that when W2 was masked, both its contextualized and its noncontextualized meanings primed the target word. This finding suggested the existence of a qualitative difference between conscious and unconscious representations. While conscious semantic processing is associated with a reduction of polysemy to a single representation most relevant to the available context, unconscious processing enables the activation of multiple parallel semantic representations irrespective of recent context and working memory content.

These findings suggest that there could be a limit on the impact of conscious processing (of W1) on unconscious semantic activation (of W2). Such a conclusion is of major theoretical importance for the ongoing debate concerning top-down influences on unconscious perception, given the recent discoveries concerning such influences (see above). Still, before reaching a strong conclusion about the unconscious semantic processing of words, we revisited this paradigm while taking into account various methodological concerns raised by these early works (see for instance the introduction of (Naccache et al., 2005)). In the current study we included both subjective and objective measures of conscious visibility, and used shorter W2-Target stimulus-onset asynchronies (SOAs) considering the fast decay of unconscious priming effects (Greenwald, 1996; Rossetti, 1998; Naccache et al., 2002). We also used distinct lists of words for masked and unmasked stimuli, in order to circumvent the misinterpretation of nonsemantic masked priming effects as being semantic, through the automatization of stimulus-response codes bypassing semantic analysis (Abrams and Greenwald, 2000; Naccache and Dehaene, 2001; Naccache et al., 2005). We manipulated top-down influence on masked W2 stimuli through two factors: semantic context as defined by consciously visible words W1, and response instructions. In LDT experiments, subjects are usually instructed to categorize targets as words by pressing a response button with their right hand (Weems and Zaidel, 2005). In order to avoid any potential confound between response instructions and priming effects, we systematically crossed these two factors without any expectation. Finally, we used both behavioral and ERP measures in order to gain access to a fine-grained description of the dynamics of masked W2 processing.

In a series of three experiments, we demonstrate that unconscious semantic processing of masked polysemous words exists but is not automatic, and depends both on conscious semantic context and on response code.

In order to clarify our research strategy, we close this Introduction with a synthetic description of expected patterns of results. In our design, directly inspired by Marcel’s work, we used the five following conditions:

Congruent (Cg): W1 and Tgt are associated with the same meaning of polysemous W2 (e.g.: HAND-PALM-WRIST). In this condition, one could expect a priming effect of W1 and of the activated meaning of polysemous W2 (relative to the context defined by W1) on Tgt.

Incongruent (Icg): W1 and Tgt are associated with different meanings of polysemous W2 (e.g.: HAND-PALM-TREE). In this most critical condition, one could expect either the presence or the absence of a polysemous W2 priming effect on Tgt. It depends on whether or not the two meanings of polysemous W2 are activated.

Initial (Init): W1 only is associated with one meaning of the polysemous W2 (e.g.: HAND-PALM-SHORE). In this first control condition, one could expect neither a W1 nor W2 priming effect on Tgt.

Separate (Sep): W2 is neither associated with W1 nor with Tgt, but W1 is associated with Tgt (e.g.: RIVER-PALM-SHORE). In this second control condition, one could only expect a W1 priming effect on Tgt. This condition is an ideal control when compared to Cg Trials.

Terminal (Ter): Tgt is associated with one of the two meanings of polysemous W2 (e.g.: RIVER-PALM-WRIST). In this third control condition, polysemous W2 is not contextualized; thus, under the hypothesis of a polysemous activation of W2, one could expect a possible W2 priming effect for each of its two associated Tgt words.

Our three successive experiments were designed in order to answer to the following two questions:

First, is there any evidence of semantic processing of polysemous masked W2? We probed semantic processing of masked W2 by comparing Cg vs Init trials. This criterion guided us to manipulate masking strength (Experiment 2) as well as other parameters, until we obtained an experimental condition with positive evidence of such masked W2 semantic processing. Note that this criterion also guided us to explore unexpected effects such as the hand-response code (Experiments 2 and 3).

The second main question guiding our strategy was: is there any evidence of unconscious automatic processing of W2 words? We probed this question by comparing the processing of Icg trials – in which only the noncontextualized meaning of polysemous W2 is related to Tgt – with Init trials, used here as a control condition. Typically, Marcel reported such an effect for masked words but not for unmasked words.

Experiments

Experiment 1

In the first experiment, we adapted Marcel's original lexical decision protocol to study both conscious (unmasked) and unconscious (masked) semantic priming elicited by a polysemous word (W2) contextualized by a consciously visible word (W1).

Material and methods

Participants. Thirty-two right-handed native French speakers volunteered for this study (mean age = 23.47 years \pm 4.36; sex ratio = 10 males/22 females). They had no neurological or psychiatric history, were free of any medication and had normal or corrected to normal vision. All participants gave written informed consent, and the experiment was approved by the Ethical Committee of the Kremlin-Bicêtre hospital APHP (no. 98-25).

Materials. The material were directly inspired by Marcel (1980). One hundred polysemous words (W2), with a length varying between three and eight letters, were selected from French dictionaries. Among them, we first selected 40 polysemous nouns with two frequent and clearly distinct meanings. Each polysemous word was then associated with two contextual words (W1), and with two target (Tgt) nouns, each associated with one of the two meanings of W2 (see Table 1 for a detailed description of lexical characteristics). Given the lack of a French database reporting the frequencies of the different meanings of polysemous words, and given the insufficient number of polysemous words in French free-association databases, we generated one W1 and one Tgt for each of the two meanings of W2. Then each polysemous W2 was paired with another semantically unrelated W2 in order to build all trial types. This counterbalanced design ensured that each target word was equally

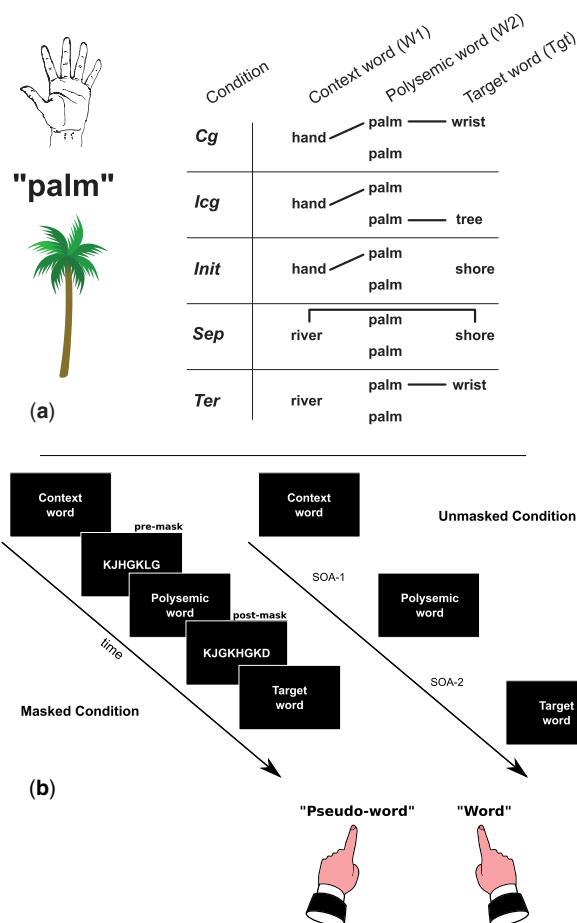


Figure 1. Experimental paradigm. Forty polysemous words (e.g.: palm) were presented in a context defined by W1, and then followed by a word/pseudo-word target stimulus. Experimental trials could be either: *Congruent (Cg)*, *Incongruent (Icg)*, *Initial (Init)*, *Separate (Sep)* or *Terminal (Ter)* regarding the semantic relations between words [represented by the black connector in (a)]. Temporal settings are detailed in Table 2. In the masked conditions, polysemous words were masked using the following durations for pre-mask, W2 and post mask [see (b)]: Experiment 1: W2 = 33 ms, premask = 33 ms and postmask = 83 ms. Experiment 2: W2 = 33 ms and we used three levels of decreasing masking: (1) premask = 33 ms with postmask = 67 ms, (2) no premask, postmask = 67 ms, (3) no premask, postmask = 16 ms. Experiment 3: same setting as in Experiment 2 with the masking level (3). Response codes (e.g.: “right hand for words, left hand for pseudo-words”) were crossed between subjects in Experiments 1 and 2, and within subjects in Experiment 3.

presented in the five semantic conditions (see Fig. 1a and Supplementary Tables 1a and 3):

Congruent (Cg): W1 and Tgt are associated with the same meaning of polysemous W2 (e.g.: HAND-PALM-WRIST).

Incongruent (Icg): W1 and Tgt are associated with different meanings of polysemous W2 (e.g.: HAND-PALM-TREE).

Initial (Init): W1 only is associated with one meaning of the polysemous W2 (e.g.: HAND-PALM-SHORE).

Separate (Sep): W2 is neither associated with W1 nor with Tgt, but W1 is associated with Tgt (e.g.: RIVER-PALM-SHORE).

Terminal (Ter): Tgt is associated with one of the two meanings of polysemous W2 (e.g.: RIVER-PALM-WRIST).

This design allowed for the generation of 400 distinct trials (40 W2 X 5 conditions X 2 meanings). The mean (SD) book

Table 1. Lexical characteristics of words

Lexical characteristics	W1 (n = 80)	W2 (n = 40)	Tgt (n = 80)
Concreteness (%)	85	57.5 ^a /32.5 ^b	83.75
Gender (masculine/feminine/neuter)	52/28/0	15/20/0 (5) ^c	66/36/0
Number (singular/plural/indefinite)	76/1/3	37/1/2	76/1/3
Movie frequency [per million of occurrence; mean (SD)]	39.3 (73.3)	59.7 (194.4)	22.4(38.8)
Book frequency [per million of occurrence; mean (SD)]	43.7 (83.8)	71.4 (199.3)	30 (52.2)
Homograph number [mean (SD)]	1.2 (0.5)	1.5 (0.7)	1.2 (0.5)
Homophone number [mean (SD)]	3.4 (2.5)	4.4 (2.6)	3 (2)
Letter number [mean (SD)]	6.1 (1.5)	5.8(1.3)	6.1 (1.3)
Syllable number [mean (SD)]	1.9 (0.8)	1.6 (0.8)	1.9 (0.6)
Phoneme number [mean (SD)]	4.7 (1.5)	4.2 (1.3)	4.7 (1.2)
Orthographic uniqueness point [mean (SD)]	5.8 (1.5)	5.4 (1.4)	5.6 (1.3)
Phonological uniqueness point [mean (SD)]	4.5 (1.3)	4.1 (1.2)	4.4 (1.2)
Orthographic neighbors [mean (SD)]	2.8 (3.9)	4.6 (4.7)	2.7 (3.5)
Phonological neighbors [mean (SD)]	8.1 (8.5)	11.2 (8.8)	6.8 (7.8)
Orthographic neighborhood ^d [mean (SD)]	1.9 (0.5)	1.7 (0.4)	1.9 (0.5)
Phonological neighborhood ^d [mean (SD)]	1.5 (0.6)	1.3 (0.5)	1.6 (0.5)

W1 = Context words; W2 = Polysemous words; Tgt = Target words; SD = Standard Deviation. Adapted from: New B., Pallier C., Ferrand L., Matos R. (2001). Une base de données lexicales du français contemporain sur internet: LEXIQUE, L'Année Psychologique, 101, 447–62. (<http://www.lexique.org>).

^a% of polysemous words with 2 concrete meanings.

^b% of polysemous words with 1 concrete meaning.

^cFive polysemous words had both a masculine and a feminine meaning.

^dLevenshtein's distance.

frequency (per million of occurrence) of the target words was 30 (± 52 ; Table 1). The mean absolute difference value of book frequency for each pair of target words was 35 (± 50). In order to create the trials with pseudo-words we followed Marcel's approach. We used a second list of 40 words drawn from the original list of 100 polysemous words. These 40 words were combined similarly to the previous one, also generating 400 trials. On half of these trials the target consisted in a pseudo-word (Supplementary Table 1b). Forty pronounceable pseudo-words (pseudo-nouns) were generated with the Lexique toolbox (<http://www.lexique.org>; New et al., 2004), matching the length of the real words targets (4–8 letters; mean = 6.8). Those two lists (the experimental list and the pseudo-word ending trials list) ensured that the presence of a semantic link between W1 and W2 was not predictive of the word/pseudo-word status of the target word. Note however that even if every trial was presented only once, words from the experimental list were always associated with target words. A total number of 800 trials were obtained, with a pseudo-word probability of 0.25. The masked and unmasked conditions were used in two different sessions. In order to prevent participants from transferring stimulus-response associations from unmasked to masked trials, which could lead to nonsemantic priming effects (Abrams and Greenwald, 2000; Naccache and Dehaene, 2001), half of the critical material originating from the first list of 400 trials was presented in the masked session, while the second half was used in the unmasked session. Therefore for a given participant, masked polysemous words were never seen as unmasked words. These two sublists were counterbalanced across subjects, as well as the order of the masked and unmasked sessions, and right/left motor response instructions in the lexical decision task, leading to eight different combinations. Finally, we decided to avoid a given word W2 being systematically contextualized in one of its two meanings across subjects. To avoid this possible bias, we inverted lists of these eight combinations of trials across subjects. Thus, the experiment is designed for numbers of subjects which are multiples of 16. We tested 32 volunteers. For each subject, trials were pseudorandomized using

Mix software (van Casteren and Davis, 2006) in such a way that no word could appear twice in any 10 consecutive trials.

Procedure and design. Each trial began with the presentation of a context word (W1), followed by a polysemous word (W2) and then by a target word/pseudo-word (Tgt) (Fig. 1b). Subjects had to perform a lexical decision task (LDT) on Tgt by pressing left or right hand buttons with their index finger. Each subject followed one set of motor response instructions (respond to words with the right button and to pseudo-words with the left button, or the opposite), and instructions were counterbalanced across subjects. Stimuli timing was different for unmasked and masked conditions (Table 2). In the unmasked condition, W1 and W2 were presented for 200 ms and Tgt was presented until subject's response with W1-W2 and W2-Tgt SOAs of 500 ms. In the masked condition, we used the following stimulus structure: W1 was presented for 200 ms and was followed by a sandwich masking sequence (pre-mask for 33 ms – W2 for 33 ms – post-mask for 83 ms) which in turn preceded the presentation of the Tgt until subject's response. Pre-masks and post-masks consisted in strings of eight random upper case consonants. Note that the values of the W2-Tgt SOA were 500 ms in the unmasked condition and 116 ms in the masked condition. Those values were chosen in order to maximize the chance of observing a subliminal priming effect, given the usually short-lived representations elicited by masked stimuli (Greenwald, 1996). In order to maximize the subject's attention, a central fixation cross was presented for 300 ms immediately before W1 and W2 onsets (or premask for the masked condition). Subjects performed a short training session (20 trials) before each of the two (masked and unmasked) sessions. The order of masked and unmasked sessions was counterbalanced across subjects. Each subject was tested on 800 trials, with a pause every 80 trials. At each pause, a feedback was delivered in order to reinforce subjects' performances (average response-time and accuracy). The experiment lasted about 60 min. Subjects were seated at a distance of 50 cm from a 13" HP® color high-resolution RGB monitor (60 Hz refresh rate), and were instructed to maintain their

Table 2. Comparison of temporal settings between the three experiments and Marcel's seminal study (time expressed in ms)

Experiment	W1	SOA-1	W2	SOA-2	Tgt
Experiment 1					
Masked	200	500	33	116	Variable ^a
Unmasked	200	500	200	500	Variable ^a
Experiment 2					
Masked	700	900	33	100	Variable ^a
Unmasked	700	900	33	500	Variable ^a
Experiment 3					
Masked	700	900	33	100	200
Seminal Marcel's study ^b					
Masked	Variable ^a	600/1500 ^c	10	610/1510	Variable ^a
Unmasked	Variable ^a	600/1500 ^c	500	1100/2000	Variable ^a

W1 = Context words; W2 = Polysemous words; Tgt = Target words; SOA = Stimulus Onset Asynchrony.

^aPresented until subject response.

^bMarcel, A. J. Conscious and preconscious recognition of polysemous words: Locating the selective effect of prior verbal context. *Attention and Performance*. 1980.

^cTime between offset of W1 and onset of W2.

gaze on the center of the screen throughout the experiment. Stimuli were displayed in white on a black background, in lower case size 14 "Time new roman" font. After the completion of the main experiment, subjects had to answer a brief questionnaire assessing: (i) the subjective visibility of masked stimuli; (ii) subjects' detection of the presence of within-trials semantic links between words; (iii) subjects' detection of the presence of polysemous words. After this questionnaire, and in order to compute an objective index of masked stimuli discrimination (d' value), subjects were asked to perform a forced-choice LDT on the masked *Congruent* condition trials in which the masked stimulus could either be a polysemous word (the original list of 40 masked W2 words) or a pseudo-word (40 masked pseudo-words never presented in the main experiment). During this experiment, subjects were instructed to respond with the code used during the masked block. Finally, a brief post-experiment interview probed subjects' ability to report the presence of polysemous words in the main experiment. We first asked subjects to report any comment about the words presented (W1, W2 or target words). We then explained them trial structure as well as the polysemy of W2, and asked them to report exemplars of polysemous W2.

Statistics. Multifactorial analyses of variance (ANOVA) were computed on median reaction times (RTs) and on error rates using a split-plot design. In all analyses we declared subjects as a random factor. For example, the plan of the first ANOVA computed in Experiment 1 was: Subjects (32) < 2 Groups (Block-order) > * Masking (2 levels) * Semantic-link (5 levels) using the "aov" R function as follow:

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aov(x ~ (Semantic-link * Masking * Block-order)
+ Error (Subjects/(Semantic-link * Masking)), data=Exp1)
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For linear correlations, we used a linear model (Wilkinson and Rogers, 1973). In order to better estimate the probability of the null hypothesis, we also used a Bayesian approach whenever the absence of effect was an important result. More specifically, we computed the JZS Bayes factor (*BayesFactor* R package; Rouder et al., 2009, 2012; Morey et al., 2015) with the following prior scales: $r = 0.5$ for ANOVAs; $r = 0.707$ for t-tests and $r = 0.354$ for linear regressions. Note that these parameters correspond to the "medium" default settings for each test.

Importantly, these priors correspond to the usually observed conscious and unconscious semantic priming effect size (Lucas, 2000; Van den Bussche, 2009; Dienes, 2015). We reported Bayesian Factor for the H_0 (BF_{01}), minimal Bayesian Factor for H_0 against all other alternative models (min- BF_{01}) or relative BF in case of models comparison (BF) using the Raftery terminology (Raftery, 1995). All tests were two-sided. All statistical analyses were computed using R 2.12.2 (Team, 2011).

Results

Subjective reports of intra-trial semantic links and of polysemy. The vast majority of subjects (31/32; 97%) reported the presence of intra-trial semantic links between words, but very few (3/32; 9%) spontaneously reported the systematic polysemous status of W2. These three subjects ran the unmasked block in the second half of the experiment ($\chi^2 = 3.31$, $P = 0.068$). Once informed about W2 status, nine subjects (9/32, 28%) including the three previous subjects, were able to report between one to three polysemous words. Seven out of these nine subjects also ran unmasked blocks in the second half of the experiment ($\chi^2 = 3.86$, $P = 0.049$). These two observations from subjective reports suggest that only consciously perceived unmasked W2 stimuli could be recalled.

Response times. We first ran an ANOVA on median correct RTs with the following factors of interest: Masking (2 levels) \times Semantic-link (5 levels) \times Block-order (2 levels). A main effect of Masking was observed ($F(1,30) = 21$, $P < 0.001$) corresponding to faster responses on unmasked blocks (effect size = 34 ms). Because the structure of the masked and unmasked trials differed in several respects, including W2-Tgt SOA, this effect may result from the masking of the target by the post-mask which follows W2 (and thus precedes the target) in the masked condition. More importantly, there was no main effect of Semantic-link ($F(4,120) = 1.52$; $P = 0.2$), but a marginal interaction was observed between Masking and Semantic-link ($F(4,120) = 2.2$; $P = 0.08$). This interaction could correspond to a trend toward a general priming effect in the unmasked condition (all conditions in which the target was preceded by a related word (*Cg*, *Icg*, *Sep*, *Ter*) as compared to *Init* trials ($F(4,120) = 2.32$; $P = 0.06$)), while there was no such tendency in the masked condition ($F(4,120) = 1.05$; $P = 0.31$; Fig. 2a). Bayes factor suggested positive evidence for the absence of masked priming (min- $BF_{01} = 8.7$).

In order to better explore the respective weights of W1 and W2 priming effects in the unmasked condition, we ran a second ANOVA restricted to unmasked trials using the following three factors of interest: W1-Tgt semantic priming, W2-Tgt semantic priming, as well as Block-order (unmasked blocks ran before vs after masked blocks). We observed a main effect of W2-Tgt semantic priming ($F(1,30) = 8.9$; $P = 0.006$), as well as an effect of W1-Tgt semantic priming ($F(1,30) = 6.6$; $P = 0.02$), and a marginal trend of block-order effect ($F(1,30) = 3$; $P = 0.10$) with subjects responding faster when unmasked trials were run first. We also found a significant three-way interaction between these factors ($F(1,30) = 4.6$; $P = 0.04$; Supplementary Table 4a). This interaction was explained by a major difference in W2-Tgt priming effects according to block-order. While a clear W2-Tgt priming effect was present in subjects who began with unmasked blocks ($F(1,15) = 5.6$; $P = 0.03$), this effect was weaker for the other group ($F(1,15) = 3.7$; $P = 0.07$). Crucially, while no significant W2-Tgt priming effect was present for noncontextualized meaning of W2 in subjects who began with unmasked blocks ($F(1,15) = 0.08$; $P = 0.8$; $BF_{01} = 2.9$), such an effect was highly significant for the other group ($F(1,15) = 12.3$; $P = 0.003$).

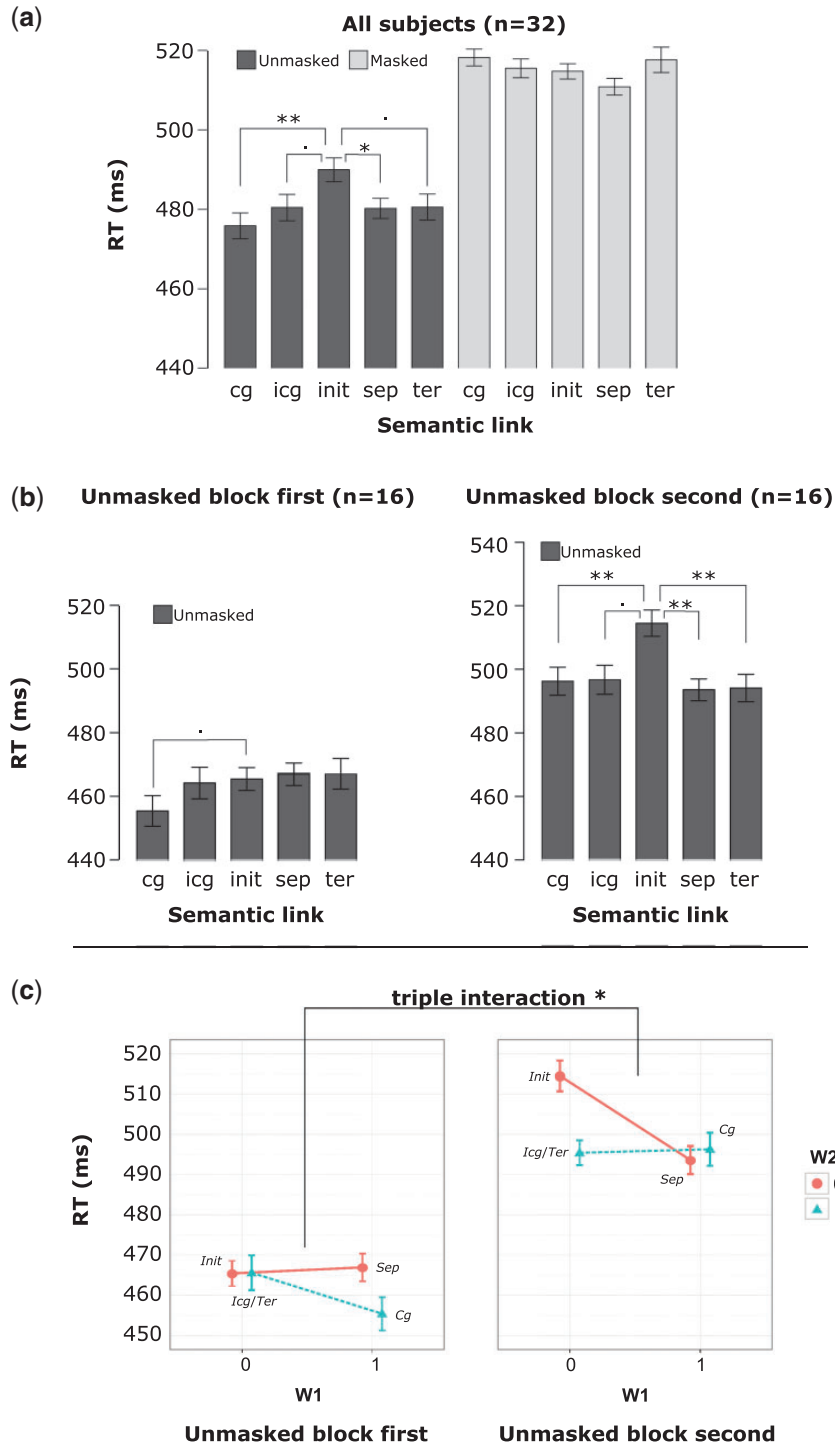


Figure 2. Semantic priming in Experiment 1. (a) Median correct RTs are plotted for each condition (Cg = Congruent, Icg = Incongruent, Init = Initial, Sep = Separate and Ter = Terminal) in masked and unmasked blocks. A semantic link effect was present only in unmasked blocks. Bars indicate standard errors of mean; ** = $P < 0.01$; * = $P < 0.05$; . = $P < 0.1$. (b) Post-hoc analyses revealed a block-order effect: subjects who performed the unmasked block in the first part of the experiment showed a priming effect limited to the contextualized meaning of the polysemous W2 (Cg), whereas subjects who performed the unmasked block in the second part of the experiment showed a semantic priming in the four conditions as compared to Init trials. (c) A significant triple interaction between Block-order, W1-priming and W2-priming effect was observed. Error bars correspond to standard error of the mean.

Taken together, these results suggest that subjects who performed the unmasked block in the second part of the experiment showed a polysemous conscious priming effect, contrary to the observation of Schvaneveldt and Meyer and of Marcel.

Error rates. Overall mean accuracy reached 98.66%. The ANOVA analysis crossing: Masking (2 levels) \times Semantic-link (5 levels), and including subject as a random factor revealed a main effect of masking ($F(1,31) = 14.74$; $P < 0.001$). Masked trials were

answered with better accuracy than unmasked ones (99.1% vs 98.2% for unmasked trials). We also observed a trend of semantic-link effect ($F(4,124) = 2.29$; $P = 0.06$) corresponding to slightly better accuracy for *Cg*, *Sep*, and *Ter* trials (98.8%) than for *Icg* and *Init* trials (98.4%). No interaction was found between masking and semantic-link ($F(4,124) = 0.69$; $P = 0.6$). The second ANOVA, which explored respective priming effects of *W1* and *W2*, did not reveal any significant effect or interaction.

Masked words visibility. After the end of the experiment, none of the subjects reported having seen polysemous *W2* in the masked trials. Moreover, when engaged in a forced-choice discrimination task (word/pseudo-word) on masked *W2* stimuli, objective discriminability did not differ from chance-level (mean $d' = 0.012$; 95% CI = $[-0.11$ to $0.09]$; t-test P -value against a zero centered distribution = 0.82) and the Bayes factor suggested positive evidence for a null distribution ($BF_{01} = 5.16$; and robustness check concluded to positive evidence for H_0 ($BF > 3$) for Cauchy prior width as small as 0.36). No significant correlation was observed across subjects between the size of priming by masked *W2* (*Init-Cg*) and d' values (adjusted $R^2 = -0.03$, $P = 0.8$; $BF_{01} = 2.9$). Finally, the size of the priming effect interpolated for a null d' did not differ from zero ($P = 0.25$). Therefore, both subjective reports and d' statistics suggested the absence of conscious perception of masked polysemous *W2* in this experiment.

Discussion

The results of Experiment 1 can be synthesized as two main findings, concerning the processing of unmasked and masked *W2*, respectively. For unmasked trials, we observed two patterns of behavior, depending on block order. In subjects who began with the unmasked *W2* blocks, we basically replicated the original finding of Schvaneveldt and Meyer and of Marcel: the semantic context established by *W1* restricted the processing of polysemous *W2* to its contextually associated meaning. No *W2*-Tgt semantic priming effect was observed in *Icg* trials. In contrast, subjects who finished the experiment with unmasked *W2* words showed a pattern of results reminiscent of the one observed by Marcel for masked words. Both meanings of *W2* were processed, as evidenced by a *W2*-Tgt semantic priming effects in all conditions compared to *Init*. Notably, subjects who began with masked trials were slower to process unmasked trials than those who began with unmasked blocks. One may speculate that the combination of RTs slowing with a loss of inhibition on the noncontextualized meaning of *W2* could reflect a decrease of executive control secondary to cognitive fatigue, but obviously other interpretations of this difference in RTs are possible.

For masked trials, whether in the first or second block, we did not observe semantic masked priming, suggesting that our masking procedure could have been too strong.

Note also that contrary to the unmasked condition, we failed to observe direct *W1*-Tgt priming effect in the masked condition (*Cg* and *Sep* conditions compared to *Init*) suggesting that the [pre-mask - *W2* - post-mask] sequence interrupted the potential priming of target words by contextual *W1* words.

Experiment 2

In the light of the previous findings, Experiment 2 was designed to maximize unmasked and masked semantic priming. To do so, we designed a new list of pseudo-words better matched with target words, in order to increase the necessity for subjects to adopt a semantic processing strategy during the task. Also, we

increased *W1* exposure to increase their influence (*W1* duration = 700 ms vs 200 ms in Experiment 1). *W2* duration was kept at 33 ms, both in masked and unmasked blocks. In addition, we decreased masking strength, tested three different masking conditions, and shortened the *W2*-Tgt SOA to 100 ms, in order to capture short-lived priming effects (Greenwald, 1996; Rossetti, 1998; Naccache et al., 2002). Finally, in an attempt to discard the potential role of fatigue in the block order effect reported in Experiment 1, we also decreased the total number of trials. To this end, we only used the three critical conditions: *Congruent* (*Cg*), *Incongruent* (*Icg*), and *Initial* (*Init*).

Material and methods

Participants. Forty-eight right-handed native French speakers volunteered to this study (mean age = 24.02 years \pm 4.46; sex ratio = 13 males/35 females), obeying the same criteria as in Experiment 1.

Materials. We only used the three critical conditions: *Congruent* (*Cg*), *Incongruent* (*Icg*), and *Initial* (*Init*) trials. Note that for a given polysemous word (e.g.: BANK), two *Cg* trials were used (e.g.: SAVE-BANK-MONEY and RIVER-BANK-SHORE) as well as two *Icg* trials e.g.: SAVE-BANK-SHORE and RIVER-BANK-MONEY). For the *Init* conditions, we used the four possible trials obtained by combining each polysemous word with *W1* and Tgt of its paired polysemous word (e.g.: SAVE-BANK-WRIST; RIVER-BANK-WRIST; SAVE-BANK-TREE; RIVER-BANK-TREE). Note that this difference from Experiment 1 allowed us to equalize the frequency of each possible *W2*-Tgt combination between *Init* on the one hand and *Cg* and *Icg* on the other hand (Supplementary Table 3). Therefore any difference in RT *W2*-Tgt priming effect between our control condition (*Init*) and our test conditions (*Cg* and *Icg*) could not be explained by a different proportion of *W2*-Tgt pairs across conditions. We selected a new list of 80 pronounceable pseudo-words using the Lexique toolbox [http://www.lexique.org; (New et al., 2004); see Supplementary Table 2], with a number of letters ranging from four to eight (mean = 6.075), and a mean trigram frequency ranging from 121 to 2933 (mean = 996). Number of letters and trigram frequency did not differ between pseudo-words and target words (P -values of respective t -tests = 0.7 and 0.4), and Bayes Factors suggested positive evidences for the absence of differences ($BF_{01} = 5.7$ and 4.2 respectively). Note that a trigram frequency difference between target words and pseudo-words was present in the material used in Experiment 1 (mean trigram frequency = 1486 for pseudo-words and 1124 in target words; t -test P -value = 0.04). A total number of 640 trials were presented to each participant vs 800 trials in Experiment 1.

Procedure and design. The procedure and design were similar to those of Experiment 1, except for the following differences. *W1* was presented during 700 ms, increasing the *W1*-*W2* SOA as compared with Experiment 1 (900 ms vs 500 ms in Experiment 1). Polysemous words (*W2*) were presented for 33 ms both in masked and unmasked conditions, with a shorter *W2*-Tgt SOA (100 ms vs 116 ms) in the masked condition. As the time of *W1* presentation had been increased, we removed the fixation cross before *W1* and *W2*. In order to avoid repetitive stimuli presentation and increase attention to *W1*, we used a discrete random jitter (1200, 1500, or 1800 ms) between trials. We used three levels of masking in three distinct groups of 16 subjects: the first group was tested with a pre-mask duration of 33 ms and a post-mask duration of 67 ms; the second group was tested with no pre-mask and with a post-mask duration of 67 ms; and the third

group was tested with no pre-mask and with a post-mask durations of 16 ms. The criterion guiding this progressive weakening of the masking procedure was the ability to identify a significant RT difference between Cg or Icg conditions vs Init condition. This comparison is the only one specifically assessing the existence of masked W2 semantic processing, given that Cg trials also include a conscious semantic prime (W2-Tgt but also W1-Tgt). Moreover, in order to better circumvent automatic associations between stimulus and response codes (Abrams and Greenwald, 2000; Naccache and Dehaene, 2001), we used the same list of W2 for trials ending with a target word and for those ending with a pseudo-word (PW) target. Finally, we equated the proportions of trials ending with a target word and of trials ending with a PW (in comparison, PW trials proportion = 0.25 in Experiment 1). A pause was proposed every 80 trials.

Statistics. See Experiment 1.

Results

Subjective reports of intra-trial semantic links and of polysemy. The vast majority of subjects (47/48; 98%) reported the presence of intra-trial semantic links between words. No subject spontaneously reported the systematic polysemous attribute of W2, while eight subjects (8/48; 17%) spontaneously reported between one to three polysemous words. Seven out of these eight subjects ran the unmasked block in the second half of the experiment ($\chi^2 = 5.4$, $P = 0.02$). Once informed about W2 status, 25 subjects (25/48, 52%) were able to report one to three polysemous words. Fifteen out of these 25 subjects ran the unmasked block in the second half of the experiment ($\chi^2 = 2.09$, $P = 0.15$). As in Experiment 1, these observations from two subjective reports suggest a possible memory effect specific to consciously perceived W2 stimuli.

Response times. We first ran an ANOVA on median correct RTs with the following factors of interest: Masking (2 levels) \times Semantic-link (3 levels) \times Block-order (2 levels). We observed a main effect of Masking ($F(1,46) = 65.3$; $P < 0.001$; Fig. 3a) corresponding to shorter RTs for unmasked trials (size effect = 36 ms) and a main effect of Semantic-link ($F(2,92) = 7.16$; $P = 0.001$) with faster RTs for Cg trials in comparison to both Init (size effect = 7 ms, $F(1,46) = 14.4$; $P < 0.001$) and Icg trials (size effect = 10 ms, $F(1,46) = 11.45$; $P = 0.001$). No significant difference was observed between Icg and Init trials ($F(1,46) = 0.78$; $P = 0.38$). Critically, an interaction was observed between Masking and Semantic-link ($F(2,94) = 6.4$; $P = 0.003$; Supplementary Table 4b). Post-hoc analyses showed that this interaction corresponded to the presence of a significant semantic priming effect for Cg trials (Cg vs Init) exclusively in the unmasked condition (size effect = 14 ms, $F(2,46) = 14.45$; $P < 0.001$ vs size effect = 2 ms, $F(2,46) = 0.22$; $P = 0.6$). No difference was observed between Icg and Init trials both in masked and unmasked conditions (Fig. 3a). As in Experiment 1, we failed to detect any effect of semantic-link in the masked condition, even for the weaker type of masking. Bayes factor analysis suggested positive evidence for the absence of masked priming (min-BF₀₁ = 12.2).

The ANOVA including the factor of masking strength did not show any significant main effect or interaction. Bayes factor analysis suggested very strong evidence for the absence of interaction between masking strength and masked semantic priming (min-BF₀₁ = 274). Moreover, no correlation was observed between masking strength and semantic priming for the Cg condition ($[Init-Cg]/Init$; adjusted $R^2 = -0.02$, $P = 0.8$), and the

Bayes factor suggested positive evidence for the absence of correlation (BF₀₁ = 3.4).

We did not find significant correlation between $[Init - Icg]/Init$ and polysemy awareness in either the unmasked or in the masked conditions (adjusted $R^2 < 0.05$; $P > 0.08$), Bayes factors suggested weak evidence for H₀ and H₁ (negative correlation) respectively (BF₀₁ = 1.53 and 0.95).

Finally, we found no significant main effect of Block-order ($F(1,46) = 0.79$; $P = 0.38$) or interaction between Block-order and Semantic-link ($F(2,92) = 0.16$; $P = 0.85$) and with Masking ($F(1,46) = 3.33$; $P = 0.08$) respectively, as well as no triple interaction ($F(2,92) = 1.29$; $P = 0.28$, Supplementary Table 4b). Contrary to Experiment 1, and in accordance with our expectations, no interaction was found between Block-order (masked or unmasked session first) and Semantic-link in the ANOVA restricted to the unmasked condition ($F(2,92) = 1.05$; $P = 0.35$), and Bayes factor suggested positive evidence for the absence of this interaction (BF = 5.27). Similarly, no significant interaction was found between Block-order and Semantic-link in the masked condition ($F(2,92) = 0.18$; $P = 0.8$; min-BF₀₁ = 1.7).

Interestingly, we discovered an unpredicted effect of response-code (hand used to answer “word” for targets) in the masked condition. We ran an ANOVA with Semantic-link (3) \times Block-order (2) \times Masking (2) \times Response-code (2). In agreement with the preceding ANOVA, we found a main effect of masking ($F(1,44) = 65.88$; $P < 0.001$), a main effect of Semantic-link ($F(2,88) = 7.69$; $P < 0.001$) with an interaction between these two factors ($F(2,88)$ value = 6.68; $P = 0.002$). We found no significant main effect of Block-order ($F(1,44) = 0.85$; $P = 0.36$) or of Response-code ($F(1,44) = 2.85$; $P = 0.1$). However, we discovered an interaction between Response-code and Semantic-link ($F(2,88) = 3.9$; $P = 0.02$), as well as a three-way interaction between Masking, Response-code and Semantic-link ($F(2,88) = 3.95$; $P = 0.02$) (Fig. 3b). The same ANOVA restricted to subjects instructed to answer “word” with their right hand revealed a main effect of Semantic-link ($F(2,44) = 14.23$; $P < 0.001$) without interaction between Semantic-link and Masking ($F(2,44) = 0.46$; $P = 0.63$). Bayes factor suggested positive evidence against the significance of this interaction (BF = 7.4). In sharp contrast, subjects instructed to answer “word” with their left hand did not show a significant main effect of Semantic-link ($F(2,44) = 1.23$; $P = 0.3$), but an interaction between Semantic-link and Masking factors ($F(2,44) = 8.53$; $P < 0.001$). This interaction corresponded to a Semantic-link effect in unmasked condition ($F(2,44) = 6.8$; $P = 0.002$), whereas there was no significant effect in the masked one ($F(2,44) = 1.6$; $P = 0.2$). However, Bayes Factor suggested weak evidence for the absence of this effect (BF₀₁ = 2.6) and we could not exclude negative priming in Cg trials for subjects instructed to answer “word” with their left hand. Said otherwise, the response-code seemed not to matter for the unmasked condition, but in the masked condition only subjects instructed to answer “word” with their right hand showed a significant priming effect. Moreover, this masked priming effect was restricted to Cg trials (restricted ANOVA for Cg vs Init ($F(1,23) = 13.11$; $P = 0.001$) and absent for Icg vs Init ($F(1,23) = 0$; $P = 0.99$). Bayes factor suggested positive evidence for the absence of masked priming by Icg trials (BF₀₁ = 3.45).

Error rates. Overall mean accuracy reached 96.92%. The ANOVA analysis crossing: Masking (2 levels) \times Semantic-link (3 levels) revealed a main effect of Semantic-link ($F(2,94) = 4.79$; $P = 0.01$), corresponding to a better accuracy for Cg trials (97.5% vs 96.8% for Icg and 96.5% for Init trials). No other effect was found to be significant ($P > 0.48$). The ANOVA crossing: Semantic-link

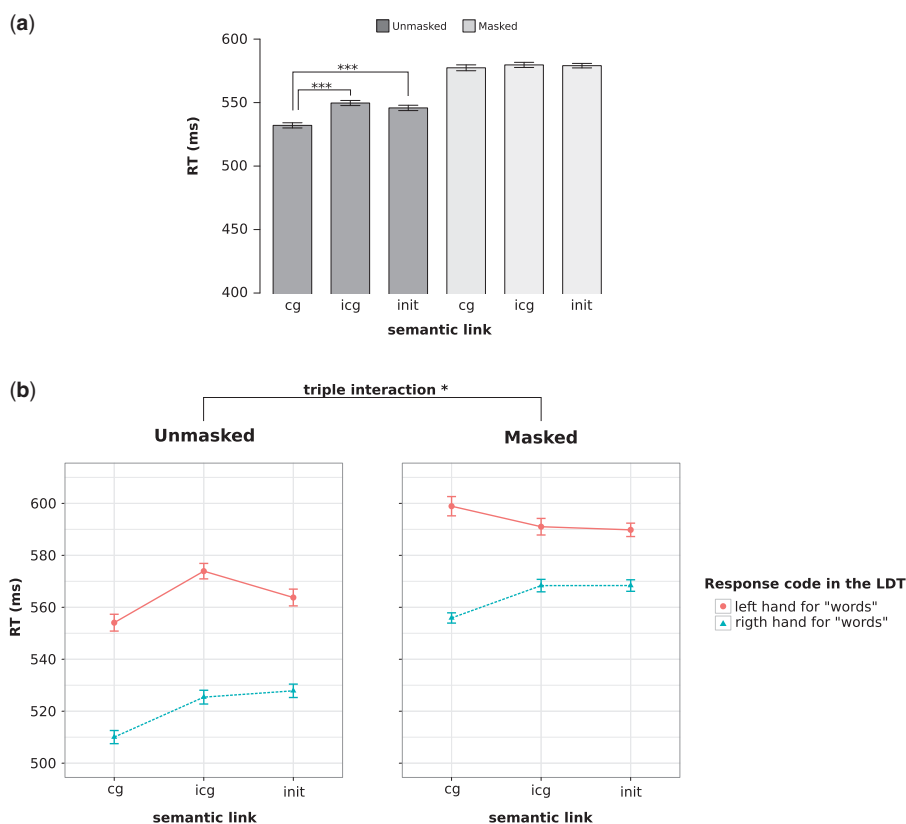


Figure 3. Semantic priming in Experiment 2. (a) Median correct RTs for each condition (Cg = Congruent, Icg = Incongruent, Init = Initial) in masked and unmasked blocks revealed a semantic link effect in unmasked block only, corresponding to shorter RTs for the contextualized meaning of the polysemous W2 (Cg). Bars indicate standard errors of mean; *** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$. (b) Post-hoc analyses revealed a priming effect in the masked block dependent on the response code: subjects instructed with the “right hand for words” response code showed a priming effect limited to the contextualized meaning of the polysemous W2 (Cg), whereas no effect was observed for the reverse instruction. Error bars correspond to standard error of the mean.

(3) \times Block-order (2) \times Masking (2) \times Response-code (2) only revealed a main Semantic-link effect ($F(2,88) = 4.81$; $P = 0.01$).

Masked words visibility. As in Experiment 1, the visibility of masked words was assessed with both subjective and objective measures (d'). No evidence of conscious perception of masked words was observed in any of the three groups of masking. Individual d' distributions were not distinct from a null distribution (mean = 0.02; CI = [-0.5 to 0.9], t -test P -value against a zero-centered distribution = 0.56) and Bayes factor suggested positive evidence for a null distribution [$BF_{01} = 5.4$; and robustness check concluded to positive evidence for H_0 ($BF > 3$) for Cauchy prior width as small as 0.37]. Linear regressions did not show a significant correlation between masked W2 priming (Init-Cg) and d' (adjusted $R^2 = -0.013$ $P = 0.52$). Bayes factor suggested weak evidence against this correlation ($BF_{01} = 2.9$). For the “right hand for words” subgroup only, the interpolated priming for a null d' revealed a significant priming effect ($P = 0.002$). No correlation was found between masked W2 priming (Init-Cg) and d' (adjusted $R^2 = -0.03$; $P = 0.6$) but Bayes factor suggested weak evidence against this correlation ($BF_{01} = 2.45$). Taken together, these results suggested that the observed priming effect was not dependent of the masked prime visibility.

Discussion

For consciously visible polysemous primes, the pattern of results obtained in Experiment 2 was very similar to the one reported in

the original studies by Schvaneveldt and Meyer and by Marcel: semantic priming was restricted to the contextualized meaning of polysemous primes, whereas no priming was observed for the alternate meaning probed in the Icg condition.

For the masked condition, the results were more complex.

First, unconscious semantic priming was present exclusively when subjects categorized target stimuli as being words with their right hand. Note that most previous LDT studies (using conscious or subliminal prime words) systematically used this response code without probing the impact of response code on priming effects. To our knowledge, and in close agreement with our own findings for unmasked visible primes, a single paper has explicitly reported similar semantic priming effects with both response codes for unmasked visible words (Weems and Zaidel, 2005). Note that this “right hand for words” response code was most probably used by Marcel in his own set of experiments, even if the information is not fully explicit in his article (see the corresponding paragraph in the “General Discussion” section).

Second and most importantly, the unconscious semantic priming effect in Experiment 2 was restricted to the contextualized meaning (Cg condition), with no behavioral evidence of automatic processing of the two semantic representations of polysemous words. This result clearly stands against Marcel’s result, and suggests that the processing of masked words is not fully automatic, but sensitive to top-down factors such as the conscious context setting.

Note that the adjunction of the Response-code factor in the first ANOVA of the Experiment 1 did not reveal any significant priming effect even for masked condition with the “right hand for word” response-code.

Experiment 3

Experiment 3 was designed to better understand the origin of contextual (*Congruent* priming effect) and task instruction (response code) influences on the fate of masked words.

In order to state our working hypotheses regarding this ERP experiment, we first propose a short synthetic story of ERP correlates of conscious and unconscious visual word semantic processing.

In 1980, Kutas and colleagues first discovered the N400, a scalp ERP event indexing violations of semantic congruity in visual or auditory sentences (Kutas and Hillyard, 1980). Since then, a rich literature investigated the precise psychological and neural properties of the N400 and of other correlates of semantic processing such as the early left anterior negativity (ELAN), or the late positive complex (LPC, also described as P600) (Pulvermüller et al., 2009; Kutas and Federmeier, 2011). While early studies described this ERP component as a marker of syntactic violation (Friederici and Meyer, 2004), recent studies challenged this interpretation by showing LPC in response to semantic violations or anomalies in the absence of any syntactic violation (Hill et al., 2002; Grieder et al., 2012). In addition, an LPC could be recorded in response to various manipulations of verbal semantics such as inversion of causality (e.g. “the cat that fled from the mice” (van Herten et al., 2005), metaphors (De Grauwe et al., 2010), or ironic stimuli (Regel et al., 2011; Spotorno et al., 2013).

We recently proposed a two-stage model of word semantic processing distinguishing between: (i) a first unconscious stage indexed by an early N400 response (~200–600 ms), and (ii) followed or not by a second stage indexed by a P3b-like (~600–1000 ms) ERP component corresponding to the classical LPC/P600, which would correspond to the conscious access to word semantic attributes (Rohaut et al., 2014). This two-stage model stemmed both from theoretical and empirical considerations. Several studies demonstrated that semantic processing of visual words can occur unconsciously in conscious subjects. For instance, when using a rapid-serial visual presentation (RSVP) task such as the “attentional blink” paradigm, subjects failed to report target words, while a N400 signature of verbal semantic processing could still be observed (Luck et al., 1996). Sergent and Dehaene replicated this finding and further showed that while the N400 could occur in the absence of conscious access to the target word, a later event (P3b) was observed exclusively when subjects were conscious of this word (Sergent et al., 2005). Kiefer found a similar result using a masked semantic priming paradigm (Kiefer, 2002). These studies converge with those obtained in the auditory modality (see above) by finding a P3b component associated with conscious access. In one masking study, Naccache et al. even revealed a modulation of amygdala activity by the emotional valence of masked words in epileptic patients implanted with intracranial electrodes (Naccache et al., 2005). Interestingly, while masked words elicited a single response in the amygdala, consciously perceived unmasked words elicited two successive responses, in agreement with our two-stage model. In a recent ERP study investigating the semantic integration of multiple words in a visual masking paradigm, we showed that the N400 effects were similar for both masked and unmasked conditions, whereas the LPC/P600 effects were

strongly affected by stimulus visibility (van Gaal et al., 2014). Such qualitative differences support our hypothesis that while the N400 is a marker of nonconscious semantic processing, the LPC/P600 indexes conscious semantic processing of words. Interestingly, other studies reported the presence of an N400 and the absence of P3b for unconsciously perceived words in the attentional blink paradigm (Luck et al., 1996; Sergent et al., 2005). Using an auditory word presentation paradigm, we recently found that whereas N400-like ERP components could be observed in unconscious (vegetative state) patients as well as in conscious subjects and in minimally conscious (MCS) patients, only MCS and conscious groups showed a LPC response, suggesting that this late effect could be a potential specific marker of conscious semantic processing (Rohaut et al., 2014).

In the light of this context, we decided to focus our ERP analyses on the N400 time-window to probe unconscious semantic processing, and on the LPC/P600 time window to probe conscious access to semantics. We also varied response code as a within-subject factor (while it was previously a between-subjects factor). Finally, we added the *Separate* condition (W1-W3 link) as in Experiment 1 to better disentangle the W1 and masked-W2 priming effects. Note that our design allowed us to test the respective weights of W1 and W2 priming effects.

According to a first hypothesis, masked words would always elicit an internal semantic priming effect localized in the left hemisphere. Therefore, assuming a more direct link between the left hemisphere and the right hand, this effect would be mostly visible behaviorally when the “right hand for word” code is used. Under such a hypothesis ERPs could reveal this systematic left-hemisphere priming effect irrespectively of the current response code. Alternatively, one may imagine that response code influences the task strategy set by subjects. For instance, one could imagine that the target assigned to the right dominant hand drives the processing strategy. Thus when words had to be answered with the right hand, a semantic strategy may be emphasized (looking for real words), whereas a lexical strategy may be facilitated when pseudo-words had to be detected by pressing the right hand (looking for pseudo-words). Clearly, ERPs should be able to compare these two explanatory models of our behavioral data. Finally, we decided to add the *Sep* condition in which Target words are semantically related to W1 and not to W2. Indeed, the *Cg* priming effect observed in Experiment 2 may be caused both by unmasked W1 and by masked W2 given that these two words are, by transitivity, semantically related to target words. Note however that our masked priming effect is not easily explainable in terms of conscious W1 priming given the absence of such a W1 priming effect in *Sep* condition in Experiment 1, and given the absence of *Cg* priming effect for “left hand for words” response-code.

Material and methods

Participants. Sixteen right-handed native French speakers volunteered for this study (mean age = 24.5 years \pm 4.59; sex ratio = 8 males/8 females). They had no neurological or psychiatric history, were free of any medication and had normal or corrected to normal vision. All participants gave written informed consent, and the experiment was approved by the Ethical Committee of the Pitié-Salpêtrière Hospital, APHP (no. 80-10).

Materials. We used the same material as in the Experiment 2. However in order to disentangle the effect of masked priming observed in Experiment 2 we added the *Separate* condition.

Procedure and design. We used the light masking condition described in Experiment 2 (W2 presented for 33 ms with no pre-mask and followed by a 16 ms post-mask), and inverted the response-code at the middle of the experiment. In order to avoid an overly long experiment we only used masked trials. In order to avoid ERPs visual artifact, Target presentation was fixed to 200 ms. In order to limit the time of the all experiment the inter-trial jitter was slightly decreased (1000 1300, or 1600 ms).

EEG recording and processing. EEG was sampled at 250 Hz with a 256-electrode geodesic sensor net connected to a high impedance amplifier (EGI, Oregon, USA) referenced to the vertex. Impedances were controlled inferior to 100 k Ω . Data were filtered from 0.5 Hz to 30 Hz. Trials were segmented from -300 ms to 900 ms relative to the onset of the target stimulus (word/pseudo-word).

Trials with more than 10 channels containing voltage exceeding $\pm 100 \mu V$ were rejected. For the remaining trials, bad channels were interpolated from contiguous electrodes. Remaining trials were averaged, digitally transformed to an average reference, and corrected for baseline over a 200 ms window spanning from -300 ms to -100 ms before Tgt onset in order to avoid W2 P1/N1 complex time window. All these preprocessing stages were performed in Fieldtrip (Oostenveld et al., 2011).

Statistics

Behavior. See Experiment 1.

ERPs. We used a combination of three complementary approaches.

We first computed a nonparametric statistic implemented in Fieldtrip described fully in Maris and Oostenveld (2007). Briefly, this procedure first compares spatiotemporal data-points across conditions using t-tests. The single-subject ERP averages elicited by each stimulus type were compared using one-tailed dependent samples t-tests. Although this t-test step is parametric, FieldTrip employs a secondary nonparametric clustering method to address the multiple comparisons problem. Specifically, t-values of adjacent spatiotemporal points whose P-values were < 0.05 were clustered together by summing their t-values, and the largest such cluster was retained. A minimum of two neighboring electrodes had to pass this threshold to form a cluster. This entire procedure, that is, calculation of t-values at each spatiotemporal point followed by clustering of adjacent t-values, was then repeated 1000 times, with recombination and randomized resampling of the ERP data before each repetition. This Monte Carlo method generated a non-parametric estimate of the P-value representing the statistical significance of the originally identified cluster. This approach provides increased power relative to other corrections for multiple comparisons such as Bonferroni correction and false discovery rate.

Second, we also computed a less conservative triple-threshold parametric method as reported in our previous studies (Bekinschtein et al., 2009; Faugeras et al., 2011; Faugeras et al., 2012; Rohaut et al., 2014). This method consists in sample-by-sample paired t-tests with a triple criterion: t-test P-value was categorized in three levels (nonsignificant, $0.01 \leq P < 0.05$ or < 0.01), for a minimal duration of five consecutive samples (20 ms), at least on 10 electrodes.

Finally, we used a spatial regression method in which we probed the resemblance of time-courses of ERPs with spatial

vectors defining topography of interest (Pegado et al., 2010; Faugeras et al., 2012; Rohaut et al., 2014).

Note that for the sake of visualization we also used a region of interest (ROI) approach by computing sample-by-sample paired t-tests on the mean signal averaged across the contiguous electrodes of three spatial ROIs (two posterior lateral ROIs and an anterior mesial ROI). Note that this method is circular when applied to a preselected region in which an effect has been detected by the mean of one of the two previous methods [see the “double dipping” issue raised by Kriegeskorte et al. (2009)], but it is useful to better capture and visualize the overall differences of time-courses across conditions.

Results

Behavior. All subjects reported the occasional presence of intratrial semantic links between W1 and Target.

Reaction times. We first ran the following ANOVA: Response-code (2) \times Semantic-link (4) \times Block-order (2), with subject declared as a random factor. A trend toward a main effect of Semantic-link was observed ($F(3,42) = 2.34$; $P = 0.09$), corresponding to shorter RT for Cg and Sep. No other significant main effects or interactions were found (all $P > 0.2$; see [Supplementary Table 4c](#)). Bayes factors suggested weak evidence for one model including Semantic-link factor ($BF_{01} = 0.9$) while others BF_{01} were > 1.5 . We then assessed separately priming effects of W1 and W2 by declaring the following ANOVA: Response-code (2) \times W1-Tgt semantic priming (2) \times W2-Tgt semantic priming (2) \times Block-order. A weak effect of W1-Tgt priming was present (529 ms vs 534 ms; $F(1,14) = 4.2$; $P = 0.06$), while no significant effect of W2-Tgt priming was found significant ($F(1,14) = 0.7$; $P = 0.4$) and none of the other effects or interactions reached statistical significance (all $P > 0.1$; [Supplementary Table 4c](#)).

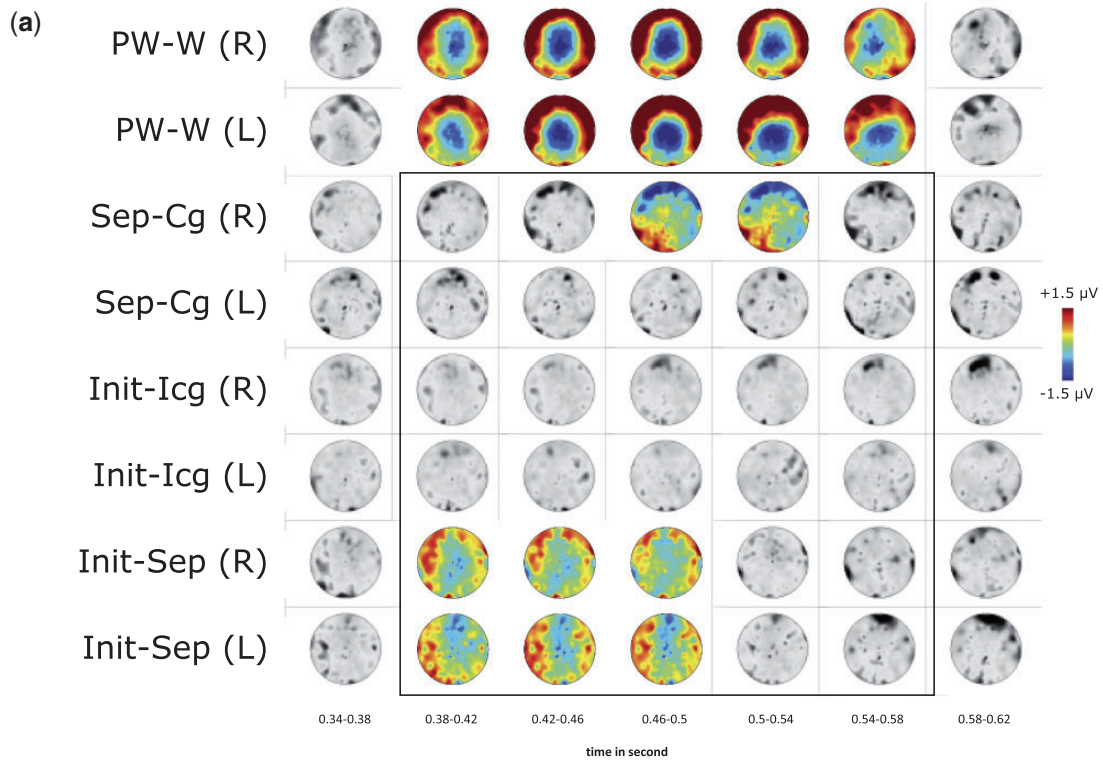
Error rates. Overall mean accuracy reached 96.99%. Both ANOVAs revealed no significant effect (all $P > 0.25$).

Masked words visibility. In spite of the absence of subjective report of prime visibility, the distribution of individual d' values was significantly distinct from a null distribution (mean $d' = 0.18$; $CI = [0.05 \text{ to } 0.31]$, t-test P-value against a zero centered distribution = 0.01). Linear regression analyses did not show any correlation between d' and priming index in Cg trials ($[Sep - Cg]/Sep$, adjusted $R^2 = -0.03$; $P = 0.5$), Bayes factor suggested weak evidence against this correlation ($BF_{01} = 1.93$). The interpolated priming for a null d' (corresponding to the estimated priming effect for a null visibility) was not different from zero ($P = 0.84$).

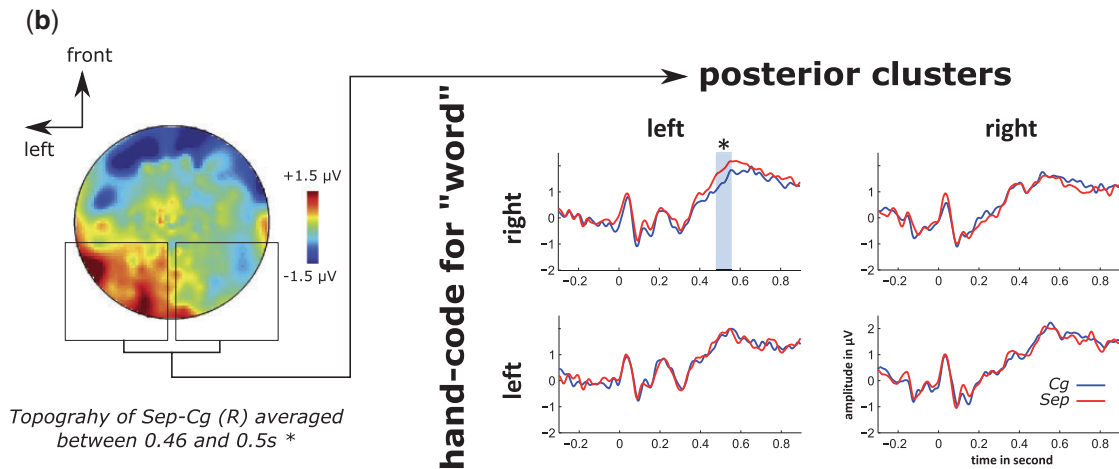
ERPs. We first computed the lexical contrast [Pseudo-words - Words] in order to define the temporal window(s) of interest for lexico-semantic effects. A massive N400 effect was observed on the central region, followed by a late positive component (LPC or P600). These effects were significant with both cluster-based permutation and triple-threshold statistic methods, and spanned respectively from 200 ms to 650 ms for the N400, and from 640 ms to 880 ms for the LPC/P600 ([Fig. 4a: PW-W](#)).

We then probed each of our contrasts of interest regarding W2 semantic priming effects in these two lexico-semantic time-windows as defined with the most stringent method (cluster-based permutations statistics).

In order to isolate neural correlates of the contextualized semantic priming effect of polysemous W2 on Tgt, we computed the [Separate - Congruent] contrast. This analysis revealed a significant posterior left-lateralized positivity during the N400 window (480-



Topographies of contrasts of interest in the N400 window

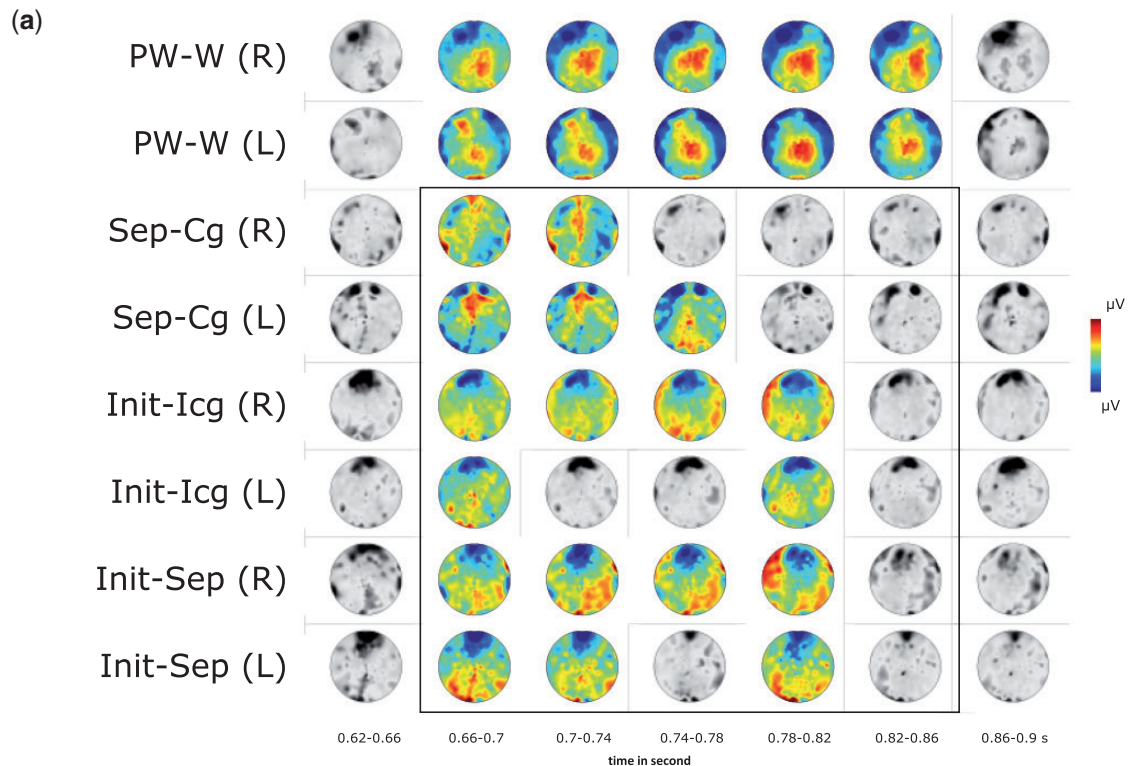


ERPs averaged across clusters for the (Sep-Cg) contrast

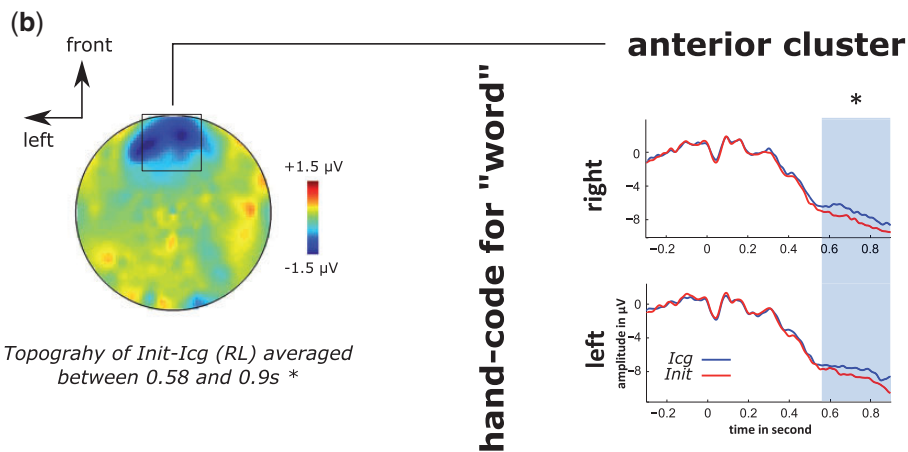
Figure 4. Semantic priming ERP effect within the N400 time-window. (a) ERP effects occurring within the general N400 time-window are reported. The N400 time-window was defined by the contrast Pseudo-word (PW) – Word (W). Statistical effects using a nonparametric cluster-based approach for the PW-W contrast (first two rows), and a parametric approach based on a sample-by-sample paired t-test with a triple criterion are plotted in color map. Nonsignificant topographies are plotted in black and white. Cg = Congruent, Icg = Incongruent, Init = Initial, Sep = Separate; R = “right-hand for words” code; L = “left-hand for words” code. The [Sep-Cg] contrast revealed a left-lateralized priming effect of the contextualized meaning of masked polysemous words for the “right-hand for words” code. (b) The ROI approach showed the time-course of the left lateralized priming effect of the contextualized meaning of masked polysemous words for the “right-hand for words” code. Bars indicate standard errors of mean; * = $P < 0.05$.

530 ms; triple-threshold procedure with $P \leq 0.05$). As observed in the behavioral results of Experiment 2, this effect was dependent on response-code: it was significant for “right hand for words” code, and absent for “left hand for words” code (Fig. 4, third and fourth rows). We confirmed this result by running an ANOVA with: Response-code (2) \times Semantic-link (2) with subject as a random

factor, on voltages averaged in the left posterior ROI over the 480–530 ms time-window. A significant interaction was found between Semantic-link and Response-code ($F(1,15) = 4.75$; $P = 0.045$). Restricted contrasts confirmed that this effect was observed for “right hand for words” code ($F(1,15) = 7.9$; $P = 0.01$), while no significant effect was observed for the other code ($F(1,15) = 0.33$; $P =$



Topographies of contrasts of interest in the LPC window



ERPs averaged in anterior cluster for the (Init-Icg) contrast

Figure 5. Semantic priming ERP effect within the LPC/P600 time-window. (a) ERP effects occurring within the general LPC/P600 time-window are reported. The LPC/P600 time-window was defined by the contrast Pseudo-word (PW) – Word (W). Statistical effects using a nonparametric cluster-based approach for the PW-W contrast (first two rows), and a parametric approach based on a sample-by-sample paired t-test with a triple criterion are plotted in color map. Nonsignificant topographies are plotted in black and white. Cg = Congruent, Icg = Incongruent, Init = Initial, Sep = Separate; R = “right-hand for words” code; L = “left-hand for words” code. A significant effect was observed in all conditions as compared to Sep or Init. (b) The ROI approach showed the time course of the anterior negativity observed in [Init-Icg] contrast, which did not to depend on the response code. * = $P < 0.05$.

0.57). Bayes factor suggested weak evidence for the absence of an effect with the “left hand for words” code ($BF_{01} = 2.65$). In the late LPC/P600 window, we observed an anterior positivity in both response codes conditions (Fig. 5, third and fourth rows and Supplementary Figure and Table 4d).

In order to isolate the neural correlates of the noncontextualized semantic priming effect of polysemous W2 on Tgt,

we computed the [Initial – Incongruent] contrast. This analysis revealed no significant effect using each of the three first statistical methods (all $P > 0.2$) in the N400 time-window. However, the regression approach computed with the topography of the peak of W2-Tgt semantic priming effect ([Sep-Cg]) revealed the existence of a significant activation of the noncontextualized meaning of W2 during the N400 time-window, exclusively for

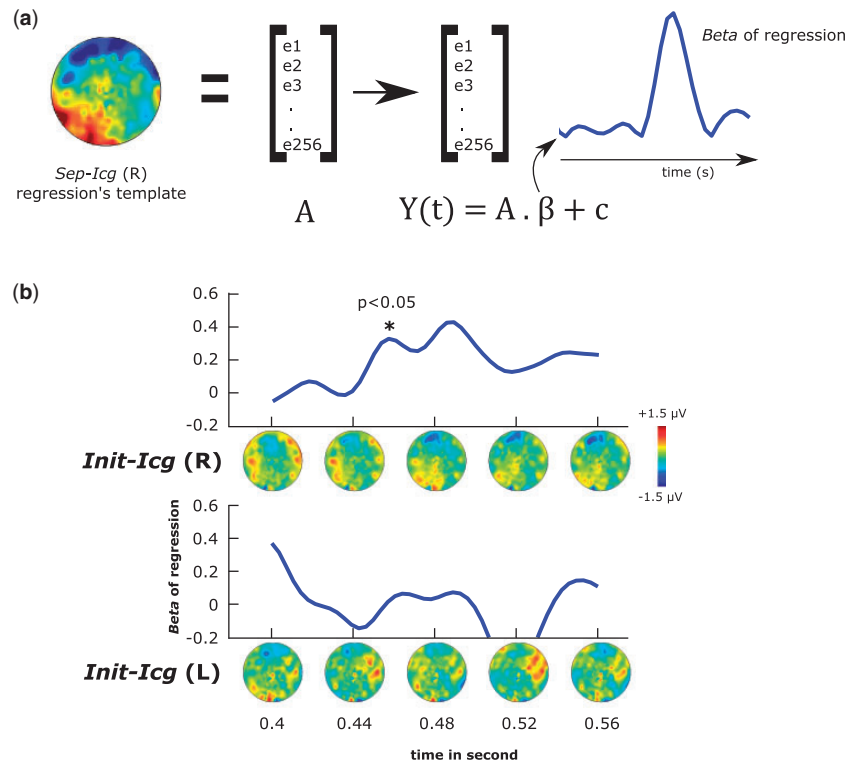


Figure 6. A correlate of unconscious semantic processing of the noncontextualized meaning of polysemous words. Using a regression approach on canonical topography of the [Sep-Cg] effect [see (a) and text], we detected a significant semantic priming effect for noncontextualized meanings of W2 during the N400 window, exclusively for trials answered with the “right-hand for words” code.

“right hand for words” response code (Fig. 6). In the late LPC/P600 window, a sustained anterior negativity, similar to the one present in the LPC/P600 topography, was present in both response codes conditions (Fig. 6, fifth and sixth rows) using the triple-threshold method. The ANOVA computed on the anterior ROI confirmed this pattern by showing a main effect of Semantic-link ($F(1,15) = 8.2$; $P = 0.012$), with no significant effect of the response-code factor and of the interaction between these two factors (both $P > 0.5$; Supplementary Table 4d).

Finally, we performed three ANOVAs similar to the one run in Experiment 1, in order to assess orthogonally W1 and W2 priming effects on target words: W1-priming (2) \times W2-priming (2) \times Response-code (2) with subject declared as a random factor, on voltages averaged across the N400 time-window for left and right posterior ROIs separately, and averaged across the LPC/P600 time-window for the anterior midline ROI (Fig. 7). In the left posterior ROI, we observed a marginal N400 effect of W1-priming ($F(1,15) = 4.24$; $P = 0.06$), as well as a significant effect of W2-priming ($F(1,15) = 5.54$; $P = 0.03$), with no main significant effect of response code ($F(1,15) = 1.52$; $P = 0.24$). Most crucially, an interaction between W2-priming and response-code was present ($F(1,15) = 6$; $P = 0.03$), corresponding to a significant W2-priming effect for “right hand for words” condition ($F(1,15) = 8$; $P = 0.01$) while there was no effect for the other response-code ($F(1,15) = 0.27$; $P = 0.6$; Supplementary Table 4d). Bayes factor suggested positive evidence for no effect with the “left hand for words” code ($BF_{01} = 3.65$). The same analysis performed on the right posterior ROI did not reveal any effect and all BF_{01} for models including W1 or W2-priming effect were >4.8 , suggesting positive evidence for the absence of an effect. For the anterior midline ROI, this ANOVA revealed a main effect of W2-priming ($F(1,15) = 5.39$; $P = 0.03$) which did not interact

with response-code ($F(1,15) = 0.02$; $P = 0.9$). All other effects were not significant with $BF_{01} > 3$.

Discussion

We did not obtain behavioral priming effects in Experiment 3 in which only masked trials were used. In spite of this negative finding, ERPs were in agreement with our previous behavioral findings on the impact of response-code on contextualized-W2 target masked priming effects. The left-lateralized effect occurring during the N400 window was exclusively present for “right hand for words” response-code. Moreover, we detected a similar but weaker effect – significant only in the topography regression analysis – for the noncontextualized meaning of polysemous W2. These two findings suggest that both meanings of masked polysemous words were activated, although the contextualized meaning was more activated than the noncontextualized one. Finally, the late processing of target words (LPC/P600 window) revealed an original pattern: an anterior negativity was present in all conditions in which targets were semantically primed, either by W1 and/or by W2. This last effect was not dependent on response-code.

General Discussion

In this work, we revisited the seminal experiments of Marcel on the unconscious processing of polysemous words using: (i) more stringent methods to present masked stimuli and to assess visibility as well as semantic processing, and (ii) a combination of behavioral and ERP measures. Our results can be summarized in four points leading to a convergent conclusion.

First, concerning consciously visible polysemous prime words, we replicated the original result reported by

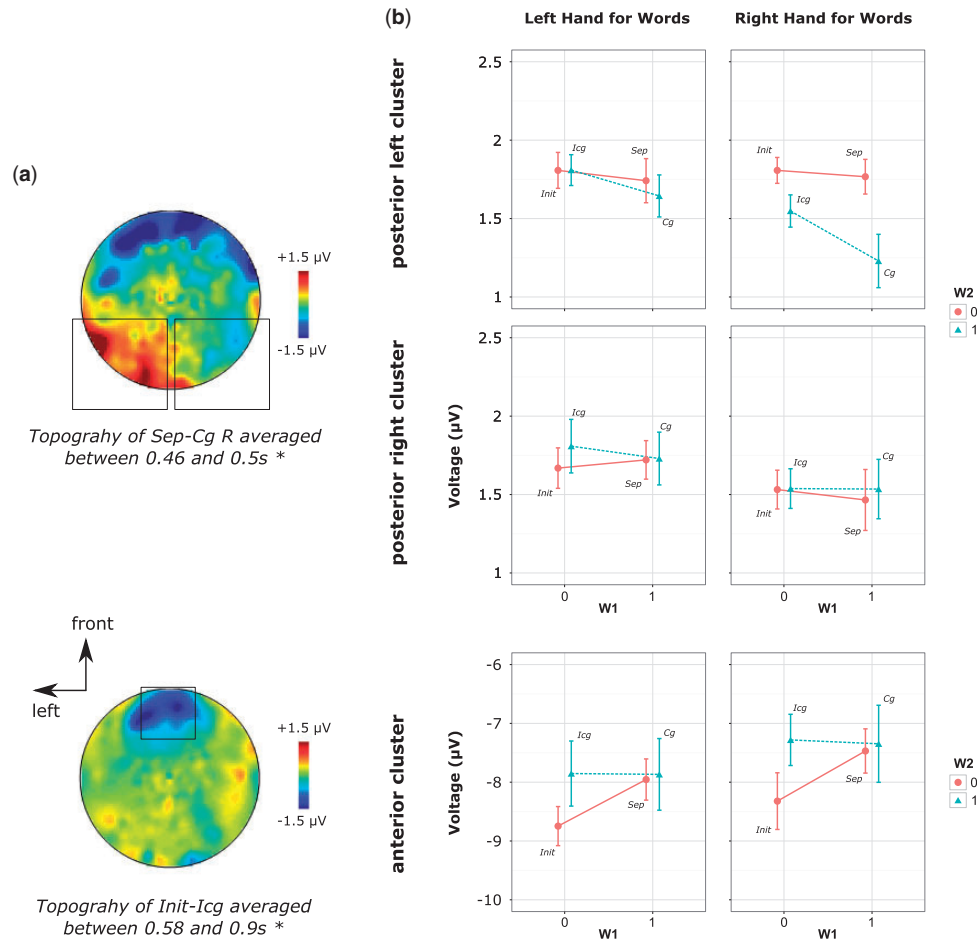


Figure 7. ERP correlates of W1 and W2 semantic priming effects. (a) Topographies of masked W2 contextual priming effect in the early window for “right-hand for words” (N400 window), and of masked W2 noncontextualized priming effect in the late window (LPC/P600 window) of target processing. * $P < 0.05$. (b) Correspondent ROIs voltages: while the W2 early effect was exclusively observed for “right-hand for words” code, the late effect was observed for all conditions including a semantic link between target words and W1 and W2 words, irrespective of response code (see main text for statistical values). Error bars correspond to standard error of the mean.

Schvaneveldt and Meyer (1976) and by Marcel (1980): only the contextualized meaning of consciously perceived polysemous words primed target processing. However, we observed that this selectivity of priming could disappear under conditions of slowing down of RTs suggestive of cognitive fatigue.

Second and most importantly, concerning masked polysemous prime words, our results diverged totally from Marcel’s findings. Unconscious semantic processing of masked words was observed both in behavior and in ERP data, but was also sensitive to the conscious context defined by W1.

Third, this sensitivity of unconscious semantic processing was also found in relation to the response-code used to answer targets.

Fourth, we detected an ERP correlate of semantic processing of both meanings of the masked word in the late window of conscious processing of target words.

We will now discuss each of these four results.

Restriction of polysemy: consciousness or cognitive control?

The partial replication of Marcel’s result (selective and nonselective priming) for consciously perceptible prime words may be interpreted in two distinct ways.

One interpretation may posit that the restriction of polysemy according to the context requires the contribution of executive control in addition to conscious perception. When subjects are conscious of W2 but tired (as we hypothesized for those who performed unmasked blocks during the second half of the experiment and with longer RTs), they may lose this restriction of polysemy due to insufficient cognitive control resources during this rapid-serial-visual-presentation task. Indeed, several studies reported the implication of prefrontal cortex areas in the implementation of contextual selection processes over ambiguous or polysemous verbal semantic representations (Thompson-Schill et al., 1997, 1999; Ihara et al., 2007). A more causal link between the left inferior frontal gyrus (LIFG) and this selection process of contextual semantic representations of polysemous words has been provided by patient studies showing that it is impaired when a focal brain lesion affects this precise area (Hagoort, 1993; Swaab et al. 2003). Recently, a transcranial direct current stimulation over this area has been reported as enhancing this contextual selection process in the case of ambiguous words (Ihara et al., 2015). Interestingly, previous studies using shorter SOAs than the one we used here (<300 ms vs 500 ms in our case) also reported behavioral evidence of processing of the multiple meanings of polysemous visible words (Swinney et al., 1979; Onifer and Swinney, 1981).

Alternatively, one may imagine that under conditions of fatigue, subjects would not have used the contextual word (W1) efficiently, and therefore would not have defined a strong semantic context. If so, then the semantic priming of both meanings of unmasked words would not reflect the loss of polysemy restriction, but rather the mere absence of context. At this stage we cannot decide between these two hypotheses. However, this ambiguity stresses that future experiments using this triple-word paradigm must include objective evidence of W1 processing. For instance, the use of ERP correlates of early (P1/N1) and late (P300/N400) stages of W1 processing may be necessary to provide a univocal interpretation of the absence of polysemy restriction effect.

Restriction of polysemy for unconscious prime words

In Experiments 2 and 3, we collected behavioral and then ERP evidence demonstrating a strict restriction of unconscious semantic processing of masked polysemous words according to the conscious context. A behavioral priming effect (Experiment 2) as well as an N400 effect (Experiment 3) was observed in response to *Congruent* trials and not to *Incongruent* trials. Per se, these two results establish the existence of top-down contextual control over nonconscious verbal semantic representations. Resolution of lexical ambiguity in the case of consciously visible words is still a subject of theoretical discussion between four types of models (Simpson, 1984): context-dependent, ordered-access, exhaustive access, and hybrid models. In our case, the absence of behavioral effect in the *Incongruent* condition at short SOAs (100 ms) suggests either a context-dependent model even for unconsciously perceived words, or a very early inhibition process. Eckstein and colleagues probed both unmasked and masked priming effects across SOAs ranging from 100 ms to 1500 ms, and reported a faster subliminal selection of dominant vs rare meanings of polysemous words for masked primes (Eckstein et al., 2011). Our study adds a notable result to this previous report: in our case, this semantic selection process was not inherent to W2 meaning frequencies, but was driven by the conscious context defined by W1, and occurred among the two meanings of polysemous words W2, irrespectively of their relative strength. This indicates that the modulation was not intrinsic to W2 but contextualized by W1.

We are well aware that the absence of behavioral effect in ERP Experiment 3 constitutes a limitation of our results. However, note that only masked polysemous W2 were used in this experiment, and that the probability of semantic relation between W1 and Tgt was greater than in Experiment 2 (0.5 vs 0.25; Supplementary Table 3). This difference could have prevented the optimal focusing of exogenous and endogenous temporal attention to the critical masked words (Naccache et al., 2002; Kiefer and Brendel, 2006). Moreover, the absence of behavioral effect might have stemmed from the smaller number of participants in Experiment 3 ($n = 16$) compared to Experiment 2 ($n = 48$). This difference was motivated by our aim to analyze ERP responses which are usually more sensitive than composite measures such as RTs (Sternberg, 2001). Finally, the similarity of response-code impact on both behavior and ERP effects (see below) strongly suggests that these two experiments tap into the common unconscious semantic processing of masked polysemous words. This result clearly contradicts the original finding of Marcel who used less rigorous methods of prime visibility assessment (at the time), and who used much longer SOAs than we did. A possible explanation of the discrepancy between Marcel's results and our own results could be found in the

following scenario based on three premises: (i) while most masked priming effects show a fast decay with no residual effect after a few hundred milliseconds (Greenwald, 1996; Naccache et al., 2002), Marcel's effects persisted with a much longer SOA of 1500 ms; (ii) most Marcel's effects have been criticized due to the lack of correct assessment of the absence of conscious visibility of masked primes (Purcell et al., 1983; Cheesman and Merikle, 1984; Holender, 1986); (iii) the restriction of polysemy by context requires the context to be attended and processed (as demonstrated in our Experiment 1 with a conscious polysemous priming effect when the context is not well processed). Therefore, it may well be the case that in Marcel's experiments masked W2 primes were consciously perceptible but with the need of some effort. In turn, this may have induced an attentional focus onto the prime stimuli, at the expense of deep and sustained semantic processing of contextual word W1. As a net result, Marcel may have measured conscious priming effects in the absence (or relative absence) or contextual setting. This scenario predicts a conscious polysemous priming effect with masked primes, and a conscious priming effect restricted to the contextualized meaning for unmasked primes. As we stated above, these comments call for a crucial control in future experiments on polysemous priming: in order to claim the absence of polysemy restriction by the context, one must provide evidence of context processing, using either behavioral or functional-brain imaging evidence (e.g.: ERPs, fMRI).

Our demonstration of a similar sensitivity of conscious and unconscious processing of polysemous words to the conscious context constitutes a new step in the general description of rich and various influences on many unconscious cognitive processes. The whole notion of modularity and of automaticity seems to be breached by a collection of diverse empirical reports, and further strengthens the functional proximity of conscious and unconscious cognitive processes which are hosted by similar cortical networks as theorized in the global workspace model of consciousness (Baars, 1989; Dehaene and Naccache, 2001; Dehaene et al., 2006; Naccache, 2006). Interestingly, the detection of the behavioral or functional brain-imaging correlates of these conscious influences on unconscious processing may prove extremely useful in a challenging medical context. They may help determine the level of conscious awareness of patients suffering from disorders of consciousness, in whom clinical examination is very limited (Laureys et al., 2004; Rohaut et al., 2013; Giacino et al., 2014). Coleman et al. used fMRI to probe the processing of ambiguous sentences and reported the contribution of LIFG in some severely disabled patients (Coleman et al., 2007). Our group recently demonstrated that an auditory N400 priming effect was present in conscious controls as well as in minimally conscious (MCS) and vegetative state (VS) groups of patients, whereas only MCS patients and conscious controls showed of LPC/P600 effect (Rohaut et al., 2014). The demonstration of an impact of a semantic context on the processing of polysemous words could be a solid index of conscious integration of the semantic context.

A new effect of hand-response code

The third original finding of our study consists in the strong impact of response code on unconscious priming. While this response code factor did not interact with conscious semantic priming effect, unconscious priming occurred exclusively for "right hand for words" instruction in this LDT. We may put forward two main explanations for it. On the one hand, unconscious semantic processing could be localized in a left-

hemispheric processor (Dehaene and Naccache, 2001; Schmidt et al., 2010), whereas conscious access to this representation would co-occur with its availability to widespread bihemispheric global workspace. Under such a hypothesis, conscious priming would be detectable irrespective of response-code while unconscious semantic priming would only (or mostly) prime the left-hemispheric motor network, and subsequently translate into behavior (RT) only when subjects had to use their right hand to categorize target stimuli as words. This hypothesis predicts that this systematic left-hemispheric semantic priming effect should be detected using ERPs in both response code conditions. In contrast, one may imagine a less parsimonious scenario in which the instruction of responding to words with the right hand would enhance left-hemispheric language network activity, and would then strategically orient subjects to perform a “word meaning detection” task, whereas the opposite instruction would bias them to perform “unfamiliar letter-string (pseudo-word) detection” task. Additionally, this bias would be more effective on unconscious representations. This hypothesis predicts that left-hemispheric correlate of masked words would be highly dependent on response code. ERP results of Experiment 3 were clearly in favor of this second scenario. The left-hemispheric N400 effect was observed only for “right hand for words” trials. This intra-subject effect could not be explained as a correlate of right hand motor preparation given that we contrasted trials answered with the right hand ([Sep-Cg]), and given the absence of RT difference between these two conditions (Sep and Cg). Additional studies would be important to probe the level of metacognitive knowledge of subjects: do they voluntarily engage in such a task strategy? At least, is this process accessible to their conscious introspection? Is this effect also present on unmasked words, even if it does not translate to behavior? As a first step in that direction, we probed (Experiments 1 and 2) the reportability of unmasked W2 polysemy, which was not negligible (~10–30%).

Finally, it is noteworthy that LDT studies are usually conducted with a right hand response code for words. This corresponds either to a “right hand for words/left hand for pseudo-words” response code, or to a right hand response-code for both words and pseudo-words (e.g.: index vs middle finger). There is no clear justification for this consensual convention, except the finding that response code does not affect semantic priming effects of consciously visible words (Weems and Zaidel, 2005). We performed a systematic PubMed research using the following search string: “semantic AND priming AND (unconscious OR subliminal OR masked)” for a period of 4 years spanning from January 2012 to December 2015. We identified 97 articles. Thirty-two of them were excluded either because the full text was not available online (15), or because the article did not correspond to a masked semantic priming experiment (12), or used a nonmanual response (5). Among the 65 remaining studies, a counterbalanced bimanual response-code was used in 10 papers (15%) and a fixed right hand response for words was used in 16 papers (25%). Note that the effect of this hand factor was never analyzed in any of these 10 counterbalanced studies. Fifteen (23%) studies used a fixed hand code (index or middle finger of the dominant hand) to respond to all experimental conditions. In the 24 remaining studies (37%), the responding hand was simply not documented explicitly in the “Methods” section.

Surprisingly, note that subjects handedness was documented in only 28 (43%) of these 65 studies. Taken together, this provides a systematic use of the right hand to answer some words conditions (e.g.: any word in a LDT or living animals in a

semantic categorization task) in at least 31/65 (48%) studies. This unknown exact proportion may reach 85% when including the 24 studies in which this information was not explicitly documented. Similar percentages were obtained when restricting the analysis on LDT studies (28 studies). We summarize this systematic review in the [Supplementary Table 5](#). According to our results, this heuristic choice of asking subjects to respond to words with their right hand may stem from the left-hemispheric task-induced strategy enhancing verbal semantic representations that we identified in the present study. Finally, we suggest that future studies exploring language processing should cautiously document the instructed response-codes, particularly when masking is involved. Ideally, this factor should be controlled either within or across subjects.

Target words acting as retro-contextual cues?

An unexpected finding of our ERP experiment is the late LPC/P600 component modulated by all forms of semantic link between targets and other words: masked or unmasked prime words (W2) or contextual words (W1). This late effect did not translate into behavior and was not dependent on two factors manipulated in this experiment: semantic context and response-code. As we noted, this effect was not restricted to prime words and escaped these two factors which dramatically affected both behavioral and ERP priming effects. We propose that rather than being a priming effect of W1 or W2 on target words, this ERP modulation could reflect a retroactive effect: once the consciously visible target word is processed semantically, this current semantic representation could retroactively modulate all other available lexical or semantic representations of W1 and/or W2 which are still actively encoded in lexico-semantic networks. If correct, our interpretation means that a lexical pre-semantic representation of masked polysemous W2 is still active at this latency. This hypothesis is reminiscent conceptually of a recently demonstrated retro-cueing effect corresponding to an enhancement of unconscious representations after the presentation of a spatial attention cue (Sergent et al., 2011; Sergent et al., 2013).

We conclude by stating that the results of the present study extend the concept of flexibility and sensitivity of high-level unconscious processes to several top-down factors.

Supplementary data

[Supplementary data](#) is available at *Neuroscience of Consciousness Journal* online.

Acknowledgements

We thank Christophe Pallier and Tal Seidel Malkinson for their help on statistical issues. This work was supported by the Fondation pour la Recherche Médicale (FRM; “Equipe FRM 2015” grant to LN), by INSERM (“Poste Accueil INSERM” from November 2010 to October 2012 to BR), and by the program “Investissements d’avenir” ANR-10-IAIHU-06. We thank the editor, Prof. Anil K. Seth, as well as the two anonymous reviewers for their constructive feedback. Data are available on request.

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