MORPHOLOGY AND WORD RECOGNITION: AN ERP APPROACH*

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Research in linguistics and the cognitive sciences in general has undergone major changes in the last two decades. New methodologies have been developed for the investigation of psycholinguistic processes that are complementary to more traditional approaches to the study of language. In particular, neuroimaging using fine-grained temporal tracking of brain signatures is possible now with electroencephalographic (EEG) recordings that are time-locked to specific linguistic events. These result in event-related brain potentials (ERPs) that allow us to tease apart the processing of semantics, morphology and orthography, for example. We present here an example of how the issue of morphological access during written word recognition (French verbs in a visual lexical decision task) can be investigated using ERP techniques.

There is still much disagreement as to the nature of morphological representation in the mental lexicon (e.g., Bates & Godham 1997; McQueen & Cutler 1998). In particular, we are interested in understanding the temporal dynamics of inflectional morphology in visual word recognition. Importantly, we also attempt to shed light on the *nature* of "morphological effects". That is, are they different from semantic effects, orthographic effects, or a combination of these two? Directly contrasting online ERP measures of these various conditions will allow us to address the issue of which current models can best account for the patterns of real-time brain activation observed. More specifically we wish to evaluate two competing views about the role of morphology in the organization of the mental lexicon. According to one view, motivated within the framework of *connectionism*, morphology does not have any special status in the lexicon and is, therefore, not relevant to lexical representation and processing. Thus, words do not have internal (morphological) structure, and are not organized according to morphological families but rather according to the intersection of *formal* (orthographic/phonological) and *semantic* information, or to the "convergence of codes" (Bates & Godham 1997; Devlin, Jamison, Matthews & Gonnerman 2004; Seidenberg & McClelland 1989; Seidenberg & Gonnerman 2000). Other approaches grounded in traditional linguistic theories assume morphological structure in their models lexical processing and representation (Baayen, Schreuder & Sprodt 2000; Domínguez, de Vega & Barber 2004; McQueen & Cutler 1998).

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1. Experimental Evidence

Much research has been produced in support of both traditional morphological and connectionist views, and the debate has not yet been closed. For example, based on ERP findings showing that morphological parsing has different effects on word recognition than semantic parsing in Spanish, it has been argued that the role of morphology is not attributable to semantic effects (Domínguez, de Vega & Barber, 2004). Moreover, studies of derived English words suggest a principled distinction can be made between orthographic and morphological priming (Lavric, Clapp & Rastle 2007; Morris, Frank, Grainger & Holcomb 2007; Morris, Grainger & Holcomb 2008) This position is however not maintained by other researchers, who show data from ERP and fMRI (functional magnetic resonance imaging) that seems to indicate that semantic and orthographic relationships *are* sufficient to account for apparent morphological effects in priming tasks (Devlin et al. 2004; Diependaele, Sandra & Grainger 2005).

In general, the study of *inflectional* relationships between words while using ERP paradigms is quite rare. This is surprising, since inflectionally related forms have consistent semantic relationships, while derived forms do not systematically show transparent meaning relations between derived and base forms. However, this semantic regularity found in inflectional morphology also holds the potential risk of introducing a complete confound between morphological and semantic effects, such that any observed priming may be equally attributed to morphology *or* semantics. For example, consider the N400 component in ERPs, which is a negative going waveform thought to reflect processing costs during lexical access and semantic integration. ERP research on semantic priming has consistently shown that the N400 component for the target word (e.g., *nurse*) is attenuated when the preceding prime word is semantically related (*doctor-nurse*) compared to when it is not (*apple-nurse*) (e.g., Bentin, McCarthy & Wood 1985; Koivisto & Revonsuo 2001). This N400 reduction reflecting facilitation of word processing is ever stronger in repetition priming (e.g., *face – face*; e.g., Rugg 1987). Importantly, *morphological* priming can also have similar effects on the N400. However, as discussed below, it can also have more complex effects on the ERP wave. Moreover, as we will show below, including additional control conditions can then help tease apart morphological and other types of priming (e.g., orthographic or semantic).

Returning to Spanish inflected words, Domínguez and colleagues (2004) have presented data according to which (i) the integration of morphological and semantic information seems to have quite different time courses and, moreover, (ii) the segmentation of words into stem and affix (*hij-o – hij-a*, 'son-daughter') may not simply be based on shared orthography between prime and target (as in *foc-o – foc-a,* 'floodlight-seal'). In their study, they show that, in comparison with unrelated priming (e.g., *pav-o – met-a* 'turkey-goal'), morphologically related primes (*hijo-hija*) result in a reduced N400 between 250 and 450 ms. In contrast, stem homographs, with similar orthographic overlap but *no* morphological relationship (*foc-o – foc-a*), show an early attenuation of the ERP wave (at 250-350 ms), followed by an *increased* negativity relative to the control condition in the late (450-650 ms) time-window. Words with orthographic overlap such as *rasa – rana* ('flat-frog') showed no modulation of the ERP wave in comparison to unrelated priming, while being significantly different from morphological priming. Synonym pairs (*cirri-o – vel-a* 'candle.m-candle.f') showed both very early and late attenuations of negativity (in the 250-350 ms the 450-650 ms time-windows) with no significant difference from unrelated priming in the 350-450 time window. Morphological priming was significantly stronger (i.e., less negative) than that found for semantics in the early (250-350 and 350-450ms) time windows, but not at the later stages of processing (450-650ms). In sum, this study suggests distinct ERP profiles for orthographic, semantic and morphological priming. A potential problem of their design includes unmatched target words across conditions. Moreover, the early priming effect for synonyms was somewhat surprising and may have to do with the specific way of presenting the stimuli (i.e., rather long stimulus onset asynchronies [SOAs] of 300 ms between prime and target). These issues can be addressed by using masked priming paradigms and short prime presentation times (see below).

A small number of ERP studies have investigated the processing of verb morphology. Münte and colleagues (Münte, Say, Clahsen, Schiltz & Kutas 1999) and Rodriguez-Fornells and collaborators (Rodriguez-Fornells, Münte & Clahsen 2002) used long-lag morphological priming for English and Spanish real and novel verbs (e.g. *broded – brode*) using regular and irregular inflection. Regular verb priming showed stronger attenuation of the N400 than irregular pairs, although only for real and not novel items. The results of these two studies were interpreted as showing differential access to regular and irregular verbs (see for example, Pinker, 1999) and thus sensitivity to morphological structure. These experiments do not however question the essential role of morphology in their models but assume is as a given. Second, a major problem in Rodriguez-Fornells et al. (2002) is orthographic overlap is confounded with morphological regularity in the stimuli, such that it is unclear which of these factors was driving the observed differences between regular and irregular verbs. Note also that these studies do not have semantic priming control conditions, although Münte and colleagues do have an orthographic priming control condition for effects of formal overlap.

Masked priming (which was not used in the previously cited papers) is widely used in studies focusing on primed lexical access. Its main strength is that it seems to prevent any strategic processing. Both expectancy-based predictions and post-lexical verification of the relationship between prime and target can be major confounds in the interpretation of data from priming studies (Forster & Davis 1984; Forster 1998). Masked priming has been successfully used in ERP priming studies of derivational morphology aiming to study three types of complex forms: morphologically related (and semantically transparent) pairs (e.g. *darkness-DARK*), pairs with pseudo-morphological relationships that could be decomposable into pseudo-morphs (*corner-CORN*), and unrelated (and un-analyzable) but orthographically similar pairs (*brothel-BROTH*) (Lavric, Clapp & Rastle 2007; Morris, et al. 2007, 2008). Using lexical decision or semantic categorization, the three experiments showed similar results, namely reduced negative waves at early time windows (approx. 250 ms post onset) for the two first conditions as compared to control pairs (unrelated in form and meaning), and lesser modulation of this early negative wave for the third condition as compared to the morphological condition. Lavric et al. (2007) conclude that priming effects for morphological pairs (and pseudo-morphological pairs) show that morphological processing is not dependant on word semantics. Morris et al. (2008) agree that there seems to be an early pre-lexical phase where morpho-orthographic segmentation obtains independently of semantic relationships. Behavioural studies of French and English derived word priming experiments using lexical decision tasks have also shown similar effects of shared form in the absence of shared semantics have already shown these effects (see for example, Longtin, Segui & Hallé 2003; Taft & Kougious 2004). Stockall and Marantz's recent study used magnetoencephalography (MEG) to compare morphological (*taught-teach*) to formal priming (*curt-cart*) as well as combined semantic and formal (but not morphological) priming (*boil-broil*). Their data showed stronger priming effects for the pure morphological condition, but not for the combined condition (Stockall & Marantz 2006).

The evidence strongly points toward models of lexical processing where words are initially accessed via their formal properties and subsequently though their morphological ones. This morphological processing also seems to be qualitatively different from both orthographic and semantic processing. However, in most of these experiments brain waves are measured for different stimuli in each different priming condition. This has been argued by Forster (2000) to be problematic as different stimuli might cause difference to arise in results by virtue of their differences and no because of the variable we are trying to test. This is a recurrent issue in priming studies (Forster 2000), be they of the behavioral or of the ERP/MEG type. Although the stimuli in previous experiments are well controlled (i.e., usually of the same lexical category and are (most often) matched on many linguistic and psychometric measures such as morphological structure, length and frequency), it would be ideal to use the *same* targets in different priming conditions. In addition, none but one of the above reviewed studies has ever compared more than two of the three priming conditions that interest us (morphological, semantic and formal-orthographic) (Domínguez et al. 2004). We wish to do this in order to clearly disentangle the effects and timing of these three different types of processing. Yet another issue is the type of prime-target pairs used to study semantic processing. Synonym priming is the closest possible experimental condition to that of morphological priming. However, many studies use semantic associates, which are essentially random word pairings generated by pen and paper tasks or corpus searches, and can contain many different types of relationships that usually are not equivalent to the one observed between morphological pairs. We believe that more stringent test of the morphological semantic dissociation would be to include synonym pairs in experimental designs, and have thus used these. Because inflected forms have the advantage of having regular semantic relationships, we prefer them to derived morphological forms. This allows us to have highly constrained semantic similarity conditions for morphological relatedness as well as semantic ones. Finally, we 'sandwich-masked' the primes with both backward and forward masks and used short prime presentation times (30 ms) and SOAs of 100 ms (see Figure 1, below), thus reducing to a minimum any potential strategic effects that could arise from prime perception. In fact, with such a masked priming paradigm, semantic priming should be suppressed in its entirety. Importantly, if morphological priming is similar to that of semantic priming or susceptible to strategic effects, we should be able to similarly reduce morphological priming using masking.

In our ERP study, we aimed to tease apart semantic, formal, and morphological priming effects. With short masked prime presentation, this paradigm should suppress semantic priming, both behaviorally (Feldman & Prostko 2002; Forster 1998; Holcomb & Grainger 2009) and in brain waves (Lavric et al. 2007; Morris et al. 2007, 2008), while still yielding both formal and morphological priming, thus allowing us to test the hypothesized distinction of formal and morphological priming effects from semantic ones.

2. Hypotheses

A number of outcomes are expected based on the models outlined above. Because the strongest connectionist proposals expect all types of information to be simultaneously and interactively available for language processing, all priming conditions should promote target recognition and have noticeable effects on the brain waves. Furthermore, morphological priming effects should be similar to a combination of semantic and formal priming effects. Predictions based on morphology-based psycholinguistic frameworks would be quite different. Because morphological structure is a crucial factor in the architecture of the mental lexicon, morphological priming should result in qualitatively different ERP signatures from formal or semantic priming as access routes would presumably engage different cognitive processes. We would also expect the combined effects of orthographic and semantic priming to be different from that found for morphological priming. However, some authors claim that formal overlap can be helpful in word recognition *only* if there is a semantic relationship between the prime and the target (Seidenberg & Gonnerman 2000; Morris & Grainger 2009). This is however difficult to distinguish from a classical morphological view. It is therefore difficult to find any results that would *not* be explainable according to at least some connectionist accounts (we will come back to this in the discussion section). Here we follow the most parsimonious approach to data interpretation. We will assume that an ERP effect present for morphology but *qualitatively* absent in *both* of the other conditions is best accounted for by traditional morphological views, while *any* other outcome would support connectionist accounts.

Based on prior findings using similar paradigms to those we propose to use (short presentation times and masking), we predict a number of outcomes. We expect semantic effects to be absent in response latencies and ERP measures due to masking (Holcomb & Grainger, 2009). Facilitation is expected for morphological and orthographic priming on the basis of behavioral work (Feldman & Prostko 2002). ERP research leads us to predict different modulation of two ERP components – the N250 and the N400 – reflecting formal and morphological priming, respectively. N250 reductions have been observed in masked repetition priming (table-TABLE), partial repetition (teble-TABLE; Holcomb & Grainger 2006), and transparent derivations (hunter-HUNT; Morris et al. 2008). It thus seems to index access to the sub-lexical/lexical interface where mapping to both sub-lexical phonology and word-level orthographic representations occurs (Holcomb & Grainger 2006). These effects are expected to be less strong for orthography (e.g., scandal-SCAN) than morphology (Morris et al. 2008). The crucial question addressed here is whether the expected absence of semantic priming effects (due to the masked priming paradigm) will co-occur with morphological effects on the N400, and whether these will differ from formal priming. This outcome would be difficult to specifically predict within a connectionist account.

3. Methods

3.1 Participants

Twenty-four healthy adults (12 male) 18 to 35 years of age participated in the experiment. All were right-handed (Edinburgh Handedness Inventory, Oldfield, 1971), native speakers of French and had (corrected to) normal vision. They read and signed a consent form before the recording session, and received 45$ 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 electromagnetically shielded room in front of a computer screen. They were visually presented with one of three lists during the recording session, and were asked to decide if the string of letters on the screen (target word) was a French word or not by clicking a mouse key (subjects were typically unaware of the presence of a prime word.) Every prime-target pair was presented following the scheme outlined in Figure 1 (below). Primes, preceded by a (forward) mask for 500 ms, stayed on the screen for 50 ms and were followed by a 20ms (backward) mask. A target was then presented for 300 ms and was followed by a blank screen which lasted until the subjects made a lexical decision of 1000ms, whichever occurred first. A two-second interval was then allotted for eye blinking.

3.3 Stimuli

In order to reduce list effects, we tried to strictly control stimulus properties. For each verb target, three primes and their controls 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'). Controls were matched with primes in length (syllable and letter) and surface frequency. All oral frequency counts were taken from the LEXIQUE on-line database (New et al., 2001) 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. Semantic and morphological primes were matched on their semantic overlap with the target in addition to other linguistic and psycho-linguistic properties (see Royle et al. in preparation for details). Because of our stringent criteria for stimuli selection, we ended up with a master list of

42 target items. Filler items (half of the stimuli) and experimental pairs were pseudo-randomized, with each list arranged into 4 blocks, with all conditions equally distributed across the blocks. Finally, to avoid purely formal letter overlap (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.

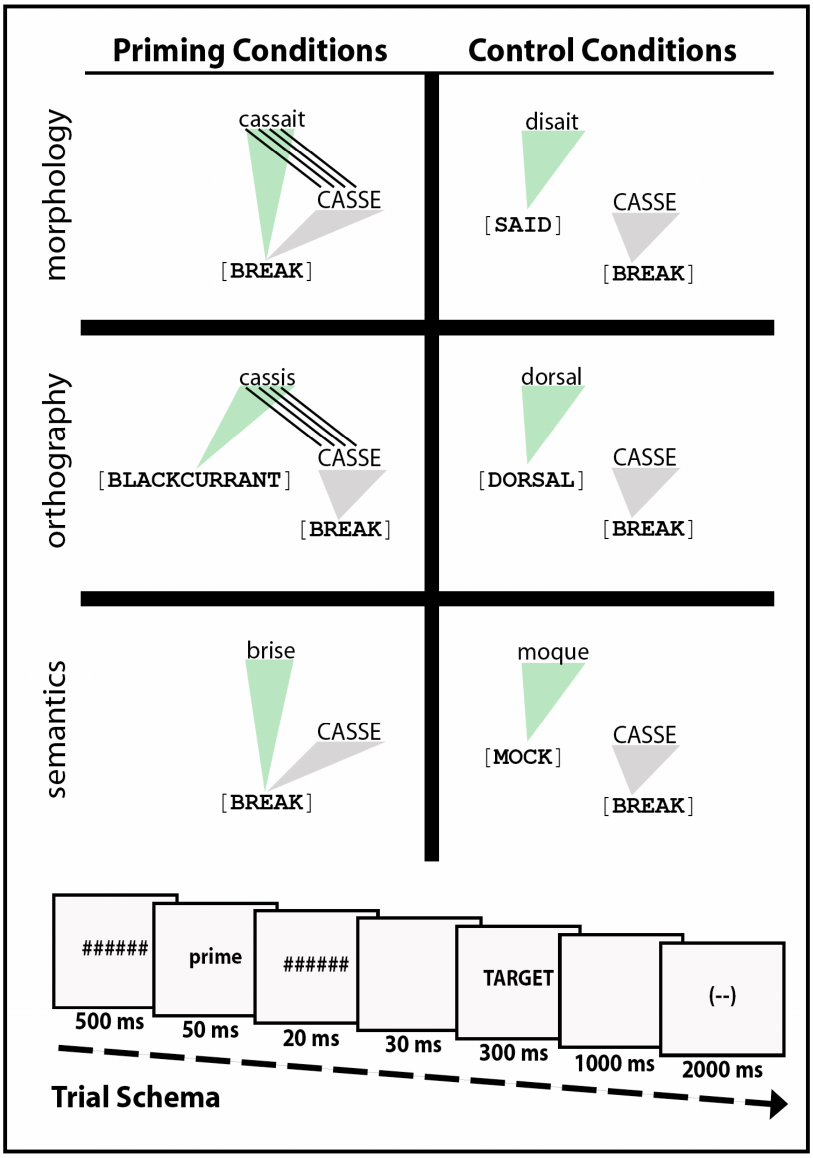

Figure 1: Experimental conditions and stimulus presentation scheme

3.4 Data recording and analysis

The EEG was recorded continuously with a 500 Hz sampling rate from 64 cap-mounted Ag/AgCl electrodes (Figure 2). Eye movements were monitored using EOG (electro-oculogram) electrodes. All impedances were kept below 5Ω. The EEG was amplified using Neuroscan SYNAMPS2 amplifiers and filtered offline with a bandpass of 0.16 to 30 Hz. ERPs were computed for each subject at each electrode in each condition and then entered the group averages. ERP amplitudes were quantified in representative time windows and subjected to repeated-measures ANOVAs.[1]

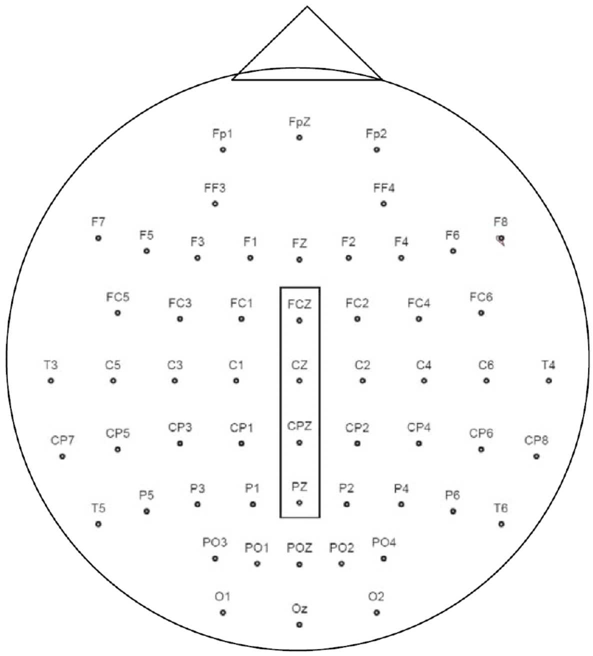

Figure 2: Array of 64 electrode positions used in the current study (top view, the triangle represents the nose). The four midline electrodes FCz, Cz, CPz and Pz (black rectangle) were selected to illustrate the ERP effects in Figure 3.

4. Results

All effects reported below were significant at an alpha of less than 0.05. We first present semantic priming effects and then move on to morphological and formal ones.

4.1 Semantic priming

As expected, no processing differences were observed for targets following synonyms versus unrelated controls, either behaviorally or in terms of ERP measures (see Figure 2, dashed lines). There were no priming effects during lexical decision either in terms of accuracy (control: 88%, primed: 87%) or response latency (control: 705 ms, primed: 699 ms, a difference of 6 ms). In

[1] Note that the data described here reflect preliminary analyses presented at CLA 2010. For more detailed information please refer to Royle et al. (in preparation).

line with the behavioral data, the ERP waveforms (Figure 2) for the primed versus control conditions were remarkably similar throughout the entire measurement epoch and did not differ statistically in any of the 50 ms time-windows tested (125-675 ms post target onset).

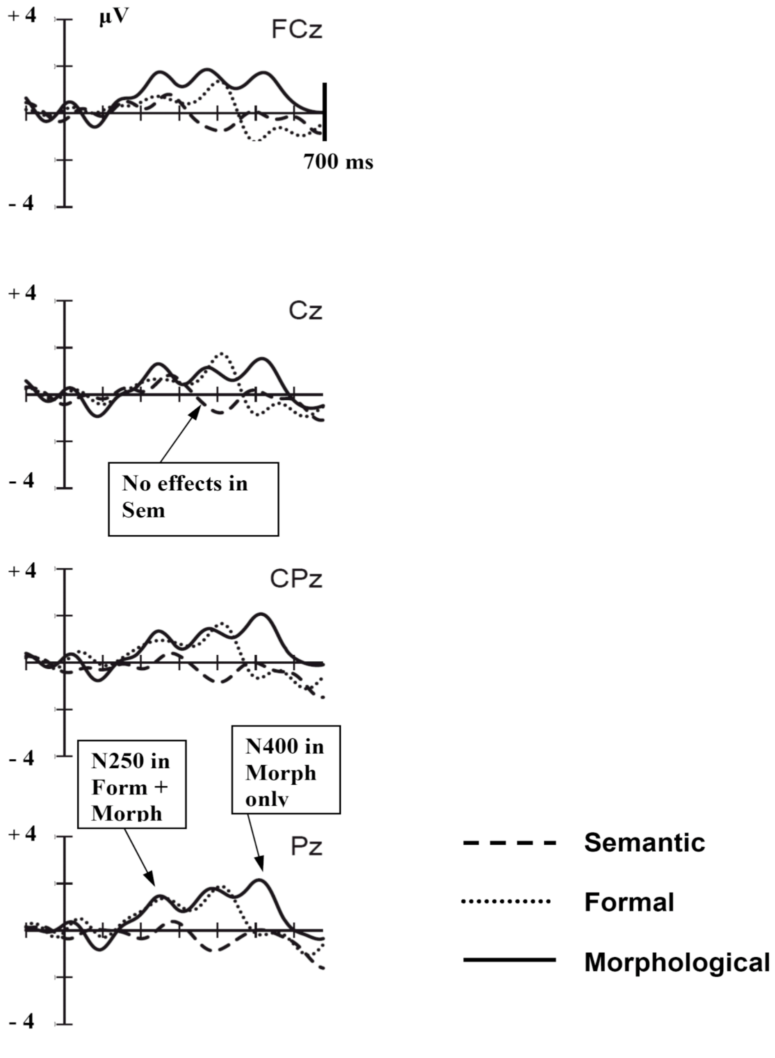

Figure 3: ERP difference waves (experimental minus control conditions) illustrating priming effects at four midline electrodes (see Figure 2). Positive amplitudes are plotted upwards. The difference waves are displayed from the onset of the target word (vertical line) until 700 ms thereafter for *Semantic* (dashed), *Formal* (dotted), and *Morphological* conditions (solid lines) and were low-pass filtered at 7 Hz for visualization purposes only. Whereas the morphological condition showed both an early (N250) and a later (N400) effect, the formal condition only displayed the early effect. No significant differences were found between the semantic condition and its control condition.

4.2 Formal and Morphological priming

Contrary to the semantic condition, both the formal and morphological priming conditions showed effects in behavioral and physiological data. Response accuracy was significantly lower for the control (83%) versus formally-primed (89%) conditions. In terms of decision times the primed condition (687 ms) was 14 ms faster than the control (701 ms); however, this difference did not reach significance [$p > 0.1$].

Contrary to formal priming and similar to semantic priming, there were no differences in response accuracy for primed and control conditions (both 86%). However, similarly to formal priming this time, decision times demonstrated a significant priming effect: the morphologically primed targets (693 ms) were identified 29 ms faster than control ones (722 ms), and this difference was significant.

These *quantitative* differences in the behavioral data were complemented by *qualitative* differences in the brain waves, thus revealing a pattern that can be linked to cognitive sub-processes and their specific temporal dynamics. Whereas in an early time window, between 225-275ms, both conditions displayed a similar attenuation of the negativity (see Figure 2) as compared to the control condition, in a later time window, between 475-575ms, only morphological priming was observed. That is, we see a strong and sustained reduction of the N400 for morphological priming only.

5. Discussion

The behavioral data are consistent with, but enriched by, ERP data not only in terms of relative timing of when the priming effects are observed in the brain wave but also in terms of their cognitive interpretation. In the ERP wave, we observe early shared effects for formal and morphological priming that are reflected in attenuated N250s, already shown in Holcomb and Grainger (2006). We also observe an attenuation of the later N400, however, only in the morphological condition. This effect seems to index repeated access to the lexical-semantic interface. This is interesting since, in the "pure" semantic condition, we do not find any significant modulation of the brain wave, let alone a classic N400 priming effect.

These three distinct patterns of activation, that is, no semantic priming in the presence of formal and morphological priming are telling. We discuss these in turn. Firstly, the fact that semantic priming is not found was expected in light of previous studies using masked priming and short prime presentation. Formal priming resulted in an early attenuation of the N250. This effect is similar to that found for orthographic priming by Lavric et al. (2007) and Holcomb and Grainger (2009). As one would expect, given orthographic overlap between prime and target in the morphological priming condition, the exact same effect was also observed in this priming condition. The consistency of this N250 attenuation across these two conditions (and not for semantic and control conditions) supports the interpretation that this component indexes priming at the orthographic-lexical interface (Holcomb & Grainger, 2009). Importantly, a broadly distributed and significant attenuation of the negative going wave observed in the morphologically primed versus unrelated condition between 425 and 575 ms post onset (resembling a classic N400 priming effect).

These patterns are consistent with morphological access having both pre- and post-lexical brain responses (indexed by both N250 and N400 effects). The early effect probably reflects the automatic processing of orthographic overlap between prime and target, as has been shown in previous ERP and psycholinguistic experiments (Morris et al. 2008; Longtin et al. 2003). As such, morphological and orthographic priming would not differ in this early time window. As expected, semantic effects are not apparent in this time window at all, as there is little or no formal overlap between prime and target in this condition.

The most important results of our study are the differences between all priming conditions at the N400 time-window, where the negative component is modulated by morphological but not by orthographic or semantic priming. These results converge with data from Domínguez, et al. (2004) showing that orthographic overlap (even in the presence of homographic stems) is not sufficient to produce similar effects to morphological priming. What our data add is a replication of their findings with a stronger experimental design, where a) targets words were identical across conditions, and b) masked priming prevented strategic processing as well as semantic priming, as shown both behaviorally and in ERPs. Similarly, Stockall and Marantz (2005, see above) have shown that semantically and orthographically related pairs (*broil-boil*) do not pattern like morphological pairs in MEG priming. This, in conjunction with our data and the experiments on Spanish, points to the existence of morphologically based parsing of words during lexical access.

It is theoretically possible that connectionist approaches could also account for our data. Under this view, semantic facilitation – which we successfully suppressed in our paradigm – may arise *only* when there is *also* orthographic overlap, thus explaining our putative morphological effect. However, because connectionist approaches must stipulate these additional assumptions to end up with predictions that are essential to morphological accounts, we interpret the data as support for traditional models. 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 morphological organization in the lexicon (see, e.g., Domínguez, et al., 2004; McQueen & Cutler, 1998). Finally, we have shown how the use of ERP testing paradigms can help us better understand the subtle differences between different types of processing in linguistically motivated research. In particular, these paradigms can give us a finer appreciation of the time-course of lexical processing and the cognitive mechanisms implicated during these processes.

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