

Event-related Brain Potentials Elicited by Morphological, Homographic, Orthographic, and Semantic Priming

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Abstract

■ The morphological structure of words, in terms of their stem morphemes and affixes, could influence word access and representation in lexical memory. Three experiments were carried out to explore the attributes of event-related potentials evoked by different types of priming. Morphological priming, with pairs of words related by their stem (*bijo/bija* [son/daughter]), produced a sustained attenuation (and even a tendency to positivity) of the N400 shown by unrelated words across the three experiments. Homographic priming (Experiment 1), using pairs of words with a superficially similar stem,

but without morphological or semantic relation (*foco/foca* [floodlight/seal]), produced an initial attenuation similar to the morphological pairs, but which rapidly tended to form a delayed N400, due to the impossibility of integration. However, orthographic priming (*rasa/rana* [flat/frog]) in Experiment 2 does not produce attenuation of the N400 but an effect similar to that of unrelated pairs. Experiment 3 shows that synonyms advance more slowly than morphological pairs to meaning coherence, but finally produce a more positive peak around 600 msec. ■

INTRODUCTION

Words are complex structures generally composed of more than one morpheme. For example, in the word *walker*, the suffix *-er* adds to the stem *walk* a variation that transforms the meaning of the stem. This morphological compositionality could be a structural property of words taken into account by the human linguistic processor. If words are organized in memory according to their morphological properties, then stem and affixes are the best candidates as access units. But if whole words are represented in the mental lexicon, then these units could be letters. These two possibilities differ in their demands of cognitive resources and processes. Whole word representation is very expensive in terms of memory resources because this requires a lexical entry for each derived or inflected word. On the other hand, morphological representation drastically reduces the memory demands, although this requires a previous segmentation of the input words into their constituent morphemes, which may slow down word recognition. In addition to the problems of access and lexical representation, research is concerned with the functional architecture of the system, whether modular or interactive, as we will refer to later.

This article focuses on the size of the access units, whether letters or morphemes, that guide the ascent from input words to meaning. This topic has been approached using different methodologies, for example,

manipulating the frequency of the root, building morphologically structured pseudowords (nonwords made up of existing morphemes), exploring the recognition of past tense irregular verbal forms, or evaluating production and comprehension in patients with cerebral damage in language areas. Perhaps the most powerful manipulation, however, at least for our purposes, is the contrast between morphological priming (i.e., a prime word, such as *niño* [boy] is briefly presented and then followed by a target word, such as *niña* [girl], both sharing the stem but differing in the gender suffixes) and some other types of priming. In particular, Laudanna, Badecker, and Caramazza (1989, 1992) reported in Italian slower lexical decision times for a pair of stem homographs such as *port-are/port-e* (to carry/door) than for pairs of words with similar orthographic overlap and different stem descriptions, such as *coll-o/colp-o* (neck/blow). The special relationship between these words is based on the letter overlap in the stem of both prime and target. There is, in fact, no semantic or morphological relationship between these, but superficial processing of the prime could lead to the target being taken as a morphological relative of the prime and therefore, to a garden path in the meaning access. Similar results were obtained in Spanish by Allen and Badecker (1999, 2002). The inhibition obtained for *mor-ía/mor-os* (the prime is the third person singular imperfect form of the verb *mor-ir* “to die”; the target means *Arabic*) was higher than the inhibition for *moral/mor-os* (morality/*Arabic*). These results point, firstly, to an orthographic activation of the stem *mor-*, and, secondly, to a competition

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between the two morphemes and meanings (death and race) activated by the orthographic features of the stem *mor-*. The homographic stem inhibition is not explicable in terms of letter overlap, but only in terms of morphological parsing. The study of Laudanna et al. (1989) in Italian and that of Allen and Badecker (1999) in Spanish have assumed that the AAM model provided the best frame to explain their results (Caramazza, Miceli, Silveri, & Laudana, 1985; Caramazza, Laudana, & Romani, 1988). In this model, the entries are stored in an Input Orthographic Lexicon as a structured sequence whose first element is the orthographic form of the stem and all the grammatical features associated with this form. Thus, the entries for *moría* and *moros* initially have the same orthographic form (they are stem homographs) and, consequently, a competition or inhibition between these would take place at the moment of lexical selection.

In Spanish, Domínguez, Cuetos, and Seguí (2002) compared stem homographic priming, such as in *foco/foc-a* (lightbulb/seal) with morphological priming, such as *bijo/bij-a* (son/daughter), obtaining significant facilitation for morphological pairs and a tendency to inhibition for stem homographic pairs. Using similar stimuli, García-Albea, Sánchez-Casas, and Igoa (1998) also found a tendency to inhibition for stem homographs. However, in none of these studies was the inhibitory tendency for stem homographs statistically significant, in comparison to unrelated pairs.

Although the above behavioral measures do not reveal a significant stem homographic effect, electrophysiological measures, such as event-related potentials (ERPs), have shown a clearer dissociation between stem homographs and morphological pairs. Thus, Barber, Domínguez, and de Vega (2002) obtained for both conditions a similar attenuation of the N400 component, in the 350–500 msec window and a broader negativity for stem homographs in the 500–600 msec window. This late negativity was compatible with the Laudana et al. (1989) proposal that the early inhibitory effect of stem homographs delays the stage of meaning integration.

Experiment 1 addresses the first aim of the present study: To replicate the dissociation between stem homographs and morphological pairs, and to extend the ERP analyses up to 1000 msec. Extending the temporal window beyond 600 msec is potentially interesting because it allows us to see whether the stem homographic curve involves a sustained negativity or, conversely, a later peak followed by a positive recuperation (delayed N400.) The latter would support Barber et al.'s (2002) suggestion that stem homographs cause an initial interference, followed by a delay in the meaning integration stage. If this is not the case, the sustained negativity would not find easy agreement in the literature.

A second objective was to rule out a possible confounding between stem homographic effects and orthographic priming. With this aim, a new orthographic priming condition was introduced in Experiment 2,

involving pairs of words such as *rasa/rana* (flat/frog). These orthographic pairs are semantically unrelated but they overlap in all letters except one. In this way, the formal similarity between primes and targets parallels that of morphological pairs or stem homographs. If the previously obtained results for stem homographs denote initial morphological stem segmentation; then no N400 attenuation should be expected for orthographic pairs, since they do not imply stem overlap.

The final objective was to solve another confounding of the previous experiments. Morphological priming is also semantic priming. In Experiment 3, pairs of synonym words such as *cirio/vela* (candle/candle) were introduced. These synonym pairs maintain the same semantic relationship as morphological pairs but avoid any orthographic or morphological relation. If the morphological effect denotes only semantic integration, we will find a similar N400 attenuation both in morphological pairs and in synonym pairs. In contrast, if morphological effects are due to genuine morphological priming, then the N400 attenuation will be clearer for morphological pairs than for synonyms. Thus, for the morphological pair *bijo/bija*, processing of the prime stem would facilitate the correct lexical entry to the target, whereas no morphological facilitation would occur for *cirio/vela*, despite their semantic relation.

To sum up, the aims of the present research will be firstly, to know whether or not the unit of lexical access is the morpheme; secondly, to ensure that the stem homographic effect is morphological and not just an orthographic effect; and thirdly, to separate morphological from merely semantic effects.

EXPERIMENT 1: STEM HOMOGRAPHS

The goal of this experiment was to replicate the experiment of Barber et al. (2002) taking a longer window of ERP for analysis. In this way we may observe whether stem homographs produce a delayed N400. This would support the hypothesis of a later difficulty in meaning integration, following the initial failure in morphological parsing. A morphological priming—*bijo/bija* (son/daughter)—was compared with a stem homographic priming—*foco/foco* (seal/floodlight)—and an unrelated control condition—*pavo/meta* (turkey/goal). It was expected that stem homograph pairs would produce a delayed N400, whereas morphological pairs would result in a more permanent attenuation of N400. It was also expected that stem homographs would not produce a significant inhibition in reaction times in comparison with the unrelated condition.

Results

Behavioral data

Mean reaction times for correct responses in each condition are presented in Table 1. Statistical analyses

[$F(1,10) = 28.98, p < .001$]. Stem homographic priming on the unrelated items did not produce a significant effect but interacted with the electrode factor [$F(2,20) = 11.85, p < .001$; $F(2,20) = 17.37, p < .001$, normalized], the difference only being significant at the Pz electrode [$F(1,10) = 9.27, p < .05$].

450–650 msec

Figure 1A clearly shows that at this late window, stem homographic pairs markedly differ from morphological pairs. The former shows an N400-like component, similar to that of the unrelated pairs, but approximately 100 msec later. Statistical analyses showed that the mean amplitude was more negative for stem homographs than for morphological pairs [$F(1,10) = 15.5, p < .005$]. Also, stem homographs were more negative than unrelated priming, but in this case the difference was only marginally significant [$F(1,10) = 4.22, p = .067$]. No statistical differences were found between the morphological and the unrelated priming conditions.

A peak latency analysis was carried out to determine more exactly the difference between the N400 produced by unrelated pairs and what we called the N400 retarded component produced by the stem homographs condition (the mean of peak latencies can be seen in Table 2). This analysis was run on the more negative latency in the curves for each subject between 250 and 650 msec, and it resulted in a significant difference between the moments of the two peaks [$F(1,10) = 14.84, p < .005$].

Discussion

The results obtained by Barber et al. (2002) were replicated in this experiment. Morphological priming produced an attenuation of the N400 as a result of the easy integration between the prime and the target, that not only share a part of their meaning but also their stem morpheme. Homographic pairs show a wave that overlaps that of the morphological pairs until 350 msec, suggesting that participants initially try to integrate words as if they were morphological pairs. However, the later

Table 2. Peak Latencies (msec) from the Onset of the Target and Standard Deviations for Unrelated Priming and Stem Homographic Priming at the Three Analyzed Sites: Fz, Cz, and Pz (Experiment 1)

Electrode Sites	Type of Priming			
	Unrelated		Stem Homographic Priming	
	Mean	SD	Mean	SD
Fz	372	45	463	80
Cz	385	44	486	101
Pz	438	91	521	100

rapid decay to negativity, peaking around 500 msec for homographs (a retarded N400 component), greater at the parietal site, should be interpreted as a word inhibition caused by the meaning disparity found at later stages of word processing. By contrast, the morphological condition produces a more distributed and sustained negativity in the three central electrodes. The results seem to support a model of lexical access partially based on the morphological organization of words, but before accepting this interpretation we have to rule out alternative explanation of the data. Thus, we are assuming that the retarded N400 for stem homographs indicates initial morphological processing, but this could also be explained as simply the result of the orthographic relation between the prime and the target. The next experiment tries to test this possibility.

EXPERIMENT 2: ORTHOGRAPHIC PRIMING

Stem homographs such as *foca/foco* orthographically overlap in their stem morphemes (e.g., *foc-*). But, in fact, *foc-* in *foca* is a different morpheme from *foc-* in *foco*. This might be the cause of the inhibition found with reaction time measures in Italian (Laudanna et al., 1989, 1992) and in Spanish (Allen & Badecker, 1999), and also the cause of the N400 retardation in Experiment 1. However, we need to discard the alternative explanation that the inhibition is merely caused by the orthographic overlap. Many reaction time studies have demonstrated that pairs of words sharing all except one letter (neighbors) but without any morphological relation produced inhibition. These results were obtained with a similar experimental procedure to our experiments: large prime duration (200 msec), and prime–target frequency relation (low-frequency primes and high-frequency targets). Furthermore, some ERP studies compared unrelated priming with formal priming (Doyle, Rugg, & Wells, 1996) and rhyme priming (Radeau, Bensson, Fonteneau and Luis-Castro, 1998) obtaining an N400 amplitude modulation for formal priming pairs, in comparison with unrelated pairs. In a wider experimental context, words with many lexical neighbors produced larger N400 than words with fewer lexical neighbors (Holcomb, Grainger, & O'Rourke, 2002), denoting that this component is sensitive to orthographic variables of the lexicon.

Experiment 2 compared morphological priming (*bijo/bija* [son/daughter]) with orthographic priming (*rasa/rana* [flat/frog]). If the orthographic condition causes the same delayed N400 we obtained in Experiment 1 for stem homographs, then we might consider that orthographic overlapping, rather than morphological processing, is the appropriate explanation for all priming effects observed in Experiment 1. If the orthographic condition, however, produces no delayed N400, then we may accept that morphological processing is a better explanation for both morphological priming and stem homographic priming.

Note that in this experiment, the orthographic pairs maintain in both words the same final vowel, which in Spanish is the gender suffix, *-a* for feminine words and *-o* for masculine words. No other possibility exists to obtain pairs of words sharing all letters except one and without morphological or stem overlapping. A potential problem is that, unlike in stem homographs and morphological pairs, in orthographic pairs a gender and/or rhyme priming could take place, for instance, *rasa/rana* (flat/frog). To control this difference between orthographic and morphological priming, an additional baseline condition (rhyming) was introduced in this experiment: pairs of words overlapping only in their final letter, such as *cuba/goma* (barrel/rubber).

Results

Behavioral Data

Mean reaction times for correct responses in each condition are presented in Table 3. The morphological condition produced a facilitation of 70 msec on the unrelated pairs [$F(1,9) = 41.15, p < .001$] and 57 msec on the rhyme pairs [$F(1,9) = 72.28, p < .001$]. Also, morphological pairs were processed 105 msec faster than orthographically related words [$F(1,9) = 76.40, p < .001$]. In contrast, orthographically related pairs produced 35 msec of retardation on the unrelated words [$F(1,9) = 10.20, p = .01$] and 48 msec on the rhyming words [$F(1,9) = 20.48, p = .001$]. No significant difference was produced between unrelated and rhyming words.

ERP Data

Figure 1B clearly shows an overlap of the orthographic priming and the two control conditions in this window. The orthographic condition looks, in fact, undistinguishable from the unrelated and the rhyming conditions. The three waves show a negative deflection peaking around 400 msec after target presentation. However, morphological priming has a wave with the same shape observed in Experiment 1, namely, a positivity (above 5 μV) starting at 250 msec and remaining throughout the three windows.

250–450 msec

The positive wave of the morphological condition differs significantly from the negativity of unrelated words

[$F(1,9) = 36.49, p < .001$], from the control rhyming words [$F(1,9) = 63.08, p < .001$], and from the orthographic priming [$F(1,9) = 69.50, p < .001$]. Morphological priming in the unrelated pairs interacted with the electrode factor [$F(2,18) = 4.77, p < .05$], but this effect was lost when normalized [$F(2,18) = 2.86, p = .08$]. Also morphological priming in the rhyming words interacted with electrodes [$F(2,18) = 4.71, p < .05$], the effect being marginal when normalized [$F(2,18) = 3.18, p = .066$]. Although orthographic priming is not significantly different from unrelated or rhyming pairs, there was a difference at certain electrode sites [$F(2,18) = 4.53, p = .05$]. Orthographic priming was more negative than rhyming priming at the Pz site, however, when this difference was analyzed electrode by electrode, no significant effect was reached.

350–450 msec

In this window, morphological priming maintained the positivity in the unrelated words [$F(1,9) = 56.71, p < .001$], rhyming words [$F(1,9) = 73.08, p < .001$], and orthographically related words [$F(1,9) = 63.53, p < .001$]. No other difference was significant.

450–650 msec

Morphological pairs show a significant difference with unrelated pairs [$F(1,9) = 6.06, p < .05$], larger at the frontal site [$F(2,18) = 5.11, p < .05$; normalized $F = 5.92, p < .05$], and also with rhyming pairs [$F(1,9) = 9.00, p < .05$], especially at the Fz site [$F(2,18) = 6.27, p < .01$; normalized $F = 6.40, p < .01$]. This result contrasts with the central or parietal localization of the morphological effect at the previous epochs.

Orthographic pairs, after their maximum negative peak at 400 msec, still show a very slow recovery of positivity. In fact, the wave for orthographic pairs is significantly more negative than for morphological pairs [$F(1,9) = 32.93, p < .001$], and rhyming pairs [$F(1,9) = 6.21, p < .05$]. There were no orthographic priming effects when measured on the totally unrelated pairs.

Discussion

The unrelated priming condition produced a standard N400, whereas the morphological priming condition showed a clear positive wave in the same temporal region. This positivity, found in both Experiments 1 and 2, suggests that the semantic integration between prime and target is facilitated when they share the same morpheme. The only variation with respect to Experiment 1 was that the effect of morphology was also visible at the late temporal window, and was larger at the anterior site Fz (see Figure 1B).

Orthographic pairs, on the other hand, tend to be more negative than rhyming pairs at the early and late

Table 3. Mean Reaction Times (msec) and Standard Deviations in Experiment 2 for Each Experimental Condition

Type of Priming, Mean (SD)			
Morphological	Orthographic	Rhyming	Unrelated
668 (74)	773 (75)	725 (83)	738 (87)

windows, very different from the positive tendency of morphological pairs. The late effect is quite similar to the stem homographic effect found in Experiment 1 for the same window of 450–650 msec. However, unlike orthographic pairs, stem homograph pairs also produced a modulation of N400 at the 250–450 msec window, overlapping the morphological wave during the first 100 msec. Putting together the results of Experiments 1 and 2, a clear dissociation emerges between stem homographs and orthographic pairs at the early window, despite the fact that in both conditions the prime and the target share the same number of letters. Thus, stem homographs were initially processed as morphologically related words (early positivity), starting a sort of morphological “garden path” (Figure 1A). In other words, for stem homographs, a morphological stage of stem segmentation takes place, which is similar to that for morphological pairs and that occurs as a first component between 250 and 350 msec.

The orthographic pairs, however, were initially processed as unrelated pairs until 450 msec (see Figure 1B), and from this point they produced a late negativity at the window of 450–650 msec, possibly as a consequence of orthographic overlapping rather than morphological processing.

Concerning reaction times, facilitation was found for morphological pairs in Experiment 1 and Experiment 2, an inhibition effect was observed for orthographic pairs in Experiment 2, replicating some other studies which found inhibition for neighbors.

In conclusion, the morphological condition produces facilitation on RTs and attenuation of N400, stem homographs produce a delayed N400, and the orthographic condition produces inhibition on RTs and a late negativity in ERP. These differences support an early morphological treatment of words when the prime and the target have an orthographically similar stem, such as occurs for morphological pairs and stem homographs. This morphological processing cannot be merely reduced to orthographic overlapping.

EXPERIMENT 3: SYNONYM PRIMING

The previous experiments demonstrate that stem homographic inhibition is a morphological phenomenon that cannot be confused with orthographic formal priming. Experiment 3 aims to rule out another confounding issue: To what extent could morphological priming be reduced to a semantic priming effect? Notice that, unlike orthographic and stem homographic words, morphological pairs are semantically related (primes and targets constitute the feminine and the masculine version of the same root morpheme). To address this question, a synonyms condition was introduced, including orthographically and morphologically unrelated words that maintain, however, a semantic relation and a change in gender suffix, similar to those of morphological pairs, for

instance, *cirio/vela* (candle masculine/candle feminine), or *vara/palo* (stick masculine/stick feminine). Using these pairs, it is possible to know whether the source of the observed morphological priming is simply the semantic relation between the prime and the target. If this is the case, the ERP waves for the morphological and the synonym condition would be similar, otherwise the morphological wave would differ from that of the synonym pairs.

Results

Behavioral Data

Mean reaction times for correct responses in each condition are presented in Table 4. In comparison with unrelated pairs, both morphological pairs [$F(1,10) = 8.99, p < .001$] and synonyms produce facilitation [$F(1,10) = 26.53, p < .001$]. Synonyms produced an even larger facilitation of 56 msec than morphological pairs (45 msec), although no significant difference was found between them.

ERP data

Again, unrelated words produced the typical N400, whereas morphological pairs and synonyms showed a clear attenuation of N400 (see Figure 1C).

250–350 msec

Morphological priming was more positive than unrelated pairs [$F(1,10) = 19.03, p = .001$]. The contrast between synonyms and unrelated words was significant [$F(1,10) = 5.82, p < .05$], and also the difference between synonyms and morphologically related words [$F(1,10) = 10.51, p < .01$].

350–450 msec

At this window, the morphological priming persists in a positive tendency significantly different from the negative curve for unrelated words [$F(1,10) = 45.04, p < .001$], and more important at the central and posterior sites [$F(2,20) = 10.32, p = .001$; normalized $F(2,20) = 9.37, p = .001$]. The attenuation of the N400 for synonyms obtained at the previous window does not now reach statistical significance, as perhaps a larger variability of the data was obscuring this effect.

Table 4. Mean Reaction Times (msec) and Standard Deviations in Experiment 3 for Each Experimental Condition

Type of Priming, Mean (SD)		
Morphological	Synonym	Unrelated
687 (146)	676 (136)	732 (113)

The morphological positivity stabilizes, whereas the semantic priming wave becomes even more positive, peaking around 600 msec. The only significant difference was between synonyms and unrelated pairs [$F(1,10) = 5.01, p < .05$], especially important at Cz and Pz [$F(2,20) = 5.56, p < .05$; normalized $F(2,20) = 5.78, p < .05$]. No statistical difference was found between semantic and morphological priming, but there is a small region in the middle of the epoch in which differences are quite visible. Therefore, a separate analysis was carried out for this region, in the window 500 to 600 msec. The results showed that synonyms maintain a significant difference with unrelated words at the posterior sites [$F(2,20) = 4.33, p < .05$] but, in addition, synonyms were also significantly more positive than morphological words [$F(1,10) = 6.49, p < .05$].

Discussion

Semantic integration in the early epoch seems easier for morphologically related words than for synonyms. In both cases, the tendency to positivity appears, but morphologically related words produce an even more pronounced slope that stabilizes approximately at $10 \mu\text{V}$, 400 msec after the target onset. In contrast, synonyms surpass the positivity of morphologically related words at the third window, about 600 msec. These effects are probably caused by different processes. In the early epoch, morphological pairs are more effectively integrated than synonyms because the synonym target may not take advantage of the previous stem treatment of the synonym prime. The morphological treatment is only successful for morphological pairs, which are more rapidly integrated.

GENERAL DISCUSSION

This ERP study made a systematic contrast between morphological priming and three other sources of possible confounding: stem homographic, orthographic, and synonym priming. The electrophysiological wave for morphological priming was clearly dissociated from the waves observed for the other priming conditions, suggesting that, during lexical access, readers apply a genuine rule-based process of stem segmentation. In all three experiments, the morphologically related words showed a clear modulation of N400 in the 250–450 msec epoch, maintaining the positivity later (see Figure 1). The initial overlap between morphological and stem homographic waves was interpreted as an attempt to apply a rule-based procedure to segment the word stems and to integrate them. This action is effective for morphological priming, whereas the delayed N400 indicates an integration failure for stem homographs. An explanation for this

is that stem homographs, like morphologically related words, have the same orthographic root in spite of not being morphological relatives.

The results support, for Spanish word processing, a time-course starting with morphological parsing of word stem and affixes, followed by lexical contact and finally proceeding to word–word meaning integration (Marslen-Wilson & Tyler, 1998; see Domínguez et al., 2002 for similar conclusions with RT measures). Our approach is compatible with the AAM model (Caramazza et al., 1985, 1988) presented in the introduction to this article and basically coinciding with a model defended by Allen and Badecker (2002). They propose a two-stage model to explain the inhibitory effect they obtained on reaction times with stem homographs. The form of the stems is represented at the *lexeme* level, whereas an abstract representation of the stem, including grammatical class and meaning information, is located at the *lemma* level. Stem homographs use a common representation at the lexeme level and different representations at the lemma level where competition for lexical selection takes place. This model could be applied to explain our ERP results. Stem homographic pairs initially accede to a common lexeme unit, and this explains why, at the 250–350 msec window, the stem homographic priming and the morphological priming waves overlap. However, after 350 msec the lemma contact stage begins. Stem homographs produce a delayed N400 because they activate two different lemmas, resulting in inhibition. However, morphological pairs maintain a late positivity, because they activate the same lemma, producing facilitation.

As to orthographic pairs, these do not share a lexeme representation and, therefore, do not show an early facilitation (positivity at the 250–350 msec window). When the lemma level is reached, orthographic pairs are processed as ordinary unrelated words, that is, they activate two different lemmas, showing the standard N400 effect (neither activation nor inhibition).

Finally, when synonym words are presented, the lexical selection should be facilitated because they share the same lemma. Therefore, as for morphological pairs, a large positivity could be predicted. However, the time course of this positivity was rather different between morphological and synonym pairs (see Figure 1C). Morphological priming involves an early positivity maintained throughout both temporal windows, because the facilitation is produced both at the lexeme and at the lemma stage. In contrast, synonyms produce a slow developing positivity which reaches maximum at the late window, because only at the lemma stage does facilitation take place.

This is not the only theoretical framework to interpret these experimental results. It might also be possible to implement our proposal in terms of the Interactive Activation Models, on the condition of including morphological units, midway between letters and meanings (Taft, 1994; Taft & Zhu, 1995). In fact, Allen and

Badecker's (2002) model, and their explanations in terms of activation and inhibition, suggests interactive and partially distributed processing.

In contrast with these two-step models, totally distributed connectionist models defend the position that the morphological properties of words emerge uniquely from the correlation between orthographic and semantic features of morphological relatives, and therefore they reject a genuine morphological level of processing (Seidenberg & Gonnerman, 2000; Joanisse & Seidenberg, 1999). We think that distributed models might not account easily for our results because they would predict a similar priming effect for stem homographic priming as for neighbor orthographic priming.

In short, the use of ERPs to study the access and representation of morphologically related words allowed support for a model of word recognition that starts by segmenting the stem and then proceeds to select an appropriate semantic representation at a higher level. These two levels could be related to the two-step model proposed by Allen and Badecker (1999, 2002). A second consequence derived from the results is that N400 modulation could be reflecting two different subcomponents: an early component (250–350 msec) at the level of morphological decomposition (the lexeme level) and a later component related to lexical and meaning selection (the lemma level).

METHODS

The three experiments conducted share the same experimental procedures, EEG-recording protocol, signal treatment, and statistical analysis, as well as some of the materials. We will describe them in the following sections.

Materials

The morphological priming condition and two other control conditions were common to all three experiments, whereas the stem homographic, orthographic, and synonym conditions were introduced in Experiments 1, 2, and 3, respectively. All conditions consisted of 42 pairs of prime–target stimuli. Morphological pairs shared the same stem and varied only their gender suffix, the final letter *-a* for feminine and *-o* for masculine, for example, *bija/bijo* (daughter/son). Unrelated words involved words with one standard suffix of gender (*-o* or *-a*) and differing in all their letters and meanings, for instance, *pavo/meta* (turkey/goal). Another list of nonexperimental fillers whose final letters were not the suffixes *-a* or *-o* was also composed *azar/pais* (chance–country). All experiments also included nonexperimental word–pseudoword pairs. Eighty-four of these shared all letters except one (*lago/laga* [lake/laga]) and the other eighty-four were totally unrelated (*beso/foja* [kiss/foja]). The distribution of the ortho-

graphic similarity in the word–pseudoword pairs and word–word pairs aims to reduce the possibility that participants may guess whether the target is a word or not, merely by observing the orthographic overlap between prime and target.

In addition to the above conditions, Experiment 1 introduced stem homographic pairs, which shared all the letters of their stems but differed morphologically and therefore semantically, for example, *foca/foco* (seal/floodlight). The specific stimuli of Experiment 2 were the orthographic pairs and the unrelated rhyming pairs. In the orthographic condition, primes and targets shared all letters except one that was not the final letter, for example, *rasa/rana* (flat/frog). In this way, prime and target were neighbor words but not stem homographs. In the rhyming condition, unrelated words differed in all letters except the final letter, for instance, *cuba/goma* (barrel/rubber). This condition may be a better baseline than totally unrelated pairs because neighbor pairs shared the last letter. Finally, the specific condition of Experiment 3 was synonym pairs: Primes and targets were synonym words differing in gender, for example, *cirio/vela* (candle [masculine]/candle [feminine]).

The experimental stimuli were Spanish nouns or adjectives of four, five, or six letters long. The lexical frequency of targets, obtained from Alameda and Cuetos (1995), was controlled across conditions and their means are shown in Table 5. The frequency of the prime was maintained lower than the frequency of the target. This condition has been demonstrated effectively to produce inhibition in the recognition of targets orthographically related with their primes, at least when exposure time for primes is long enough to be consciously recognized. This is the case for our primes that were exposed for 250 msec. Each subject received 210 word pairs (168 experimental) and 168 word–nonword pairs. The characteristics of the stimuli may be seen in Table 5 and the total list of experimental stimuli is offered in the Appendix.

Procedure

Each trial was organized as follows: (1) a pure tone of 200 msec indicated the beginning of the trial; (2) a blank interval of 300 msec; (3) a fixation point in the center of the screen for 200 msec; (4) a blank interval of 500 msec; (5) the prime was presented in lowercase letters for 200 msec; (6) an interstimulus blank interval for 100 msec; (7) the target word or nonword in uppercase letters remained 1 sec or until the participant responded; (8) the word PARPADEA (BLINK) appeared for 2 sec; (9) and finally, another blank interval remained for 1500 msec until the next trial. Participants were told that a word would appear in the center of the screen followed by a second uppercase letter string; the target stimulus. They were asked to pay attention to both words and were required to indicate whether the target

Table 5. Lexical Frequency, Longitude, and Target Gender in All Experimental Conditions

	<i>Prime Frequency</i>	<i>Target Frequency</i>	<i>No. of 4/5/6/ Letter Words</i>	<i>-o/-a Target Words</i>
Stem homographs	18	117	21/17/4	21/21
Orthographic	13	114	23/15/4	19/23
Semantic	55	110	22/16/4	16/26
Morphological	52	115	22/16/4	16/26
Unrelated rhyming	28	113	22/16/4	21/21
Unrelated	25	112	22/16/4	20/22

was or was not a word by pressing one of two buttons on the response keyboard (lexical decision task). Their right index finger was used for the button “YES” and their left index finger for the button “NO”. Participants were also asked to maintain fixation on the center of the screen and to avoid eye movements during the interval from the fixation point until the appearance of the word PARPADEA (BLINK).

EEG Recording

The EEG was recorded from 15 thin electrodes mounted on an electrode elastic cap according to the 10% standard system of the American Electroencephalographic Society and amplified using a Medicid-4 system. The recording sites were placed on F7, Fz, F8, FT7, FT8, T3, C5, Cz, C6, T4, CP5, CP6, Pz, O1, and O2. All EEG channels were referred to linked mastoids. Interelectrode impedance was kept below 5 K Ω . The bio-signals were recorded in the 0.05–50 Hz band and were digitized continuously with a sampling rate of 200 Hz. Two EOG electrodes, one suborbital left eye and another on the external canthi of the right eye monitored for vertical and horizontal eye movements and blinks.

Analyses

Baseline correction was performed using the average EEG activity in the 100 msec preceding the onset of the target word as a reference signal value. After the baseline correction, trials with ocular artifacts exceeding 80 μ v were rejected. Separate ERPs were averaged for each experimental condition, for each of participants and for each of the electrode sites.

Three epochs were selected for analyses. A visual inspection of waves evidenced that 250 msec was approximately the point at which all the related experimental conditions began to differ from the unrelated condition in the three experiments. From this point there is a positive peak that could be considered a first component, followed by a negative tendency to conform a second component which peaks around 400 msec. The

first epoch to analyze was extended from 250 to 350 msec. The second, which includes the N400, began at 350 msec and ended at 450 msec. Finally, the third epoch was established from 450 to 650 msec, in order to clarify how some effects initiated in the previous window evolved, or the emergence of new later effects.

Multiple analysis of variance (MANOVA) was applied on the average voltage window for each experimental condition. Analyses were carried out only on the Fz, Cz, and Pz of midline sites because the effects were more powerful on the central axis. Because no laterality effects were evident in the total wave distribution, the left and right electrode sites were discarded from the analyses. All interactions described in the manuscript between electrode sites and conditions were normalized with the procedure established by McCarthy and Wood (1985).

MANOVAs on reaction times excluding errors were carried out by participants, excluding latencies exceeding or not reaching 2.5 standard deviations from the mean reaction time of each category. Because the data of interest were the differences between pairs of conditions, MANOVAs were applied to calculate significant differences between the morphological and the unrelated condition, between the morphological and the stem homographs condition, and finally, between the stem homographs and the unrelated condition. These analyses constitute a primary source of evidence to appreciate to what extent behavioral measures and ERPs are either complementary or conflicting.

Participants

Thirty-two psychology undergraduates at the University of La Laguna, Spain, participated in the experiments for course credit: 11 in Experiment 1 (8 women and 3 men, age range 18–26 years, mean 20.7); 10 in Experiment 2 (9 women and 1 man, age range 19–33, mean 22.9); and 11 in Experiment 3 (9 women and 2 men, age range 20–28, mean 21.3). All were Spanish native speakers with normal or corrected-to-normal vision and classified as right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971).

APPENDIX

Type of Priming

MORPHOLOGICAL		STEM HOMOGRAHS		NEIGHBORS		SYNONYMS		UNRELATED		RHYME	
ácida	ÁCIDO	acero	ACERA	bruma	BROMA	forro	FUNDA	ficha	JUNIO	noria	RUBIA
fino	FINA	acta	ACTO	bala	BATA	ganso	OCA	limbo	CARTA	ronco	TEXTO
neta	NETO	arca	ARCO	topo	TOMO	asno	BURRA	cerdo	FALSA	plomo	RASGO
bello	BELLA	bando	BANDA	pauta	PAUSA	rabo	COLA	rollo	DUCHA	prado	DISCO
guapo	GUAPA	barbo	BARBA	turba	TUMBA	glúteo	NALGA	pavo	META	caro	SACO
maja	MAJO	bazo	BAZA	rifa	RIMA	laxo	FLOJA	cava	YESO	zaga	LUPA
mona	MONO	caño	CAÑA	lacio	LABIO	cirio	VELA	hucha	TIBIO	sidra	TALLA
hado	HADA	cepo	CEPA	bulo	BUZO	jeta	MORRO	dina	POMO	cana	FOFA
rica	RICO	cero	CERA	rueca	RUEDA	clavo	PUNTA	ruda	POZO	gula	PATA
soso	SOSA	coco	COCA	pana	PAJA	jaca	POTRO	pasmo	TROPA	tieso	GLOBO
moza	MOZO	copo	COPA	cota	COLA	edredón	MANTA	lija	DEDO	fuga	VIVA
preso	PRESA	costo	COSTA	cuna	CURA	vara	PALO	treta	REINO	bizca	CARGA
moro	MORA	coto	COTA	rasa	RANA	lizada	NUDO	jira	TAJO	galo	CEBO
sola	SOLO	faja	FAJO	credo	CRUDO	esposa	MARIDO	peto	LONA	cazo	HIPO
vana	VANO	filo	FILA	seto	SENO	obesa	GORDO	vaca	FIJO	nená	GOTA
gata	GATO	foca	FOCO	trepá	TRIPA	sortija	ANILLO	halo	SOGA	apto	PINO
india	INDIO	gesta	GESTO	cieno	CIELO	fosa	HOYO	poema	CAMPO	silla	MEDIA
corta	CORTO	grada	GRADO	daga	DAMA	sólida	DURO	video	LUCHA	barro	TECHO
lindo	LINDA	grifa	GRIFO	musgo	MUSLO	loma	CERRO	liga	CELO	cuba	GOMA
amiga	AMIGO	labia	LABIO	calco	CALVO	espíritu	ALMA	terca	QUESO	horma	VENTA
malo	MALA	lapo	LAPA	roscó	RISCO	zoco	PLAZA	cisma	MANSO	larva	MONDA
mulo	MULA	loma	LOMO	manco	MANTO	sebo	GRASA	socio	FURIA	grato	CASCO
mango	MANGA	maya	MAYO	foro	FOTO	oda	VERSO	lila	MURO	beca	ROSA
llana	LLANO	micra	MICRO	lima	LIRA	mago	BRUJA	salmo	GUASA	cauto	RUEDO
baja	BAJO	pala	PALO	trapo	TRAGO	modo	FORMA	surco	FIRMA	horn	PACTO
roja	ROJO	papo	PAPA	luto	LUJO	brisa	VIENTO	mosto	PLENA	denso	HUECO
seca	SECO	plato	PLATA	placa	PLAYA	pompa	LUJO	teja	PURO	jefa	MODA
viudo	VIUDA	plazo	PLAZA	tela	TEMA	manto	CAPA	pisó	ROPA	mito	HUMO
burdo	BURDA	porra	PORRO	tala	TASA	rudo	BRUTA	rezo	LOSA	veto	MIMO
docta	DOCTO	bombo	BOMBA	pica	PIPA	plagio	COPIA	capo	MISA	remo	OLMO
listo	LISTA	punta	PUNTO	lazo	LADO	sepulcro	TUMBA	pena	TIPO	rara	COSA
bobo	BOBA	rata	RATO	toro	TONO	caldo	SOPA	suma	PELO	pupa	ZONA
hija	HIJO	rejo	REJA	torta	TARTA	folio	HOJA	yugo	MASA	rizo	LORO
honda	HONDO	rumba	RUMBO	timo	TIRO	cima	PICO	caza	HILO	gafa	BODA
alta	ALTO	seta	SETO	aspa	ARPA	rostro	CARA	mirra	TALLO	farra	NECIA
obvia	OBVIO	grupa	GRUPO	hola	HORA	trazo	RAYA	éter	OBRA	nata	MESA
regia	REGIO	suela	SUELO	maga	MAPA	curada	SANO	nodo	LUNA	pura	CAMA
liso	LISA	tuba	TUBO	panza	DANZA	chucho	PERRA	tufo	GIRA	sapo	PITOV
aliada	ALIADO	correa	CORREO	tarado	TAPADO	sarao	FIESTA	eslora	NEGADO	modosa	RETINA
diaria	DIARIO	garito	GARITA	calima	CALIFA	paga	SUELDO	vivero	PALETA	rumano	COCIDO
fulana	FULANA	navajo	NAVAJA	espeso	ESPOSO	alimento	COMIDA	dibujo	HERIDA	divino	CASADO
limpia	LIMPIO	puerto	PUERTA	cuerno	CUERPO	heno	HIERBA	rutina	PASADO	locura	MIRADA

Acknowledgments

This research was supported by the grants PB98-0431 and BSO2002-04301-C02-02 by the Ministerio de Ciencia y Tecnología (Spain). We thank Margaret Gillon Dowens for her revision of earlier versions of this manuscript.

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