# The temporal dynamics of inflected word recognition: A masked ERP priming study of French verbs ☆

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## ARTICLE INFO

## ABSTRACT

Morphological aspects of human language processing have been suggested by some to be reducible to the combination of orthographic and semantic effects, while others propose that morphological structure is represented separately from semantics and orthography and involves distinct neuro-cognitive processing mechanisms. Here we used event-related brain potentials (ERPs) to investigate semantic, morphological and formal (orthographic) processing conjointly in a masked priming paradigm. We directly compared morphological to both semantic and formal/orthographic priming (shared letters) on verbs. Masked priming was used to reduce strategic effects related to prime perception and to suppress semantic priming effects. The three types of priming led to distinct ERP and behavioral patterns: semantic priming was not found, while formal and morphological priming resulted in diverging ERP patterns. These results are consistent with models of lexical processing that make reference to morphological structure. We discuss how they fit in with the existing literature and how unresolved issues could be addressed in further studies.

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## 1. Introduction

The nature of the organization of the mental lexicon enabling us to link sound patterns and written words to their meaning has long been debated in psycholinguistics (e.g., Bates & Godham, 1997; McQueen & Cutler, 1998). Of particular interest is the status of morphology during word processing. By morphology we mean the structure of complex words and the dynamic processes that allow us to decompose them into simple units (morphemes) that can be recombined with other morphemes to create new words (Aronoff & Fudemann, 2011). We distinguish between (i) stem morphemes that carry the core conceptual meaning (e.g., the verb 'inform'), (ii) derivational morphemes that (can) change the word's syntactic category and may dramatically change its meaning (e.g., '-ative' can change a verb into an adjective: 'inform-ative'), and (iii) inflectional morphemes that primarily mark syntactic information without changing the word category or the core meaning (e.g., '-s' for the third person singular present tense: 'inform-s').

In the present study we address a number of questions: How is the processing of inflectional morphology integrated in the time course of visual word recognition? What *are* "morphological effects" found in behavioral and electrophysiological studies of lexical access? Can we distinguish morphological from semantic and orthographic effects? And which models can best account for these? Using event-related brain potentials (ERPs) to investigate ortho-graphic (formal), semantic, and morphological priming effects on the processing of French verbs in a visual lexical decision task, we contrasted two views on the role of morphology in the organization of the mental lexicon: morphological and eliminativist.

## 2. Background

### 2.1. Lexical processing models

Many psycholinguists regard morphological structure as an indispensible level of linguistic representation (Baayen, Schreuder,

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& Sprodt, 2000; Domínguez, de Vega, & Barber, 2004; McQueen & Cutler, 1998). It is used in real-time language processing where comprehension and production of forms like 'kicked' involves (de)composition of constituent morphemes 'kick' and '-ed' (e.g., Clahsen, 2006; Stockall & Marantz, 2006). Evidence supporting this comes from priming studies where complex target words (e.g., 'inform-ative') are easier to process when preceded by another word sharing the same base morpheme (e.g., 'inform-s'). Priming effects have also been reported in electrophysiological studies (Brown & Hagoort, 1993; Lavric, Clapp, & Rastle, 2007; Morris, Frank, Grainger, & Holcomb, 2007; Morris, Grainger, & Holcomb, 2008).

However, other views suggest that the link between the orthographic or phonological pattern of a word and its meaning does not require morphological representations (Bates & Godham, 1997; Devlin, Jamison, Matthews, & Gonnerman, 2004; Seidenberg & Gonnerman, 2000, see also Hay & Baayen, 2005 for a critical review). According to this eliminativist stance, morphology is epiphenomenal and has no role to play in lexical representation and processing. This approach claims that there is no theoretical or empirical requirement for morphological representations, nor to putative relationships between morphemes. Morphological effects are argued to be the result of co-activation of *formal* (orthographic/phonological) and *semantic* information (the "convergence of codes"; Seidenberg & Gonnerman, 2000, see also Bates & Godham, 1997; Devlin et al., 2004; Seidenberg & McClelland, 1989). Apparent "morphological" priming effects (see Section 2.2) are simply a combination of (i) orthographic priming (due to the shared letters 'i-n-f-o-r-m', possibly supported by co-activated phonological representations) and (ii) semantic priming due to the conceptual-semantic overlap between the two word meanings.

Although there is abundant data bearing on this theoretical opposition, a neutral observer can reasonably characterize the empirical evidence as inconclusive (see Seidenberg & Gonnerman, 2000 for some relevant discussion). Behavioral data in particular have often been argued to equally support both accounts (Feldman & Prostko, 2002; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997; Rueckl, 2010). However, data from such experiments (i.e., response latency and accuracy, which are mediated by motor responses) provide only *indirect* evidence for underlying cognitive processes. In contrast, ERP data enable us to tap brain processes involved in lexical access in real time, and continuously across the entire trial, i.e., long before a motor response has been initiated.

## 2.2. Event-related potentials and the study of lexical processing

A number of electrophysiological studies have shown that different ERP priming effects can be observed that are likely to reflect specific cognitive processes at distinct time periods during word recognition. First, a classic finding in ERP research using *semantic* priming (i.e., presentation of *doctor* before the target *nurse*) is the attenuation of the N400 component, a negative-going waveform believed to reflect processing costs during lexical access and semantic integration. While reductions of the N400 amplitude are the best known ERP correlates of semantic priming at the word level (Bentin, McCarthy, & Wood, 1985; Koivisto & Revonsuo, 2001), repetition priming (e.g., *face-face*) has an even stronger effect in reducing the N400 and, importantly, also affects the ERP signal in both earlier and later time windows than semantic priming (e.g., Rugg, 1987). Rugg's priming study demonstrated that repetition priming of both words and non-words affected processing as early as 200 ms and as late as 600 ms. Whereas early differences were similar in both priming conditions, the late effect was significantly larger for repeated words than non-words, suggesting that it may be attributable to the

words' pre-existing representations in lexical memory (Rugg, 1987). As our review of ERP studies will highlight, morphological priming, similarly to repetition priming, also leads to modulation of negativities in an extended latency range.

ERP studies focusing on morphological relationships between words are relatively rare, in particular those investigating inflectional – as compared to derivational – morphology. Whether results obtained in derivational morphology studies can be generalized to inflectional morphology remains unclear. Using an unmasked priming paradigm (see Section 2.3 for a discussion of masking), Domínguez et al. (2004) reported a series of experiments on lexical access using morphologically related inflected primes (*hijo-hija* 'son-daughter'). They provide evidence for morphological priming that is distinct from semantic priming and cannot be attributed solely to formal priming. Spanish regular nouns appear with a noun marker suffix (*-a* or *-o*, for feminine and masculine nouns, respectively). Contrasts were made between these and three other types of pairs: stem homographs with similar word-initial orthographic CVC[1] overlap but no morphological relationship (*foco-foca* 'floodlight-seal'), orthographic-neighbor words with partial orthographic overlap (CV_V) such as *rasa-rana* ('flat-frog') as well as (semantic) synonym pairs (*cirio-vela* 'candle.m-candle.f').[2] All conditions were compared to unrelated prime–target pairs (ex. *pavo-meta* 'turkey-goal'). Results showed that morphological pairs resulted in a strong and long-lasting attenuation of the N400 amplitude (250–650 ms). In the homograph condition, an early N400 attenuation (250–350 ms) was observed, but this was followed by a *more* negative amplitude in the 450–650 ms time-window (a delayed N400). Orthographic neighbors did not show any signs of priming, while synonym priming showed only late N400 amplitude reductions (in the 450–650 ms time window). The authors interpreted their ERPs as evidence for three stages relevant to morphological processing, all resulting in relative positivities (reduced negativities): (1) effects of word segmentation into stem and affix (*hij-o*) and form priming at the lexeme level (250–350 ms), which were also found for stem homographs; (2) effects of lemma contact activating syntactic and semantic stem information (350–450 ms), which were absent for homographs; and (3) effects of semantic integration (450–650 ms), which were also observed for synonyms. As only morphological priming reduced the N400 amplitude across all three stages, the authors concluded that models lacking a morphological level of representation would be unable to explain these data.

Münte, Say, Clahsen, Schiltz, and Kutas (1999) studied the effects of (long-lag) morphological priming in English inflected regular (*walked-walk*) and irregular (*went-go*) verb pairs, for both real and novel (e.g., *broded-brode*) verbs. They observed reduced N400s for regular as opposed to irregular verbs. The effect, later replicated with Spanish verbs (Rodriguez-Fornells, Münte, & Clahsen, 2002), was restricted to real (as opposed to novel) word pairs. The results of these two studies were interpreted as showing differential access to (decomposable) regular and (non-decomposable) irregular verbs, illustrating how the N400's can be modulated by morphological structure. However, the authors simply assumed the existence of morphology and did not attempt to justify its status as an independent level of representation. Note that these studies did not have semantic priming control conditions, although Münte et al. use orthographic priming to control for formal overlap effects. A more recent study by de Diego-Balaguer, Sebastián-Gallés, Díaz, and Rodríguez-Fornells

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[1] CVC = a consonant–vowel–consonant sequence.
[2] The '.m' in candle.m indicates it is a masculine noun in Spanish (.f = feminine).

(2005) does contain a semantic control as well as a novel-word priming orthographic control condition. They studied regular and irregular verb processing in bilingual Catalan-Spanish speakers, while using an unmasked priming paradigm, with a concurrent letter search on the prime to reduce semantic priming effects. They show that morphological priming is much stronger than semantic priming and that regular and irregular verbs show different priming patterns (stronger reductions of the N400 in regular conditions only). A problem in Rodriguez-Fornells et al.'s (2002) and de Diego-Balaguer et al.'s (2005) stimuli is a possible confound between orthographic overlap and morphological regularity (i.e., the fact that regular verbs have more orthographic – and phonological – overlap, walked-<u>walk</u>, than irregular verbs, went-<u>go</u>), making it unclear which of these factors was driving the observed differences.

## 2.3. Masked priming

Another issue that arises with the studies discussed above is the use of (consciously) perceptible primes. This can affect how the target is processed as participants might develop hypotheses about the relationship between the prime and the target (e.g., Lorch, Balota, & Stamm, 1986). Semantic priming is highly susceptible to this type of effect in behavioral studies (Kouider & Dehaene, 2007; Neely & Keefe, 1989). An elegant way of addressing this concern is the technique of masking, i.e., the combination of a very short prime presentation (in the range of 25–50 ms) that is immediately followed (and often preceded) by a meaningless character string such as "######". The backward mask can overwrite the visuo-sensory representation and conscious perception of the prime and its features (also preventing retinal after-images) (Holcomb & Grainger, 2006; Kiefer, 2007).

Masked priming reduces strategic processing (Forster & Davis, 1984; Forster, 1998). Most importantly, in conjunction with short prime presentation, masking can entirely suppress semantic priming, both behaviorally (Feldman & Prostko, 2002; Forster, 1998; Holcomb & Grainger, 2009; see Kouider & Dehaene, 2007 for a review) and in ERPs (Brown & Hagoort, 1993; Kouider & Dehaene, 2007; Lavric et al., 2007; Morris et al., 2007, 2008), while yielding both formal and morphological priming, allowing us to test the putative dissociation of formal and morphological priming effects from semantic ones. A few studies have reported semantic priming with masking and short prime presentation, either with behavioral methods (Draine & Greenwald, 1998; Greenwald, Draine, & Abrams, 1996; but see Abrams & Greenwald, 2000 for a re-interpretation of their own data), or using brain imaging (Deacon, Hewitt, Yang, & Nagata, 2000; Dehaene et al., 2001, 1998; Kiefer, 2002; Kiefer & Spitzer, 2000). However, semantic priming effects from a number of the above-cited behavioral and brain imaging studies are driven by prime–target congruency, by attention being directed to the primes, or by strategies based on partial perception of primes (Abrams & Greenwald, 2000; Klinger, Burton, & Pitts, 2000; Kouider & Dehaene, 2007; Kouider & Dupoux, 2007). Kiefer and Brendel (2006) found that, in masked semantic priming, modulation of the N400 did not reach statistical significance when participants were instructed to focus on the target, even though priming could appear at short SOAs (67 ms) when they were asked to attend to the prime. Kiefer (2007) concludes that these studies provide "strong evidence that attention to an unconsciously perceived masked stimulus is a prerequisite for semantic N400 ERP priming effects to occur." (p. 298) Kouider and Dupoux (2007) concur that "the only situations in which semantic priming is found are cases of global [… or] partial awareness. Truly unconscious priming is restricted to formal (or morphological) identity priming." (p. 81).

Lavric et al. (2007) as well as Morris et al. (2007, 2008) used masked priming in ERP studies with English derived words, grouped into three types of pairs: morphologically related (and semantically transparent) (e.g. darkness-DARK), pairs with no morphological relationship (but see discussion below) that could in principle be decomposed into pseudomorphs (corner-CORN, see Section 2.4 for a discussion of pseudomorphs), and unrelated (and un-analyzable) but formally similar pairs (brothel-BROTH). The three studies found similar priming effects for the two first conditions. They observed an attenuation of the early N250, which may correspond to the early 'segmentation and form priming' effect reported by Domínguez et al. (2004). Interestingly, these effects were weaker for the formal than the morphological condition, suggesting at least some modulating role of lexical factors. This is compatible with an interpretation of the N250 as indexing access to both sub-lexical phonology and word-level orthographic representation at the sub-lexical/lexical interface (Holcomb & Grainger, 2006). Importantly, most authors agree that the contribution of lexical processing on N250 effects does not implicate semantics (Lavric et al., 2007; Morris et al., 2008). These data are in line with similar behavioral experiments (Longtin, Segui, & Hallé, 2003; Taft & Kougious, 2004).

More recently two studies using magneto-encephalography (MEG) have focused on similar relations. Lehtonen, Monahan, and Poeppel (2011) used Rastle et al.'s stimuli in a forward masked priming task. They show that an early MEG signature around 220 ms, potentially analogous to the N250 in ERPs, is differently affected by the type of prime–target relationship. Transparent morphological pairs prime more than opaque ones, and these in turn prime significantly more than orthographic pairs. The latency of the MEG component was also reduced in both morphological conditions, but not the orthographic one. The authors argue that these results show similar prelexical effects of shared form to those of the ERP studies. Likewise, an unmasked priming study for inflected English verbs shows that identity and both regular and irregular verb priming (jump-jumped, teach-taught) result in shorter M350 latencies (the MEG equivalent of the N400) than either pure formal (orthographic) priming (curt-cart) or a priming condition combining formal and semantic but not morphological relationships (boil-broil) (Stockall & Marantz, 2006). Taken together, these studies support morphology as a distinct level of representation with an important role in lexical processing, even in the absence of complete formal orthographic overlap. These data converge toward a picture of lexical access that is initially mediated by shared form, followed by morphological effects, and that this second aspect of lexical processing is different from that found for orthography or semantics.

## 2.4. List effects arising from stimuli

However, a number of issues remain, partly due to methodological shortcomings of previous studies. For one, a majority of the experiments reported here compared ERP or MEG components elicited by different target stimuli in each of their experimental conditions, as is the case with all the studies based on Rastle, Davis, and New's (2004) stimuli lists including Lavric et al. (2007), Morris et al. (2007, 2008) and Lehtonen et al. (2011). This is a recurrent issue in priming studies (Forster, 2000) and can result in 'list effects' that are independent of the manipulation of interest. For example, the priming found for derived forms might be driven in part by the repeated presentation of specific derivational suffixes (Morris et al., 2008). In addition, the linguistic criteria used to create stimuli for different 'morphological' conditions are often problematic. For instance, the stimuli developed by Rastle et al. (2004) are divided into three groups based on orthographic overlap and morphological structure. The first group

has transparent morphological stems and forms derived from these such as *bake-baker*, the second has pseudo-morphological relations such as *board-boarder*, where the derived word could be decomposed into a pseudo stem (*board*) and a pseudo suffix (-*er*). These are morphologically complex forms only in appearance.[3] The third group of stimuli pairs has orthographic overlap with no possible (pseudo- or real) morphological parse, such as in *arse-arsenal*. These distinctions should help us tease apart morphological and orthographic parsing, since the semantic relationship between the stem and derived form in the so-called *opaque* (pseudo-morphological) condition is similar to that of simple orthographic overlap. However, a closer look at these lists raises a number of issues (see also Baayen, Milin, Filipović Đurđević, & Hendrix, 2011). First, some of the items in the orthographic condition are in fact true (opaque) morphological pairs (*phone-phonetic*, *append-appendix*, *stamp-stampede*). Many pairs, such as *colon-colonel* do not share phonological structure (contrary to morphological pairs) (see Marslen-Wilson, Bozic, & Randall, 2008; Morris et al., 2008 on this issue). More importantly, in the so-called *opaque* (pseudo-morphological) list, we find true morphologically derived forms (such as *arch-archer*), which cannot therefore be pseudo-morphological. In fact, Rastle et al. (2004) state that "[a]lthough some of the prime target pairs [bore] an etymological relationship […] *this was not a requirement*." (p. 1092, our italics). According to our evaluation, some 15 of the 50 pairs in the pseudomorphological list bore a true morphological relationship. Such a stimulus blend is clearly suboptimal if the research question is whether an early automatic parser could recognize potential morphemes and might treat them differently from items having no real or apparent morphological structure. Notice also that there were items in the orthographic ('non-morphological') priming pairs that contained pseudomorphemes (*fusel-age*, *iron-irony*). So the case for rapid and automatic parsing of possible (real or pseudo) morphemes is not clearly established by these studies, as these stimuli confound the linguistic dimensions of interest.

One specific issue in the context of our main research question (i.e., whether morphological effects can be fully explained as formal plus semantic effects) is that none of the reviewed studies, except that of Domínguez et al. (2004), compared more than two of the three priming conditions that interest us (morphological, semantic and formal-orthographic). Another concern related specifically to semantic priming is the *type* of pairs used to study this dimension of lexical processing. Many studies use semantic associates or other types of semantic or even collocational relationships (words found together or in close space in the corpus) that are arguably much more variable than the strong and consistent nature of the connections between morphologically related pairs (see Ferrand & New, 2003, for a review). In fact, *associative* relatedness (as in *salt-pepper*) may be of a quite different nature than that between the inflectional forms of a verb stem, given that the latter are much less likely to co-occur within the same sentence. This issue has spawned debate in the behavioral literature. Lucas (2000) argues that genuine semantic priming effects cannot be reduced to association priming, while Hutchison (2003) argues that apparent semantic priming is in fact based on association. In our view, a more stringent test of the semantic relationship in morphological pairs is that found either with synonym pairs or repetition priming (the latter, however, has the obvious problem of a full confound between morphological and formal priming).

Finally, the majority of morphological priming studies has focused on derivational morphology while neglecting inflectional morphology. To understand morphological processing as a whole, it seems necessary to investigate if effects obtained for derivational morphology hold for inflected word processing as well. We decided to replicate effects found for derived words with inflected words, using masked priming in an ERP study. An added advantage in using inflected forms is that they encode regular semantic relationships, allowing for highly constrained semantic similarity measures.

## 2.5. Predictions for the present study

Based on the literature discussed above, we expected our priming conditions to modulate two ERP components: the N250 and the N400. Formal priming effects on the N250 seem quite robust and have been observed in repetition priming (*table-TABLE*), partial repetition (*teble-TABLE*,[4] Holcomb & Grainger, 2006), and transparent derivation priming (*hunter-HUNT*, Morris et al., 2008). We thus expected N250 reductions for morphological as well as orthographic (formal) priming, with these effects being weaker for orthography, as found by Morris et al. (2008).

Unlike the N250, predictions for later priming effects in the N400 time-range crucially depend on whether (a) masking successfully suppresses semantic priming and (b) an independent status is assumed for morphology. One would expect to find a reduced N400 reflecting morphological priming, as has been found in numerous studies using masked-morphological priming (see, for example, Forster, 1998) and in a number of ERP studies (Diependaele, Sandra, & Grainger, 2005; Lavric et al., 2007; Morris et al., 2007). Moreover, the interpretation of such effects also depends on the results for orthographic priming: here we expected to replicate Morris et al.'s (2008) finding that orthographic overlap without semantic relationship (*scandal-SCAN*) yields only weak trends toward N250/N400 effects as compared to morphological priming.

The most robust N400 priming effects in previous studies are associated with semantic effects. In our study, morphological and semantic (synonym) primes were matched in their semantic relatedness with the targets, and semantic priming effects attenuating the N400 could be expected to be the same for both conditions. According to eliminativist models, this semantic priming effect would be the only source for N400 attenuation in *both* the semantic and – crucially – also in the morphological priming condition. Semantic priming, however, was expected to be absent in response latencies and ERP measures due to the masking procedure, as reported by Holcomb and Grainger (2009). This scenario leads to the following predictions for the models outlined above:

(1) According to eliminativist proposals, semantic and formal priming combined should result in a similar pattern to morphological priming. In terms of ERP components, one would expect to see similar early orthographic effects (attenuation of the N250) for the formal and the morphological conditions, and similar late semantic effects (attenuation of the N400) for the semantic and the morphological conditions. Importantly, if semantic priming effects are successfully suppressed by the masking procedure, this should prevent N400 attenuation equally in the semantic and the

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[3] They are called *semantically opaque* by Rastle and colleagues, although this is a misnomer, as this term usually indicates the presence of a semantically non-transparent morphological relationship, as in *master-mistress*.

[4] Note that this is in conflict with the absence of effects for orthographic neighbors in Domínguez et al. (2004), however, Holcomb and Grainger use a sandwich masking design.

morphological conditions (resulting in comparable ERPs in the formal and the morphological conditions).

(2) Predictions based on a morphological perspective on word processing are quite different. Morphological priming should result in qualitatively different ERP signatures from formal or semantic priming, and one would also expect the *combined* orthographic and semantic effects to be different from those found for morphological priming. Crucially, successful suppression of semantic priming due to masking is *not* expected to eliminate priming effects on the N400 in the morphological condition. Facilitation for morphological and orthographic priming on the early N250 is also expected.

## 3. Methods

### 3.1. Participants

Twenty-four adults (12 women) between 18 and 35 years of age and with no history of neurological or language disorders participated in the experiment. All were right-handed as per the Edinburgh Handedness Inventory (Oldfield, 1971), were native speakers of Quebec French and had (corrected to) normal vision. They read and signed a consent form before the recording session and received 45.00$ for their participation. The study was reviewed and approved by the ethics boards of the Faculties of Medicine of McGill and the University of Montreal, as well as the Centre de recherche CHU Ste-Justine.

### 3.2. Procedure

Participants were seated in a comfortable chair in a sound-attenuated and electromagnetically shielded recording booth, at a distance of ∼1m from a computer screen. Participants were presented with one of three lists during the recording session and were asked to decide if the string of letters on the screen was a French word or not by clicking a mouse key (lexical decision task, LDT). Every prime–target pair was presented following the schem a outlined in Fig. 1. Primes, preceded by a (forward) mask for 500 ms, stayed on the screen for 50 ms and were followed by a 20 ms (backward) mask. A target word was then presented for 300 ms and was followed by an LDT response interval of up to one second. As soon as the response key was pressed, a visual prompt ("- -") was presented for two seconds to indicate the interval allotted for eye blinking (reducing the number of eye-blink contaminated trials).

#### 3.2.1. Stimuli

For each verb target, three primes and their controls[5] were used: Morphological: *cassait-CASSE* 'broke-break' (control: *disait* 'said'); Formal: *cassis-CASSE* 'blackcurrant-break' (control: *dorsal*); Semantic: *brise-CASSE* 'break-break' (control: *moque* 'mock'). We used the same targets in all priming conditions, thus allowing direct comparisons across conditions and avoiding list effects. Stimuli are presented in Appendix A. Formal primes were real words of French without internal morphological structure. They did not share any semantic relationship with the target. Morphological and formal primes were matched (item by item) on the amount of formal overlap they shared with the target, as well as on orthographic, syllabic and phonological structure and oral language frequency (New et al., 2001). All initial letters and phonemes were the same in these two conditions (e.g., cassait vs. cassis, for target CASSE). Semantic primes were synonyms of the targets, and had no formal overlap with the target. To maximize the similarity of semantic priming strength across the two conditions, semantic and morphological primes were additionally matched on their semantic overlap with the target. We had native speakers rate semantic overlap on all prime–target pairs on a Likert scale from one to six (1 meaning none, 6 meaning complete) presented in pairs of sentences. Because of our stringent criteria for stimuli selection, we ended up with a master list of 42 target items. We decided to repeat targets within presentation lists, considering we wanted to compare responses to the same target primed in different conditions. However, we reduced to four the amount of times a given target was seen within a session. Three presentation lists were generated from this master list. Stimuli lists are in Appendix B (examples of conditions for a given target are shaded in grey (for consistency with rest of text, Canadian English). This yielded 28 items for each of the six main priming conditions per list. Each target word repetition within a session appeared in two distinct experimental conditions along with their respective controls. Target word repetitions never occurred within the same ¼ of any list. The order of target repetitions (e.g., experimental before control, or vice-versa) was evenly

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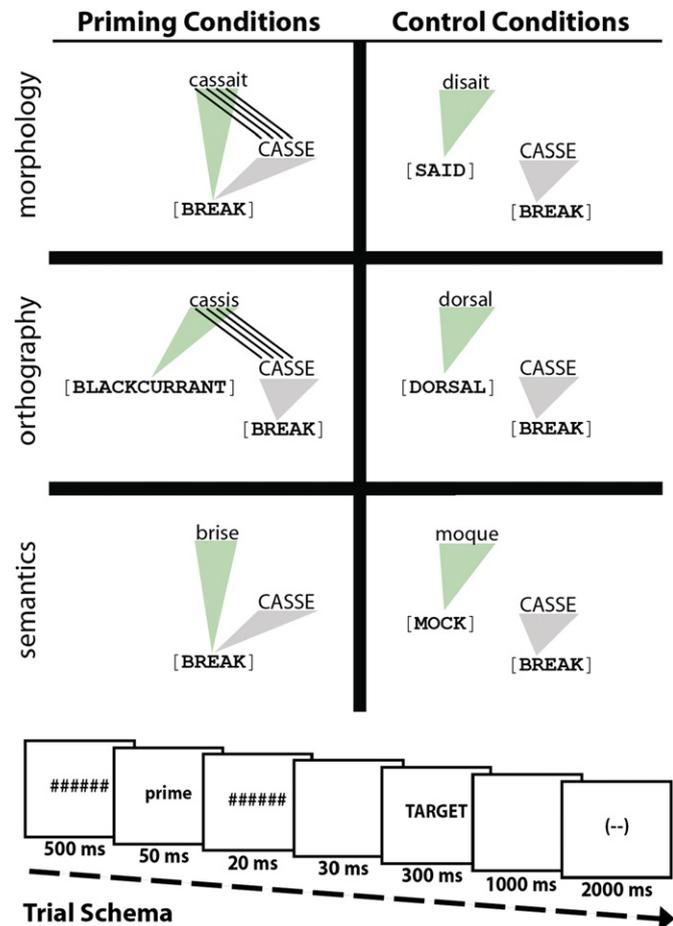
**Fig. 1.** Sample stimuli of the various experimental conditions and stimulus presentation scheme. Green and grey triangles illustrate semantic networks (semantics are in CAPITALS within square brackets); green triangles represent the prime and grey the target semantics. Lines between prime and target represent orthographic overlap. The trial schema shows the time course of the experimental trials. Each trial started with the presentation of a backward mask, followed by a prime that was replaced by a forward mask, and, after a short interval, by the target to which participants made a lexical decision. A blinking period terminated each trial. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

distributed and flipped across lists. Filler items and experimental pairs were pseudo-randomized, with each list arranged into 4 blocks (allowing three breaks), with all conditions equally distributed across the blocks. Finally, to avoid purely formal letter overlap and ERP effects arising from this (Chauncey, Holcomb, & Grainger, 2008), all of the pairs in every list were presented with the primes in lower-case and target word in UPPER CASE, or vice-versa, these conditions were counterbalanced across lists and conditions.

#### 3.2.2. EEG data recording and analysis

The EEG was recorded continuously with a 500 Hz sampling rate from 64 cap-mounted electrodes (Electrocap International Inc., Eaton: OH). Four additional electrodes were attached above and below the left eye as well as on both temples to monitor vertical and horizontal eye movement respectively. All impedances were maintained below 5 Ω (impedance for eye electrodes was under 10 Ω). The EEG was amplified using a Neuroscan SYNAMPS2 DC amplifier, referenced to the right mastoid. All subsequent steps of EEG/ERP data processing and analysis were carried out with the EEProbe software package (ANT; Enschede, The Netherlands). Offline, data were re-referenced to linked mastoids and filtered with a bandpass from 0.3 to 40 Hz. Trials contaminated with eye blinks and other artifacts were rejected using a 30 μV criterion (resulting in a data loss of 9%, evenly distributed across conditions). Only trials in which target words were correctly accepted as real words in the LDT (approximately 500 trials per condition) entered the final analyses. ERP averages were computed in an 800 ms time epoch, including a 100 ms prestimulus baseline interval (from −100 to 700 ms). ERP components were quantified in three time windows: 175–275 ms (N250), 350–450 ms and 450–550 ms (early and late N400). Mean amplitude data for each of these time windows were subjected to repeated-measures ANOVAs, separately for 5 midline

electrodes (FZ, FCZ, CZ, CPZ, PZ) and 30 lateral electrodes that were organized according to factors *Hemisphere* (2 levels: left, right), *Column* (3 levels: medial [e.g., F1/F2], intermediate [e.g., F5/F6], and lateral [e.g., F7/F8]), and *Anterior-Posterior* (5 levels, see midline electrodes). In addition to these topographical factors, the ANOVAs included the experimental factors *Prime* (2 levels: related vs. unrelated) and prime *Type* (3 levels: formal, semantic, morphological).[6]

## 4. Results

### 4.1. Behavioral data

As expected, there were no processing differences for targets following synonyms vs. unrelated controls on both lexical decision response accuracy (control: 88%, primed: 87%; $F < 1$) and latency (control: 705 ms, primed: 699 ms; $F < 1$). Response accuracy was significantly higher for the formally-primed (89%) vs. control (83%) conditions [$F(1, 23) = 10.85$, $p < 0.01$]. The formally-primed condition (687 ms) was also numerically faster than its matched control (701 ms), but this difference did not reach significance [$F(1, 23) = 2.42$, $p = 0.12$]. There were no differences in response accuracy for morphologically-primed and control conditions (both 86%; [$F < 1$]). Decision times, however, demonstrated a significant priming effect: the morphologically primed conditions (693 ms) were 29 ms faster than control ones (722 ms; [$F(1, 23) = 8.23$, $p < 0.01$]).

### 4.2. Event-related potentials

Grand average waves for each of the three comparisons (semantic, formal, and morphological) are shown in Figs. 2 and 3. As expected, in the semantic comparison the primed and control conditions demonstrated similar waveforms throughout the entire measurement epoch, suggesting that masking successfully suppressed semantic priming. In contrast, for both the formal and morphological comparisons the primed and control condition waveforms diverged between approximately 200–450 ms post-target word onset (with controls more negative-going). While this priming effect continued in the morphological priming condition until after 500 ms, the formal priming condition displayed an inverse pattern in this late time range (with controls more *positive*-going). Corresponding difference waves (primed minus control) and scalp voltage maps for each of these two conditions in all three time windows are shown in Fig. 4.

#### 4.2.1. Standard analyses of ERP priming effects

Consistent with these observations, the global ANOVA revealed Type × Prime (x topography) interactions in the N250 (175–275 ms) and N400 (350–450 and 450–550 ms) time-windows, confirming significant ERP differences among the three priming conditions.

First, the N250 latency range yielded, in the lateral analyses, T × P interactions with topographic factors Hemisphere [$F(1, 23) = 3.24$, $p < 0.05$] and Hemisphere × Column [$F(2, 46) = 4.02$, $p < 0.05$]. Main effects of Prime were also obtained in lateral and midline analyses [*lateral*: $F(1, 23) = 5.81$, $p < 0.05$; *midline*: $F(1, 23) = 5.84$, $p < 0.05$]. Second, T × P interactions also manifested in the two N400 time-windows in the lateral analyses [*350–450 ms*, T × P: $F(1, 23) = 3.55$, $p < 0.05$; *450–550 ms*, T × P × H: $F(1, 23) = 3.38$, $p < 0.05$], with corresponding trends towards T × P
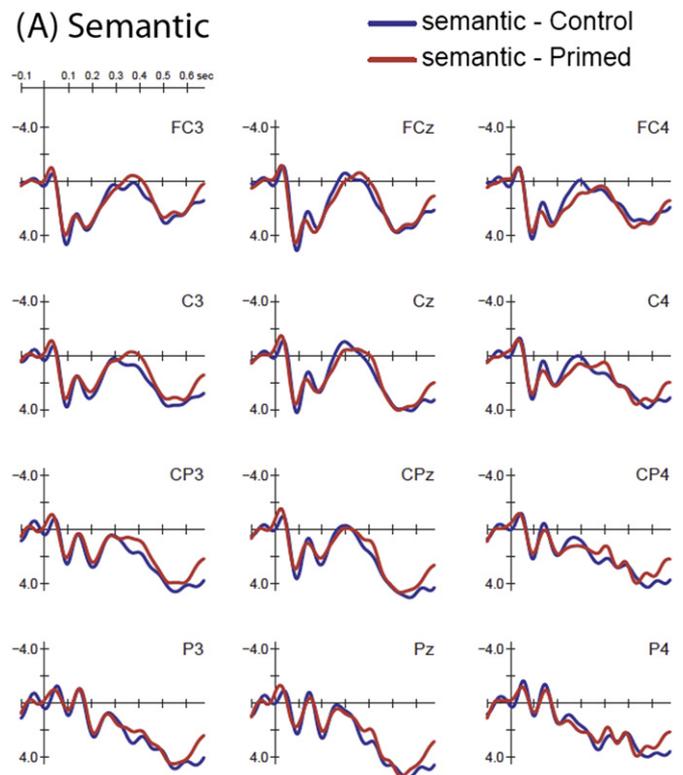


**Fig. 2.** *Grand average waves for the semantic priming condition.* The masked priming paradigm deployed here successfully inhibited semantic effects, as there were no significant differences in priming conditions for any time-window.

interactions on the midline [*350–450 ms*: $F(1, 23) = 2.98$, $p < 0.10$; *450–550 ms*: $F(1, 23) = 2.64$, $p < 0.10$].

These Type × Prime interactions were followed up in two steps. First, we confirmed the absence of semantic priming effects on the ERPs by examining that comparison in a separate ANOVA for the semantic condition. Consistent with the pattern evident in the grand average waves (Fig. 2), there were no statistically detectable effects of synonym priming on ERPs in any of the time-windows tested.[7]

Second, given the apparent pattern of partly shared and partly divergent ERP effects across the formal and morphological comparisons (see voltage maps in Fig. 4), these conditions were compared in a further ANOVA (excluding the semantic prime/control conditions). Results are shown for all time-windows in Table 1. Consistent with the visual inspection of the data, main effects of priming were evident in the N250 and in the early N400 (350–450 ms) time-windows at both lateral and midline electrodes. Additionally, there was a significant T × P interaction in the lateral analysis in the late N400 (450–550 ms) time window (and a corresponding trend at midline electrodes), as well as a four-way interaction involving the factors Column and Hemisphere in the 175–275 ms range. Follow-up analyses conducted separately for the morphological and formal priming conditions in the N250 and in the N400 time-windows are presented in Table 2.

Here we observe that the Morphological condition shows a main effect of Prime at the lateral electrodes for both N400 time-windows and corresponding trend and significant effect at midline electrodes, while a trend toward a Prime effect is observed in

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[6] Note that we also conducted analyses including all 64 EEG electrodes. However, as these more complex analyses did not reveal any relevant additional effects while requiring more follow-up analyses (and space) to identify the actual data pattern, we will report the simpler analyses here for reasons of transparency and efficiency.

[7] These analyses did reveal Prime × Hemisphere interactions in the 175–275 ms and 450–550 ms time-windows. However, neither of these interactions corresponded to main effects of priming in either hemisphere [all $F$s < 1]. These interactions were due to slight trends in opposite directions across the hemispheres (see Fig. 2).

the 175–275 window for both lateral and midline analyses. A Prime × Column interaction is also found in the 175–275 time-window, pointing to a larger priming effect at medial rather than more lateral electrodes (see voltage map in Fig. 4).

In the Formal condition, there is a trend for a Prime × Column × Hemisphere effect in the N250 time window, pointing to a weak and somewhat left-lateralized positivity. In the early N400 interval (350–450 ms), a trend for main effect of Prime is observed at midline electrodes along with an interaction of Prime × Anteriority at both midline and lateral electrodes. Trends for interactions of Prime with topographic factors Column are observed in the lateral analysis. Between 450 and 550 ms, a Prime × Anteriority effect at midline electrode reflected the inverse effect of priming in orthographic conditions alluded to in Section 4.2.

### 4.2.2. Additional ERP analyses using a common control condition

One potential concern regarding the results reported above has to do with the use of different control conditions for each priming condition. Recall that prime words in the control conditions were individually matched with the prime words of their respective priming conditions (see Appendix A). This procedure is standard in sophisticated psycholinguistic research on lexical priming (Feldman & Prostko, 2002) and was purposefully adopted here in order to control for systematic differences that necessarily exist between the prime words in our three priming conditions. For instance, primes in the morphological (and the formal) condition were inevitably slightly longer than synonyms in the semantic condition. By matching the length of the prime and its respective control within a given priming condition we ensured that any effects in the behavioral or ERP data could not be attributable to word length. This rationale also holds for *differences* observed between the priming conditions. We believe this is the best approach to our research question. However, it could be argued that the differences in priming effects reported above may be driven by differences of the control rather than the experimental priming conditions. Even though we do not agree with this view, the strongest evidence supporting our findings would be to demonstrate that the findings are robust even when the
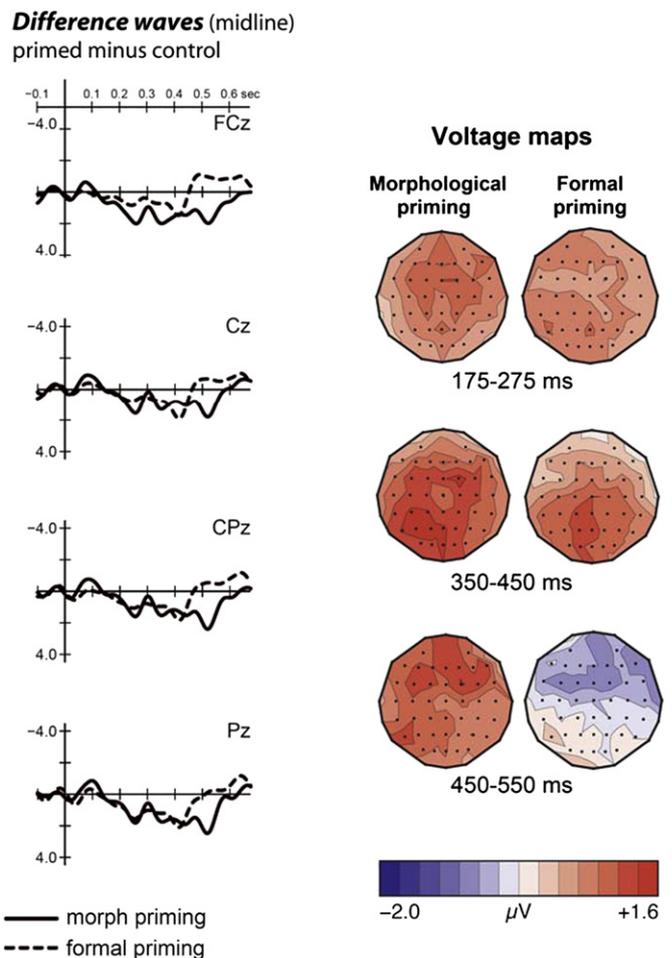


**Fig. 4.** Difference waves (primed minus control) and voltage maps for morphological and formal priming conditions. Effects are presented for midline electrodes FCz, Cz, CPz and Pz (note that waves are low pass filtered at 9 Hz for visualization purposes only).
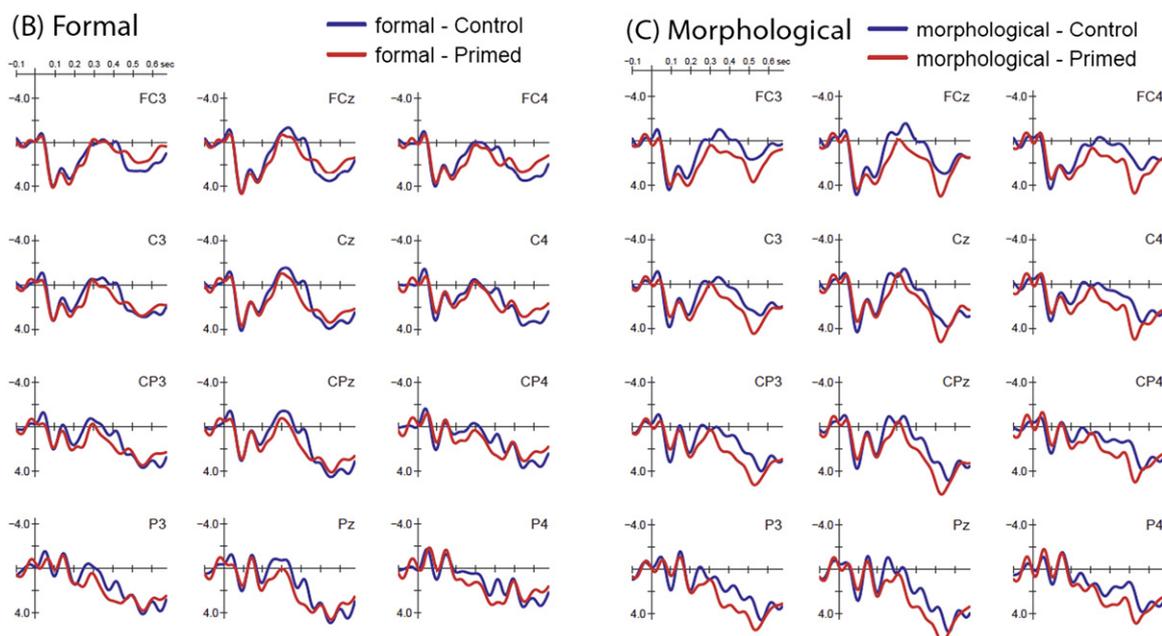


**Fig. 3.** *Grand average waves for the morphological and formal priming conditions.* Both formal and morphological ERP priming effects were obtained, which overlapped between 175 and 450 ms. Between 450 and 550 ms only morphological priming effects were evident.

**Table 1**
Global repeated measures ANOVA results comparing formal and morphological priming only.

| | df | 0–175 | (N250) 175–275 | (N400) 350–450 | 450–550 |
|---|---|---|---|---|---|
| **Lateral** | | | | | |
| **Prime** | (1, 23) | – | 6.23* | 9.24** | – |
| **P × A/P** | (4, 92) | – | – | 3.57$^{\dagger}$ | 3.50$^{\dagger}$ |
| **P × Col** | (2, 46) | – | 3.63$^{\dagger}$ | 5.32* | – |
| **P × Hemi** | (1, 23) | – | – | – | – |
| **P × A × C** | (4, 92) | – | – | – | – |
| **P × A × H** | (4, 92) | – | – | 2.56$^{\dagger}$ | 3.03* |
| **P × C × H** | (2, 46) | – | – | – | – |
| **P × A × C × H** | (4, 92) | – | – | – | – |
| **Midline** | | | | | |
| **Prime** | (1, 23) | – | 6.41* | 9.20** | – |
| **P × A** | (4, 92) | – | – | 3.62* | 3.43* |
| **Lateral** | | | | | |
| **Type × Prime** | (1, 23) | – | – | – | 4.77* |
| **T × P × A/P** | (4, 92) | – | – | – | – |
| **T × P × Col** | (2, 46) | – | – | – | 3.21$^{\dagger}$ |
| **T × P × Hemi** | (1, 23) | – | – | – | 3.09$^{\dagger}$ |
| **T × P × A × C** | (4, 92) | – | – | – | – |
| **T × P × A × H** | (4, 92) | – | – | – | – |
| **T × P × C × H** | (2, 46) | – | 4.32* | 2.47$^{\dagger}$ | – |
| **T × P × A × C × H** | (4, 92) | – | – | – | – |
| **Midline** | | | | | |
| **T × P** | (1, 23) | – | – | – | 4.08$^{\dagger}$ |
| **T × P × A** | (4, 92) | – | – | – | – |

*Notes*: P = Prime (prime vs. control); T = Type (morphological vs. orthographic); A/P = Anterior/Posterior; C = Column; H = Hemisphere.

$^{\dagger}$ $p < 0.10$.
* $p < 0.05$.
** $p < 0.01$.

**Table 2**
Repeated measures ANOVA results by condition for morphological and orthographic priming.

| | df | (N250) 175–275 | (N400) 350–450 | 450–550 |
|---|---|---|---|---|
| **Morphological** | | | | |
| Lateral | | | | |
| **Prime** | (1, 23) | 3.56$^{\dagger}$ | 5.62* | 7.77* |
| **P × A/P** | (4, 92) | – | – | – |
| **P × Col** | (2, 46) | 4.56* | – | – |
| **P × Hemi** | (1, 23) | – | – | – |
| **P × A × C** | (4, 92) | – | – | – |
| **P × A × H** | (4, 92) | – | – | 2.60$^{\dagger}$ |
| **P × C × H** | (2, 46) | – | – | – |
| **P × A × C × H** | (4, 92) | – | – | – |
| Midline | | | | |
| **Prime** | (1, 23) | 3.25$^{\dagger}$ | 4.13$^{\dagger}$ | 5.98* |
| **P × A** | (4, 92) | – | – | – |
| **Orthographic** | | | | |
| Lateral | | | | |
| **Prime** | (1, 23) | – | – | – |
| **P × A/P** | (4, 92) | – | 3.16$^{\dagger}$ | 2.88$^{\dagger}$ |
| **P × Col** | (2, 46) | – | 3.42$^{\dagger}$ | – |
| **P × Hemi** | (1, 23) | – | – | – |
| **P × A × C** | (4, 92) | – | – | – |
| **P × A × H** | (4, 92) | – | – | – |
| **P × C × H** | (2, 46) | 2.97$^{\dagger}$ | – | – |
| **P × A × C × H** | (4, 92) | – | – | – |
| Midline | | | | |
| **Prime** | (1, 23) | – | 4.07$^{\dagger}$ | – |
| **P × A** | (4, 92) | – | 3.70* | 3.69* |

*Notes*: P = Prime (prime vs. control); A/P = Anterior/Posterior; C = Column; H = Hemisphere.

$^{\dagger}$ $p < 0.10$.
* $p < 0.05$.

three priming conditions are compared to the same control condition. To this end, we computed a new 'common control' condition by averaging across the ERPs of the three original control conditions. In a second step, we compared the ERPs of each priming condition with this common control (Table 3). These statistical analyses replicated the pattern reported above. Most importantly, whereas the morphological priming condition displayed significant main effects of priming in all three time windows (at lateral and midline electrodes), both the semantic and the orthographic condition did not show any significant main effect. There was only a tendency for orthographic priming at midline electrodes in the early N400 time interval and two complex interactions of prime by anteriority by hemisphere (by column) in lateral electrodes for semantic priming in the two N400 time intervals.[8]

## 5. Discussion

The data from our experiment show that the three priming conditions result in three distinct patterns of lexical activation. That is, semantic priming is not observed either behaviorally or in the ERPs, whereas formal and morphological priming elicit different ERP signatures and behavioral results. We discuss these in turn.

*First*, the fact that semantic priming does not obtain is not surprising, given that a considerable number of different masking studies have shown that this type of priming can be suppressed with short presentation times, short SOAs, masking and the absence

[8] See footnote 7. Neither of these interactions corresponded to main effects of priming in either hemisphere [all $F$'s < 1]. These interactions were due to slight trends in opposite directions across the hemispheres.

of directed attention to the primes. As Kiefer (2007) suggests in his review of masked semantic priming, primes must be attended in order for a significant semantic modulation of the N400 to emerge. Although some complex interactions were found in the statistical analyses, these do not occur in the midline electrodes, where N400s typically surface, and appear to reflect slight differences in relative positive and negative going waves in the two hemispheres.

Our present study extends similar previous results in that it shows that sandwich-masking entirely suppresses the facilitation effects for one of the strongest possible types of semantic prime: synonyms. As we have argued above, synonyms can be viewed as a much better semantic match (or control) for morphological primes than associative primes. The absence of synonym priming cannot be explained by our types of pairs (i.e., the possibility that French synonyms may not be reliable primes), since we did observe large and significant N400 reductions in a concurrent study on *unmasked* synonym priming in French, partly involving the same participants as in the present study (Steinhauer, Nadeau-Noel, Drury, & Royle, 2008; Steinhauer, Drury, & Royle, in preparation). As we will see below, the absence of any synonym priming in our study allows us to draw much more specific conclusions regarding the nature of (late) morphological priming effects than studies that either did not use masking (e.g., Domínguez et al., 2004) or did not include a corresponding synonym prime condition (this is the case for most of the studies discussed above).

*Second*, we observed that formal (orthographic) priming facilitated word recognition behaviorally and slightly reduced the amplitude of negative-going ERPs between approximately 200 and 450 ms, which resulted in non-significant trends in the N250 and early N400 time-windows. This is similar to effects found for orthographic priming in a number of studies reported above,

**Table 3**
Global repeated measures ANOVA results comparing formal, morphological and semantic priming to all control conditions.

| | *df* | (N250) 175–275 | (N400) 350–450 | 450–550 |
|---|---|---|---|---|
| **Morphological** | | | | |
| Lateral | | | | |
| **Prime** | (1, 23) | **4.93*** | **5.72*** | **5.10*** |
| P × A/P | (4, 92) | – | – | 4.36* |
| P × Col | (2, 46) | 4.49* | 5.23* | 3.73* |
| P × Hemi | (1, 23) | – | – | – |
| P × A × C | (8, 184) | – | – | – |
| P × A × H | (4, 92) | – | 2.80† | – |
| P × C × H | (2, 46) | 4.94* | – | – |
| P × A × C × H | (8, 184) | – | – | – |
| Midline | | | | |
| **Prime** | (1, 23) | **4.79*** | **5.20*** | **4.58*** |
| P × A | (4, 92) | – | – | 3.83* |
| **Orthographic** | | | | |
| Lateral | | | | |
| **Prime** | (1, 23) | – | – | – |
| P × A/P | (4, 92) | – | – | – |
| P × Col | (2, 46) | – | – | – |
| P × Hemi | (1, 23) | – | – | – |
| P × A × C | (8, 184) | – | – | – |
| P × A × H | (4, 92) | – | 2.81† | – |
| P × C × H | (2, 46) | – | – | – |
| P × A × C × H | (8, 184) | – | – | – |
| Midline | | | | |
| **Prime** | (1, 23) | – | 2.99† | – |
| P × A | (4, 92) | – | 2.34† | – |
| **Semantic** | | | | |
| Lateral | | | | |
| **Prime** | (1, 23) | – | – | – |
| P × A/P | (4, 92) | – | – | – |
| P × Col | (2, 46) | – | – | – |
| P × Hemi | (1, 23) | – | 3.58† | 2.95† |
| P × A × C | (8, 184) | – | – | – |
| P × A × H | (4, 92) | – | – | – |
| P × C × H | (2, 46) | – | 3.52* | – |
| P × A × C × H | (8, 184) | – | – | 2.98* |
| Midline | | | | |
| **Prime** | (1, 23) | – | – | – |
| P × A | (4, 92) | – | – | – |

*Notes*: P = Prime (prime vs. control); A/P = Anterior/Posterior; C = Column; H = Hemisphere.

† $p < 0.10$.
* $p < 0.05$.

where shared orthography resulted in early N250 effects and a short-lived attenuation of the N400. However, in contrast to at least some of those studies, we made sure that the orthographic overlap was always word-initial (all first letters up to the suffix, see e.g., Domínguez et al., 2004), was equal to that found in morphological priming (no more and no less), and never created a phonological mismatch (as, e.g., colon-COLONEL would; Lavric et al., 2007; Lehtonen et al., 2011; Morris et al., 2007, 2008). Our data support previous interpretations according to which N250 attenuations can occur in the absence of any semantic or morphological overlap. However, they also suggest that purely formal priming effects in ERPs can extend into the early N400 time range, even under masked priming conditions.[9]

Third, in the morphological priming condition, we found two consecutive patterns. The first one, an attenuated negative-going wave, occurred in an early time window (in the N250 time range) and was broadly distributed with a fronto-central maximum near the midline. This effect resembles, in terms of timing and scalp distribution, the pre-lexical orthographic N250 effects previously reported in a considerable number of priming studies for morphologically-related derived words (e.g., Holcomb & Grainger, 2006). The effect is similar to that in our formal condition, but was more robust for morphological than orthographic primes. This finding (although not reflected by a significant interaction) may be viewed as support for the notion that the N250 does not exclusively reflect formal (pre-lexical) overlap between prime and target, but is instead modulated by lexical processes (Domínguez et al., 2004; Morris et al., 2007; 2008). Interestingly, the absence of any semantic priming effects in the N250 time window confirms previous suggestions that the contributions at a lexical level are, in fact, independent of semantic representations. In line with Domínguez et al.'s (2004) argument, a plausible account for this finding would locate the lexical contribution to N250 effects at the (morphologically motivated) level of word segmentation for inflection (cass-ait→cass-e).[10] The main difference between the two conditions would then point to a successful segmentation/decomposition in the morphological (cass-ait) but not the formal condition (*cassis* with no possible morphological parse *pseudo* or otherwise).

The second – and most important – effect in the morphological condition, a broadly distributed and significant attenuation of the negative going wave, was observed in the primed vs. unrelated condition between 350 and 550 ms post onset (resembling a classic N400). This effect most probably reflects co-activation of the morphological stem or root form, from the prime to the target. A direct comparison of the formal and orthographic priming conditions (see Fig. 4) reveals that these two result in significantly different patterns in late time windows, such that morphological priming causes long-lasting reductions of the N400, while the effects of formal priming are more transient. This late N400 attenuation for morphological priming is especially remarkable, as no indication for a similar effect was seen in the semantic condition. If anything, the primed semantic condition showed a *larger* N400 in the second (combined control) analysis. Since we used synonyms, the absence of any N400 effect for these primes shows that our masking procedure successfully eliminated even the slightest tendencies of semantic priming. In other words, in contrast to certain ambiguities in previous studies, the present morphological N400 effect cannot be attributed to, or confounded with, semantic facilitation. We believe it is best characterized as a genuine morphological priming effect, as predicted by traditional linguistic theory. In our opinion, eliminativist models, according to which morphology is viewed as an 'emergent' description that can be entirely accounted for in terms of (i) orthographic (or phonological) and (ii) semantic similarities among words, are unable to explain our pattern of results.

In conclusion, there were no semantic priming effects on any measure, while both morphological and orthographic facilitation effects were observed. Morphological priming using inflected forms yielded robust N250 and N400 effects. Orthographic priming yielded a weak N250 effect and a short-lived weak N400 reduction. Direct comparisons of the two types of priming in the early N250 time-window yielded no significant interactions with the factor prime-type, suggesting a shared (and graded) effect related to orthographic overlap. In contrast, the subsequent N400 effect had a significantly longer duration for morphology

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[9] Recall that a shared main effect of priming between 350 and 450 ms was found across orthographic and morphological conditions (Table 2). In absence of a significant interaction with prime type, this pattern is best interpreted as an N400 reduction in both conditions (see Nieuwenhuis, Forstmann, & Wagenmakers, 2011).

[10] As our formal primes (*cassis* [ka.sis]) had similar but not always identical syllable structures as the morphological primes (*cassait* [ka.sɛ]), a phonological effect in terms of syllable structure cannot be ruled out.

**Table A1**
Attributes of primes and targets for the task (standard deviations in parentheses).

| | Target casse 'break' | Type of Prime | | | | | |
|---|---|---|---|---|---|---|---|
| | | Semantic | | Morphological | | Formal | |
| | | Prime brise 'break' | Control moque 'mock' | Prime cassait 'broke' | **Control disait** 'said' | Prime cassis 'blackcurrant' | **Control dorsal** 'dorsal' |
| Surface frequency[a] | 51.14 (11.7) | 38.02 (9.03) | 38.15 (9.14) | 38.98 (8.27) | 39 (8.32) | 39.04 (9.91) | 39.06 (9.9) |
| p[b] | | 0.94 | | 0.99 | | 0.99 | |
| Length in syllables[c] | 1.1 (0.34) | 1.5 (0.51) | 1.64 (0.53) | 2.1 (0.37) | 2.1 (0.37) | 2.14 (0.52) | 2.14 (0.52) |
| p[b] | | 0.21 | | 1 | | 1 | |
| Length in letters | 4.6 (1.08) | 6.19 (1.17) | 6.17 (1.21) | 6.79 (0.9) | 7.02 (0.81) | 6.67 (1.12) | 6.69 (1.26) |
| p[b] | | 0.93 | | 0.2 | | 0.93 | |
| Formal overlap with target | | 0.12 (0.32) | 0 (0) | 3.74 (0.89) | 0.24 (0.53) | 3.95 (0.99) | 0.1 (0.3) |
| p[d] | | | | 0.3 | | | |
| Phoneme overlap with target[c] | | 0.12 (0.32) | 0 (0) | 3.24 (0.73) | 0.19 (0.4) | 3.17 (0.73) | 0.05 (0.22) |
| p[d] | | | | 0.65 | | | |
| Semantic relatedness to target | | 5.13 (1.01) | 1.44 (1.01) | 5.79 (0.19) | 1.64 (1.05) | 1.06 (0.12) | 1.22 (0.32) |
| Difference in semantic relatedness (Prime - Control) | | 3.46 (1.22) | | 3.95 (1.05) | | −0.16 (0.42) | |
| p[e] | | =0.049 | | | | =5.26E−30 | |

[a] In thousands, taken from LEXIQUE (New et al., 2001).
[b] Two-tailed t-test for independent samples.
[c] Quebec French phonological and syllabification rules apply here (e.g., casse and brise are both monosyllabic).
[d] Two-tailed t-test for independent samples, comparison between M–F primes. (shaded squares.)
[e] Two-tailed t-test for independent samples, comparison of mean differences in semantic relatedness between primes and controls for M-pairs vs. S-pairs, and M-pairs vs. F-pairs. (shaded squares.)

(375–575 ms) than orthography (375–425 ms), and robust priming by type interactions where obtained at 475–575 ms post-target onset.

### 5.1. Models

Some eliminativists have recently suggested that formal overlap may be helpful in word recognition *only* (or significantly more so) if there is *also* a semantic relationship between the prime and the target (Holcomb & Grainger, 2009; Seidenberg & Gonnerman, 2000)[11]. This stance is, however, indistinguishable from a classical morphological view. Thus it is quite difficult to imagine any pattern of results that would *not* be explainable (at least post-hoc) according to at least some eliminativist accounts. Nevertheless, we propose that, differences in the ERP waves and time-courses for different priming conditions for morphological pairs as compared to orthographic and semantic pairs would be grounds for a morphologically based model. In particular, if semantic priming is suppressed while orthographic and morphological priming are maintained, and these two last priming types show different time-courses and/or topographies in target processing, we believe this is related to the activation of different levels of processing in the mental lexicon (i.e., orthographic and morphological).

These patterns are consistent with a picture of morphology as having both pre- and post-lexical responses (indexed by both N250 and N400 effects). The early effect likely reflects automatic processing of orthographic overlap between prime and target as well as the parsing of potential morphological constituents, as has

been shown in previous ERP and psycholinguistic experiments (e.g., Longtin et al., 2003; Morris et al., 2008). The most important result of our study is the difference between all priming types at later time windows, in particular, strong modulation of the N400 by morphological but not by either orthographic or semantic priming. These results converge with data from Spanish showing that orthographic overlap (even in the case of Spanish homographic stems) is not sufficient to produce effects similar to morphological priming (Domínguez et al., 2004). These data also converge with studies of derivational and inflectional morphology showing morphological modulation of the N400 (e.g., de Diego-Balaguer et al., 2005; Lavric et al., 2007; Morris et al., 2007, 2008; Münte et al., 1999; Rodriguez-Fornells et al., 2002). However, under the assumption that semantics, even in the absence of main effects, can interact with orthographic effects such that they elicit quantitatively and qualitatively distinct ERP patterns, it is theoretically possible that eliminativist approaches could also account for our data. Our experiment cannot provide a clear-cut answer regarding this issue, however we can address this question based on a synthesis of the present and other work. In particular, it has been shown that semantically and orthographically related pairs (*broil-boil*) do not pattern like morphological pairs in MEG priming (see discussion of Stockall & Marantz, 2006, in Section 2.3). Thus, in conjunction with our data, the experiments on Spanish and English seem to point to the existence of morphologically based parsing of words during lexical access.

We project to develop studies using similar (*broil-boil*) pairs in French, and we expect non-morphological priming of this type to pattern similarly to orthographic priming in our task, and differently from morphological priming, if morphology is truly cognitively represented. In addition we would expect orthographic priming effects to be modulated by prime presentation duration or interstimulus intervals between prime and target, in particular,

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[11] Since these models argue all information is available, the argument could go the other way around: that semantic overlap may be helpful in word recognition *only* if there is *also* a formal relationship between the prime and the target.

we should be able to completely suppress orthographic priming (or make it inhibitory) by providing a longer inter-stimulus interval or by making the prime more perceptible to participants. We would expect morphological priming to maintain facilitatory priming effects even under these conditions.

## 6. Conclusion

In conclusion, our data are consistent with evidence from a large body of work in psycholinguistics and a growing body of neurolinguistic data showing evidence for abstract knowledge of morphological organization in the lexicon (Domínguez et al., 2004; McQueen & Cutler, 1998). However, further research, is needed to refine our understanding of the issues raised relative to the clear interpretation of these data in light of different models of visual word processing.

**Table B1**
Master list of prime–target pairs used in experiment.

| Targets | Primes | | | | | |
|---|---|---|---|---|---|---|
| | **Se** | **Sc** | **Fe** | **Fc** | **Me** | **Mc** |
| **cerne** | entoure | entiche | cerneau | pectine | cernait | restait |
| **ferme** | obture | informe | ferraille | rongeur | fermait | feutrait |
| **casse** | brise | moque | cassis | dorsal | cassait | disait |
| **fourre** | flanque | tremble | fourrure | désastre | fourrait | haussait |
| **barre** | biffe | offre | barrot | casbah | barrait | gantait |
| **fane** | fripe | pleut | fanal | loyal | fanait | teintait |
| **mure** | enferme | suppose | murmure | famille | murait | rusait |
| **pave** | tapisse | entasse | pavillon | mocassin | pavait | paumait |
| **cache** | couvre | repent | cachemire | bonniche | cachait | pouffait |
| **pompe** | puise | berce | pompeux | cageot | pompait | palpait |
| **bride** | freine | démêle | bridge | phoque | bridait | blairait |
| **campe** | loge | mate | campus | coquine | campait | suivait |
| **bute** | accule | récure | butane | cafard | butait | cognait |
| **chipe** | attrape | utilise | chipote | crevage | chipait | guindait |
| **brave** | risque | flotte | bravo | excès | bravait | trônait |
| **farde** | maquille | traverse | fardeau | boudeur | fardait | pilait |
| **cale** | assure | irrite | calibre | horaire | calait | lisait |
| **bourre** | remplit | moleste | bourrique | calebasse | bourrait | poquait |
| **croque** | bouffe | pouffe | croquet | châssis | croquait | effilait |
| **ferre** | chausse | tripote | ferret | secret | ferrait | donnait |
| **sue** | transpire | troisième | sublime | foulard | suait | sautait |
| **rate** | avorte | excite | raton | bonus | ratait | savait |
| **boude** | rechigne | ronronne | boudin | nadir | boudait | minait |
| **fige** | cloue | chipe | figaro | judoka | figeait | plongeait |
| **hale** | tire | aime | haleine | aneth | halait | gainait |
| **attire** | charme | craque | attirail | bottillon | attirait | guettait |
| **larde** | pique | trie | lardon | moulin | lardait | heurtait |
| **aspire** | souhaite | convoite | aspirine | rétinite | aspirait | admirait |
| **trame** | brasse | brette | tramway | échelle | tramait | juchait |
| **bave** | salive | colore | bavard | colloque | bavait | aérait |
| **coupe** | supprime | visionne | coupon | bottin | coupait | soudait |
| **vire** | pivote | apaise | virus | libraire | virait | nommait |
| **gare** | parque | souque | garde | rame | garait | rotait |
| **sangle** | bride | érige | sanglier | laminage | sanglait | bondait |
| **lie** | noue | jase | lierre | marron | liait | jouait |
| **noue** | arrime | cajole | nougat | subtil | nouait | rouait |
| **oriente** | dirige | relaxe | oriental | capuccino | orientait | humiliait |
| **loupe** | bousille | pardonne | loupiot | coursier | loupait | laissait |
| **couve** | protège | suggère | couvent | oeillet | couvait | votait |
| **pue** | empeste | absorbe | punit | sauna | puait | pansait |
| **hume** | flaire | pivote | humecte | frileuse | humait | frisait |
| **fuse** | gicle | vient | fuseau | fondeur | fusait | notait |

Notes: shaded cells for priming conditions on targets for each 1/3 of the list represent one of three possible sets of target repetitions within given presentation lists (see main text for details). Se: semantic experimental; Sc: semantic control; Fe: formal experimental; Fc: formal control; Me: morphological experimental; Mc: morphological control.

## Appendix A

See Table A1.

## Appendix B

See Table B1.

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