

# Stem allomorphy in the Spanish mental lexicon: Evidence from behavioral and ERP experiments

Rafael Enrique Linares<sup>a</sup>, Antoni Rodríguez-Fornells<sup>b,c</sup>, Harald Clahsen<sup>a,\*</sup>

<sup>a</sup> Department of Linguistics, University of Essex, Colchester, C04 3SQ, UK

<sup>b</sup> Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona

<sup>c</sup> Faculty of Psychology, University of Barcelona, 08035 Barcelona, Spain

Accepted 19 August 2005

Available online 21 October 2005

## Abstract

This study presents results from a nonce-word elicited production task and a reading experiment using event-related brain potentials (ERPs) investigating finite forms of Spanish verbs which consist of marked stems and regular person and number agreement suffixes. The first experiment showed that unmarked stems are productively extended to nonce words, whereas marked stems generalize more restrictively to nonce words, based on lexical similarity to existing stem forms. The second experiment yielded a lexical ERP signature for stem violations and an ERP pattern signaling morpho-syntactic (rule-based) processing for suffix violations. We argue that stem allomorphy is lexically represented in the Spanish mental lexicon, with marked stems forming subnodes of structured lexical entries.

© 2005 Elsevier Inc. All rights reserved.

**Keywords:** Inflection; ERPs; Stem alternations; Spanish

## 1. Introduction

What are the basic morphological units and operations that the speaker/hearer employs in processing inflected words? The answers to this question are controversial among psycholinguists. Some argue that words are the basic processing units and that each word form of a given lexeme has its own entry in the mental lexicon (Butterworth, 1983; Manelis & Tharp, 1977; see also Rumelhart & McClelland, 1986). Others have argued that affixes and roots are the major units in morphological processing. Taft, Forster, and their collaborators (Taft, 1988; Taft, Hambly, & Kinoshita, 1986) posited parsing operations such as ‘prefix stripping’ by which roots are identified and matched against entries stored in the mental lexicon. The distinction between roots and affixes is also essential to Pinker’s (1999) ‘words-and-rules’ model in which irregular inflection is tied to roots, and regular inflection is based

on affixation, e.g., on rules such as ‘Add *-ed*’ which concatenates a bound past-tense morpheme to a verbal root. The fact that much psycholinguistic work on inflectional morphology has only employed a restricted set of largely morpheme-based concepts (words, roots, affixes) coincides with its strong focus on English for which these morphological types seem sufficient.

In addition to words (or rather lexemes), roots, and affixes, many morphologists consider *stems* as an independent morphological type. Aronoff (1994), for example, points out that a root is morphologically unanalyzable and is defined with respect to a lexeme. A stem, by contrast, is defined with respect to a series of forms (not with respect to a lexeme), represents recurrent parts within such a series, and may be morphologically complex. To illustrate these notions, consider inflected verb forms in Spanish in which inflectional affixes are typically combined with stems, which in turn are combinations of theme vowels and roots. This is illustrated in (1) for a finite form of the verb *cantar* ‘to sing.’

(1) *cant*    *á*                      *ba*                      *mos*  
‘sing’    theme vowel    past imperfect indicative 1st plural

\* Corresponding author. Fax: +44 1206 87 2198.  
E-mail address: [harald@essex.ac.uk](mailto:harald@essex.ac.uk) (H. Clahsen).

Most verb forms in Spanish have combinatorial [root + theme vowel] stems which can be further divided into three conjugations, identified by the theme vowel, e.g., in the infinitive. The first conjugation is by far the largest (in terms of verb types), and almost all of the 1st conjugation verbs have combinatorial stems. The 1st conjugation is also the open class par excellence. For example, English *to stress* ‘to cause stress’ becomes Spanish *estresar*, English *to film* Spanish *filmar*, and so on. Approximately, 900 verbs (almost all of which are 2nd and 3rd conjugation verbs) have marked stems, i.e., forms which are not simply [root + theme vowel] combinations. About 30 of these are highly irregular, including verbs such as *estar* ‘to be,’ *caber* ‘to fit,’ *querer* ‘to want,’ *poner* ‘to put,’ *tener* ‘to have,’ *ir* ‘to go,’ *venir* ‘to come.’ This is illustrated in (2) for the past indicative of *poner* ‘to put.’

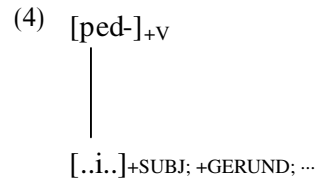
(2) <i>puse</i>	‘I put’
<i>pusiste</i>	‘You put’
<i>puso</i>	‘she/he/it put’
<i>pusimos</i>	‘we put’
<i>pusisteis</i>	‘you put’
<i>pusieron</i>	‘they put’

The paradigm illustrates that the marked stem *pus-* is used in past tense forms, sometimes without a theme vowel, as for example in *puse*, *puso*, and sometimes together with the 2nd conj. theme vowel (= *-i*), as for example in *pus-i-ste*. Another kind of marked stem form involves diphthongization, e.g., *entender—entiendo* ‘to understand—I understand,’ *rogar—ruego* ‘to beg—I beg,’ which is common in Spanish, not only in verbs. There are, however, many verbs that have (non-low) vowels which do not undergo diphthongization, e.g., *notar—nóto* ‘to note—I note.’ Diphthongized stems are therefore opaque, in the sense that their alternating behaviour cannot be predicted from either surface alternant. Likewise, the *e~i* alternation illustrated in (3) is common for a subclass of 3rd conj. verbs in Spanish. In these cases, marked (*-i-*) stems are combined with fully regular person/number agreement endings. However, similarly to the case of diphthongization, the *e~i* alternation is not fully predictable, as can be seen from verbs such as *agredir* ‘to attack’ and *transgredir* ‘to breach’ that do not undergo the *e~i* alternation, and minimal pairs such as *servir* ‘to serve’ versus *hervir* ‘to boil’ of which the former changes to *-i-* (*sirve* ‘serve-3rd sg.’) and the latter does not (*hierve* ‘boil-3rd sg.’).

- (3) a. *pid-en* ‘They ask for’ (infinitive: *ped-ir*)  
 b. *pid-es* ‘You-sg. ask for’

The case of Spanish illustrates two general properties of stems. First, stems such as *cant-a*, *pus-* or *duerm-* preserve the inherent morphosyntactic and semantic properties of the root, and they form the base for the application of inflectional rules. These properties suggest that stems (along with roots) form lexical entries and may be members

of an extended lexical stem set (Anderson, 1992, p. 133). For example, for the verb with the root *pon-* in Spanish, one may define an indexed stem *pus-* which is selected by members of the past series. The second property of stems is that they fall into two broad classes, those involving combinatorial processes and those involving non-concatenative operations. While, combinatorial stems, e.g., [*cant-a*], can be represented by a rule that introduces *-a-* as the theme vowel of any 1st conj. root, the linguistic representation of stem allomorphy is controversial. One suggestion is to derive stem alternants from a single underlying form by (morphologically conditioned) rules (Harris, 1969 and subsequent work); see also Albright, Andrade, and Hayes (2005) for a rule-based analysis of Spanish diphthongization. Challenging for this type of account are the exceptions mentioned above, e.g., verbs that do not undergo diphthongization or the *e~i* alternation. An alternative approach is to represent stem allomorphy in the lexicon, e.g., in terms of default inheritance representations with underspecified entries, or equivalent mechanisms (Corbett & Fraser, 1993; Wunderlich, 1996). Consider, for illustration, the simplified entry for *pedir* ‘to ask for’ in (4):



Each node of a structured lexical entry is defined in terms of a phonological string and a morphological feature set, and a subnode inherits all information from its mother, except for the features it replaces or adds. In (4), the base or default stem form is *ped-*, the stem that occurs in the citation form of this verb, and the subnode [*.i.*]<sub>+SUBJ</sub> inherits the onset *p-*, the coda *-d*, and the categorial feature [+V] from the higher node. The vowel in the subnode replaces the corresponding element of the higher node. Such structured entries may form lexical templates, based on shared subnodes. The structure of (4), for example, is shared by several other 3rd conjugation verbs in Spanish, e.g., *medir* ‘to measure,’ *decir* ‘to say,’ etc. In this way, lexical templates account for the overall similarity of marked stems to their base and for the family resemblance structure among these verbs.

Support for the role of structured lexical entries in morphological processing comes from priming experiments. Consider, for example, the results of a cross-modal priming experiment on German containing marked and unmarked stems as primes and targets (Clahsen, Eisenbeiss, Hadler, & Sonnenstuhl, 2001). An asymmetric priming pattern was found. In prime-target pairs in which the prime contained an unmarked stem and the target a marked one (e.g., *werft* → *warft* ‘throw-3s pres. → ‘throw-3s past’), the participants’ target response times were significantly longer than for reversed prime-target pairs with the prime

containing a marked stem and the target an unmarked one (*warft* → *werft*). Given that a marked past-tense stem such as *warf-* represents a subnode of the unmarked stem (*werf-*), parallel to (4) above, the target in the experimental condition *werft* → *warft* (in which the marked stem was primed by an unmarked stem) contained a feature (= [+PAST]) that was unavailable from the prime, whereas in the reversed condition (unmarked stem primed by marked stem), the target did not contain any features unavailable from the prime. In this way, the priming asymmetries found can be explained in terms of structured lexical entries and the morpho-syntactic feature specifications of the stem forms involved.

For Spanish, the role of stem allomorphy in morphological priming has been examined by Allen and Badecker (1999). In their first experiment, they found an effect of stem homograph inhibition (see also Laudanna, Badecker, & Caramazza, 1989a, 1989b, 1992 for Italian), i.e., responses to targets (e.g., *mor-os* ‘Moors’) were significantly slower when primed by stem homographs (e.g., *mor-ir* ‘to die’ → *mor-os*) compared to unrelated primes (*sill-a* ‘chair’ → *mor-os*) as well as relative to an orthographic overlap prime (*moral* → *mor-os*). The same effect was found in a second experiment in which marked stems of stem homographs served as primes (e.g., *muer-e* ‘die-3s pres’ → *mor-os*). Allen and Badecker assume that allomorphic stems have separate entries at the form (‘lexeme’) level of lexical representation, but not at the level of abstract (‘lemma’) representations; the inhibition effect for marked and unmarked stems is claimed to occur at this latter form-neutral level. Alternatively, however, one may assume that marked stems such as *muer-* are rule-based forms derived by processes such as diphthongization from their corresponding unmarked forms, rather than forming lexical entries. In that case, the stem homograph inhibition effects would be due to the fact that both marked and the unmarked stems access the same underlying form, and lexical entries for marked stem forms would not be required.

The present study further investigates how stem allomorphy in Spanish is represented and processed. We specifically examine whether in language comprehension and production the speaker/hearer relies on rules or on lexical representations for stem allomorphy.

## 2. Experiment 1: Elicited production

The first question we will examine concerns the generalization properties of different stem variants. One method for determining the generalization properties of inflectional patterns or rules are elicited production experiments with nonce words. In such experiments, participants are presented with one or two forms of a nonce word and are then asked to produce a different inflectional form of that nonce word which they have not seen before. Such experiments have been used to study the generalization properties of different inflectional phenomena; for Spanish see Bybee and Pardo (1981) and Eddington (1996).

Some evidence that the *e~i* alternation is not particularly productive in Spanish comes from a nonce-probe task with 36 Spanish-speaking adults reported in Bybee and Pardo (1981). They presented their participants with nonce verbs that were similar to existing Spanish verbs that undergo diphthongization as well as with three nonce verbs (*pertir*, *rentir*, *rebir*) which were meant to be similar to the existing 3rd conj. verbs that require an *-i-* stem in various finite verb forms. The subjects’ task was to complete a sentence using the 3rd sg past tense form. Bybee and Pardo (1981) found that 9 out of 36 such responses (= 25%) had the marked *-i-* stem, indicating the limited productivity of the *e~i* alternation for nonce verbs. However, Bybee and Pardo’s results are not more than suggestive as they only examined a small number of items and did not present any statistical analysis. The aim of the present experiment is to determine the generalization properties of different stem variants more systematically. We adopted the elicited production task from Bybee and Pardo (1981) and extended the set of materials. In the present experiment, we specifically investigated how the base stem (*-e-*) and the marked stem (*-i-*) generalize to nonce words. If the *e~i* alternation is rule-based, it should productively extend to nonce verbs. If, however, it is lexically represented in templates abstracted from entries such as (4), generalizations of marked stems to nonce verbs should be restricted and similarity-based.

### 2.1. Method

We employed a paper-and-pencil task in which participants were asked to complete sentences in a booklet by filling in blanks. The booklet consisted of 48 different short stories containing phonotactically well-formed nonce verbs and nouns. The crucial experimental items were 24 nonce verbs all of which rhymed with existing 3rd conjugation verbs that undergo the *e~i* alternation; see Appendix A for a complete list of items.<sup>1</sup> Twelve nonce verbs were presented as intransitives, 12 as transitives with nonce nouns in direct object position to reduce uncontrolled semantic

<sup>1</sup> We examined the frequency and the phonological neighborhood of the existing 3rd conjugation verbs that were used as a basis for constructing the nonce verbs for our experiment. Of the existing verbs we used to construct our materials, there were only six *e~i* verbs that were similar to existing non-alternating 3rd conjugation verbs; these are shown in (i) together with their word frequencies (per million) taken from the LEXESP data-base (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000):

<i>servir</i> : 268/sirven: 27	<i>hervir</i> : 10/hierven: 0.5
<i>pedir</i> : 301/piden: 15	<i>agredir</i> : 3/agreden: 0.5
<i>investir</i> : 0/investen: 0.2	<i>insistir</i> : 12/insiste: 21
<i>competir</i> : 22/compiten: 3.5	<i>omitir</i> : 7/omiten: 0.2
<i>repetir</i> : 154/repiten: 6.5	<i>emitir</i> : 52/emiten: 3.3
<i>embestir</i> : 3.3/embisten: 0.5	<i>persistir</i> : 10.5/persiste: 1.7

As can be seen, there are only two cases in which the frequencies of the non-alternating verb are higher than the ones for the alternating one (= *insistir*, *persistir*). The nonce verbs, however, that were constructed on the model of *investir* and *insistir* did not yield response patterns that were different from those of the other experimental items.

Table 1  
Percentages and absolute number (shown in brackets) of responses in experiment 1

	-e-	-i-	-ie-	other
Version 1	67.5% (324)	18.58% (94)	6.04% (29)	6.87% (33)
Version 2	18.54% (89)	78.54% (377)	0% (0)	2.91% (14)

associations (see example (5)). 24 other nonce words served as fillers. There were two experimental versions. In version 1, the 24 nonce verbs were only presented with the *-e-* stem (5a), and in version 2 in both stem forms (5b). We tested 40 adult native speakers of Spanish, 20 participants in version 1 (mean age  $25 \pm 3.89$  (*SD*) years; 9 males) and 20 in version 2 (mean age  $22 \pm 3.7$  (*SD*) years; 10 males).

- (5) a. Los campesinos acostumbran *pervir* el *borpo*. Algunos \_\_\_\_\_ el *borpo* con gran agilidad.  
'The peasants are used to *pervir* el *borpo*. Some (of them) \_\_\_\_\_ the *borpo* with great skill'
- b. Los campesinos acostumbran *pervir* el *borpo*. Yo *pirvo* el *borpo* moderadamente bien. Algunos \_\_\_\_\_ el *borpo* con gran agilidad.  
'The peasants are used to *pervir* el *borpo*. I *pirvo* the *borpo* moderately well. Some (of them) \_\_\_\_\_ the *borpo* with great skill'

## 2.2. Results

Table 1 presents percentages and absolute numbers (shown in brackets) of responses for the two experimental versions.

The first two columns show that the participants almost always employed *-e-* or *-i-* stems for the new verb forms. In version 1, 6.04% of the responses had correct inflectional endings together with diphthongized stem vowels (= *-ie-*); in version 2, there were no such responses. Tab.1 shows a clear contrast between the two experimental versions. When nonce words were presented in both stem forms (=version 2), participants produced significantly more *-i-* than *-e-* stems ( $Z = 13.341$ ,  $p < .01$ ), whereas in version 1 in which nonce words were only presented in their unmarked *-e-* stem forms, participants clearly preferred *-e-* forms ( $Z = 11.25$ ,  $p < .01$ ). The latter finding is hard to reconcile with the view that the *e~i* alternation is rule-based, since in version 1 *-i-* stems were hardly ever used, even though the rule's input conditions were met. Instead, generalizations of *-i-* stems appear to be similarity-based, occurring in circumstances (i.e., in version 2) in which a given nonce word could be seen as falling into the lexical template for existing 3rd conjugation verbs.

## 3. Experiment 2: Event-related potentials

Event-related potentials (ERPs) provide an on-line record of the brain's electrophysiological responses to a particular stimulus. Previous ERP studies have led to the identification of different components involved in lexical-

semantic and morpho-syntactic (combinatorial) processing. Lexical-semantic violations, e.g., a semantically inappropriate sentence-final word, elicit an increased amplitude of the N400 component, i.e., a negativity at centro-parietal electrode sites with a maximum at approximately 400 ms after stimulus onset (see Kutas & Schmitt, 2003; for a recent review). On the other hand, combinatorial violations in the domain of morphosyntax, e.g., incorrect subject-verb agreement and overgeneralizations of regular inflectional processes elicit left anterior negativities (LAN), see e.g., Osterhout (1997), Penke et al. (1997), Weyerts, Penke, Dohrn, Clahsen, and Münte (1997), and/or a parietal positivity with a peak latency of about 600 ms (P600); see Brown, Hagoort, and Kutas (1999) for review. While the exact functional properties of these components are still controversial, it is safe to say that combinatorial violations elicit similar brain responses across languages, which differ from those elicited by lexical-semantic violations.

Two previous ERP studies examined on-line processes involved in the comprehension of stems in Romance languages, Rodriguez-Fornells, Clahsen, Leo, Zaake, and Münte (2001) for Catalan and Rodriguez-Fornells, Münte, and Clahsen (2002) for Spanish. Rodriguez-Fornells et al. (2001) adopted the ERP violation paradigm from previous studies on regular and irregular inflection in German (Penke et al., 1997; Weyerts et al., 1997) to investigate the processing of stem forms in Catalan. Rodriguez-Fornells et al. (2001) obtained a LAN followed by a P600 effect for stem violations. LAN/P600 effects were seen for overapplications of the 1st conjugation theme vowel *-a-* to a verb form that requires a 2nd or 3rd conjugation form, e.g., *\*dorm-a-t* instead of the correct *dorm-i-t* 'slept' or *\*tem-a-t* instead of *tem-u-t* 'feared.' This ERP pattern was taken to reflect a combinatorial violation. Given that 1st conjugation stems are combinations of a verbal root and the theme vowel *-a*, the morphological anomalies in incorrect 2nd and 3rd conjugation forms such as *\*dormat* and *\*temat* represent violations of morphological structure-building in that two legal components (a 2nd or 3rd conjugation root and the 1st conj. theme vowel *-a*) appear in illegal combinations. The findings from this study show that LAN/P600 effects are not restricted to syntactic violations, but that they can also be obtained for purely morphological violations, as in the case of Catalan. From a linguistic perspective, the fact that the brain produces similar responses for violations of regular inflection as well as for violations of productive stem formation processes indicates that these involve similar processes, namely combinatorial rules.

ERPs have also been used to study brain activity in the repetition priming task. Recall that in ERP experiments unexpected words have been found to elicit an increased N400 component and that the N400 is supposed to tap processes of lexical access (Kutas & Schmitt, 2003). It has also been found that when written words are repeated within a list, the ERP to their second presentation is associated with an N400 that is reduced in amplitude relative to

non-repeated words. The reduced N400 is conceived of as a repetition priming effect in that lexical access is facilitated relative to unprimed words in the list. Adopting the design of Münte, Say, Schiltz, Clahsen, and Kutas's (1999) study of English past tense forms, Rodríguez-Fornells et al. (2002) examined the processing of different kinds of stem/root forms in Spanish in an ERP priming study. There were two experimental conditions; in the first condition, e.g., *ando* → *andar* 'I walk—to walk,' the prime and the target shared the same root (= *and-*), whereas in the second condition, e.g., *duermo* → *dormir* 'I sleep—to sleep,' the prime contained a marked stem (= *duerm-*). A reduced N400 was found for the target forms in the first condition (*ando* → *andar*), but not in the second one (*duermo* → *dormir*). Control conditions using nonce words demonstrated that the surface form properties (i.e., the different degree of phonetic and orthographic overlap between primes and targets) do not explain the observed priming difference. As mentioned above, a reduced N400 is indicative of a priming effect, i.e., facilitated lexical access to the target form. The finding of a reduced N400 for prime-target pairs such as *ando* → *andar* in Spanish is parallel to what was found for regularly inflected verb forms in English (Münte et al., 1999). In the case of Spanish, effective priming is possible because the prime and the target access the same entry, i.e., the root [*and-*], in the same way in which prime-target pairs such as *used* → *use* in English access the same entry [*use*]. By contrast, the priming effect is not present for marked stems (e.g., *duerm-*), parallel to irregular past-tense forms in English (e.g., *found*), indicating that these forms do not permit any direct access to the root and do therefore fail to produce an effective facilitatory effect on accessing the target.

The present experiment extends this research by investigating the processing of finite forms of 3rd conj. verbs in Spanish.

## 4. Method

### 4.1. Participants

Thirty-three neurologically healthy native speakers of Spanish (mean age  $21 \pm 0.7$  (SD) years; 10 males, all right handed) gave informed consent to participate in the present experiment. All subjects were paid for their participation. Three subjects were rejected due to excessive eye movement artifacts, mostly blinks.

### 4.2. Materials

Twenty-nine Spanish verbs from the third conjugation were selected (see Appendix B); all of them exhibit the *e-i* stem alternation in finite verb forms (e.g., *medir*—*mido*). Eight different sentences of nine words each were created for each verb. Besides, two 'context' sentences were created for each critical sentence which were contextually and semantically related to the critical sentence. The critical

and context sentences were taken from Spanish newspapers and contained political, social or local information. There were four experimental conditions:

- (6) a. No violation: correct *-i-* stem plus correct 3rd pl. suffix: *Los viejos rivales miden sus fuerzas el próximo lunes*. 'The old rivals measure their strengths the coming Monday'
- b. Suffix violation: correct *-i-* stem plus incorrect 2nd sg. suffix: *Los destacados estudiantes mides sus fuerzas el próximo lunes*. 'The outstanding students measure-2nd sg ...'
- c. Stem violation: incorrect *-e-* stem plus correct 3rd pl. suffix: *Los equipos foráneos meden sus fuerzas el próximo lunes*. 'The foreign teams measure-3rd pl. ...'
- d. Double violation: incorrect stem and suffix: *Los polos políticos medes sus fuerzas el próximo lunes*. 'The political parties measure-2nd sg ...'

The critical verb forms always appeared as the fourth word in an experimental sentence that began with a plural subject as in (6). Eight different lists (each consisting of 29 experimental sentences) were created yielding 232 (29 verbs × 8) sentences with corresponding contexts in which each verb form was systematically rotated across sentences and across subjects. For example, context 1 appeared with the no-violation condition in list 1 for one subject and with the suffix violation in list 2 for another subject, etc. Each subject was randomly assigned to two lists that were presented over two ERP sessions set apart by 1.5 weeks, yielding a data set of 58 trials per condition and subject. The context sentences seen in the second session were always different from those seen in session 1. The critical verbs and their corresponding violations were repeated only once across both sessions. As the sentences were different in both sessions, episodic memory effects were minimized and—given the design of the materials for the two sessions—parallel for all the experimental conditions. In each trial, the first two (context) sentences were visually presented on a computer monitor in one block over 10 s. Then, a red asterisk appeared on the screen for two seconds signaling the presentation of the critical sentence, which was shown in a word-by-word fashion (200 ms per word, SOA: 500 ms) in the middle of the screen in white letters (1.5° of visual angle). A 4.5-s pause followed before the next trial. Each ERP session lasted about 30–40 min. After 20 trials, subjects were required to answer three content questions pertaining to the context and the critical sentences read before. The mean percentage of correct responses was 91%.

### 4.3. Electrophysiological recording and data analysis

The ERPs were recorded from 29 standard positions (Fp1/2, Fz, F7/8, F3/4, Fc1/2, Fc5/6, Cz, C3/4, T3/4, Cp1/2, Cp5/6, Pz, P3/4, T5/6, Po1/2, O1/2) using tin electrodes mounted in an electrocap. Biosignals were rereferenced off-line to the mean of the activity at the two

mastoid processes. Vertical eye movements were monitored with an electrode at the infraorbital ridge of the right eye. Electrode impedances were kept below 5 kΩ. The electro-physiological signals were filtered with a bandpass of 0.01–50 Hz (half-amplitude cutoffs) and digitized at a rate of 250 Hz. Trials with base-to-peak electro-oculogram (EOG) amplitude of more than 50 μV, amplifier saturation, or a baseline shift exceeding 200 μV/s were automatically rejected off-line. 7.7% of the trials were rejected due to artifacts. Stimulus-locked ERPs were averaged for epochs of 1024 ms starting 100 ms prior to the onset of the critical verbs. All ERP waveforms displayed in the corresponding figures were digitally filtered using a low-pass filter with a 8 Hz half-power cutoff.

Several three or four-factor repeated measures ANOVAs were conducted for the evaluation of stimulus-locked ERPs (specified in each case in the results section) including as within-subject factors *Condition* (no violation, stem violations, suffix violations, double violations), *Hemisphere* (right, left) and electrode *Position* (anterior, posterior). The ANOVAs were applied at parasagittal (PS) locations with five levels for the factor Position (Fp1/Fp2, F3/F4, C3/C4, P3/P4, O1/O2), at temporal (TE) locations with three levels (F7/F8, T3/T4, T5/T6), and at midline locations (MD) with three levels (Fz, Cz, Pz). All statistical tests comprised mean amplitudes for the different time windows specified in the corresponding contrast. To further examine the resulting interactions, additional ANOVAs were carried out, which were restricted to specific pairwise comparisons applied to specific electrode sites. For all statistical effects involving two or more degrees of freedom in the numerator, the Greenhouse-Geisser correction was

used. The exact *p*-value after the correction will be reported. Tests involving Electrode × Condition interactions were carried out on data using the vector normalization procedure described by McCarthy and Wood (1985).

4.4. Results

The ERPs for the critical verbs in each condition are illustrated in Fig. 1. Fig. 2A presents a comparison of the stem and suffix violation conditions to the no-violation condition; the corresponding difference waveforms for both comparisons are depicted in Fig. 2B. ERP waveforms at selected locations comparing stem versus suffix violations are shown in Fig. 3A and topographical maps of the difference waveforms (suffix minus stem violations) in Fig. 3B. In addition, Fig. 4 depicts difference waveforms (and corresponding scalp distribution) for the double-violation condition relative to the single violation conditions (suffix and stem violations) which were computed by subtracting the average values of both single violation conditions from the values of the double-violation condition.

Fig. 1 shows that each verb elicited an early negative deflection (N100) followed by a parietocentral positive component (P200). After these early components, a negative deflection (maximal at central locations) occurred between 350 and 550 ms, which was reduced for stem violations. In addition, Fig. 3 shows a negative increase for suffix violations compared to stem violations at left frontal electrode locations (LAN) in the 300–500 ms time range. At the range of 600–850 ms, a centro-parietal positivity (P600) was seen in each violation condition relative to the

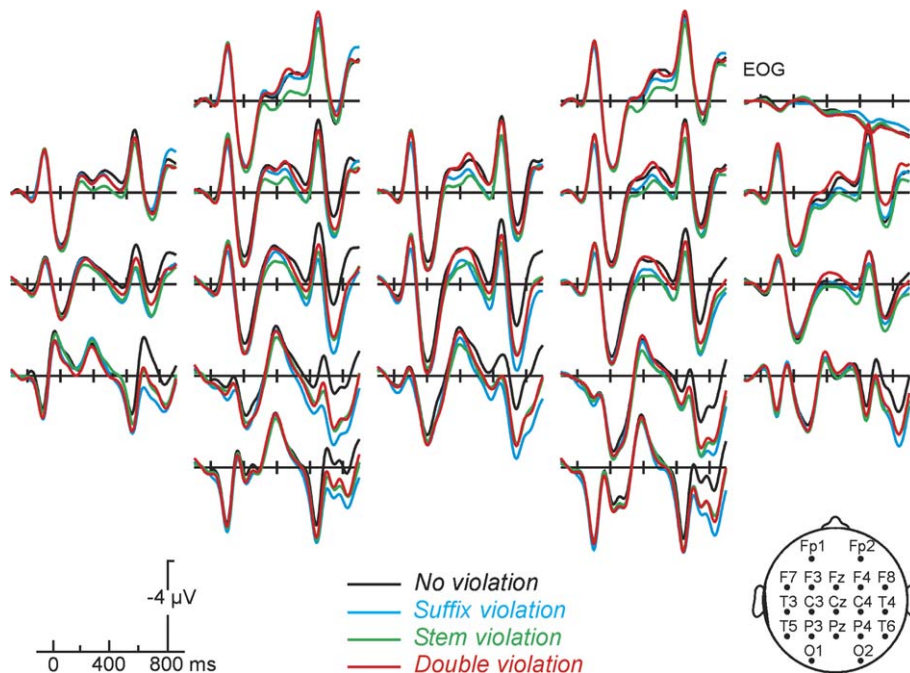


Fig. 1. Grand average (*n* = 33) ERPs to the critical verb in four conditions (see example 6).

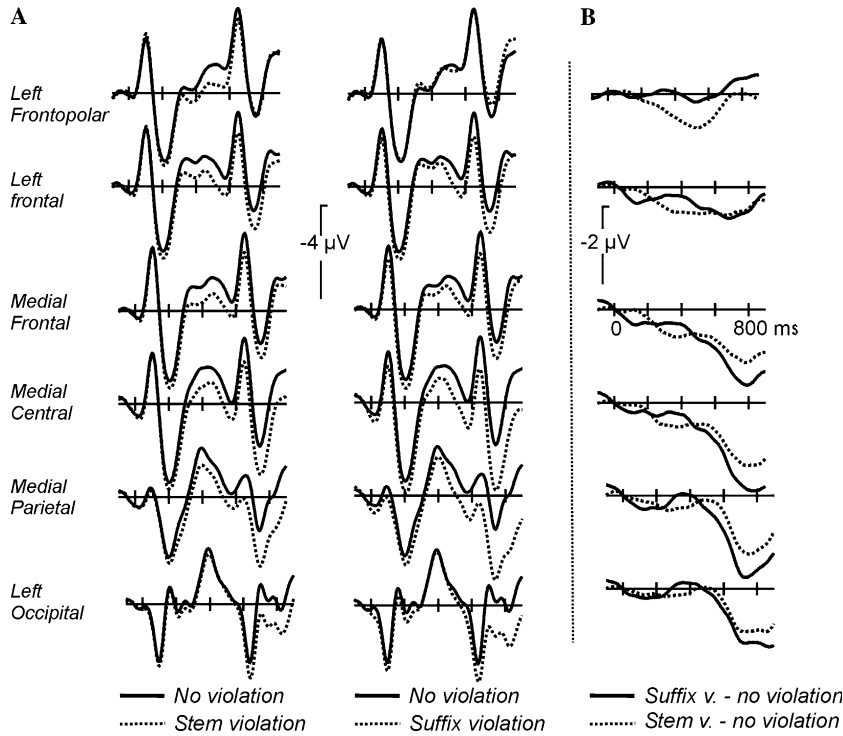


Fig. 2. (A) ERP waveforms comparing the no-violation versus the stem violation condition (left column) and the no-violation versus the suffix violation condition (right column). (B) Difference waveforms showing the suffix violation minus the no-violation condition and the stem violation vs. no-violation condition. The electrode locations depicted are (from anterior to posterior sites): Fp1, F3, Fz, Cz, Pz, and O1.

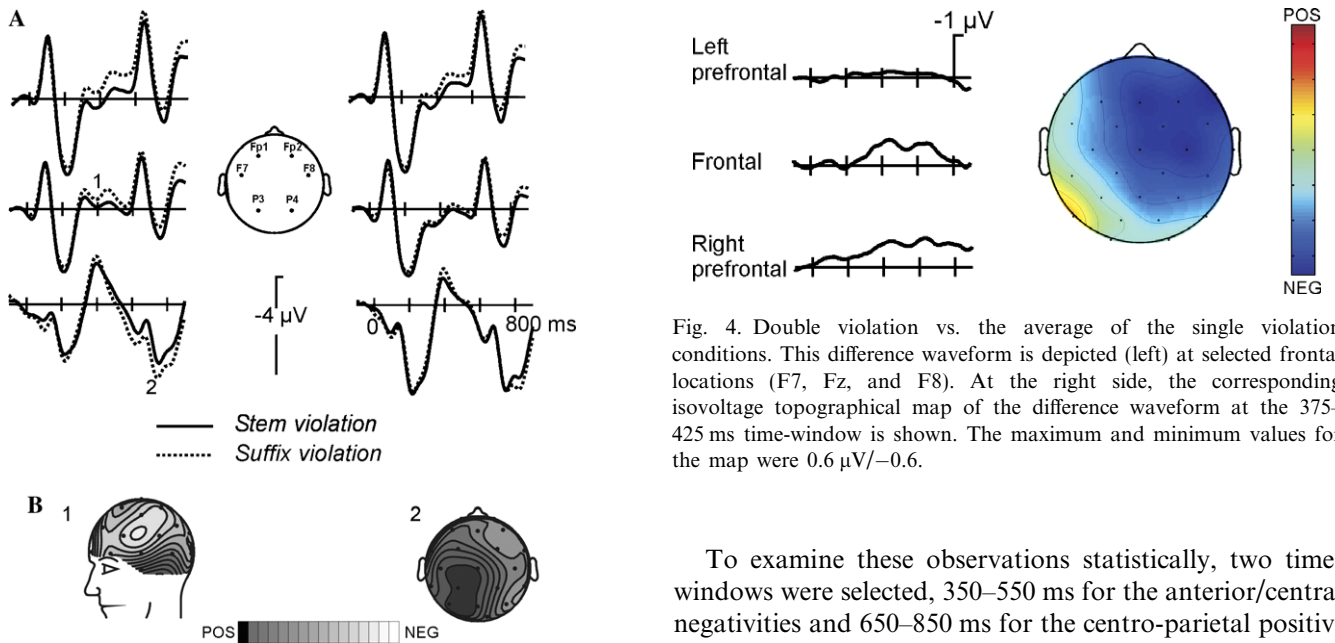


Fig. 3. Stem versus suffix violations. ERP waveforms at selected locations (A) and topographical maps of the difference waveforms (B). For the topographical maps, isovoltage spline interpolation at the time points indicated in 1 (300–350 ms, LAN effect) and 2 (750–800 ms, P600 effect) with relative scaling was used; the maximum and minimum values for each isovoltage map were 0.15  $\mu\text{V}$ /–0.5 for the earlier time-window and 0.79  $\mu\text{V}$ /–0.62 for the later one.

correct verb forms (see Fig. 1). The amplitude of the P600 component was enhanced for suffix violations compared to stem violations (see Fig. 3).

Fig. 4. Double violation vs. the average of the single violation conditions. This difference waveform is depicted (left) at selected frontal locations (F7, Fz, and F8). At the right side, the corresponding isovoltage topographical map of the difference waveform at the 375–425 ms time-window is shown. The maximum and minimum values for the map were 0.6  $\mu\text{V}$ /–0.6.

To examine these observations statistically, two time-windows were selected, 350–550 ms for the anterior/central negativities and 650–850 ms for the centro-parietal positivity. A summary of the statistical results obtained in the overall ANOVAs in which the experimental conditions were treated as one critical within-factor (Condition) are presented in Table 2. In the first time-window, significant main effects of Condition were found at MD, marginally at PS, and a significant Cond  $\times$  Hem interaction at TE. In the later time-window (650–850 ms), main effects of Condition were seen at all locations (MD, PS, TE) as well as interactions between Condition, Hemisphere, and Position. To further explore the effects of Condition and its

Table 2  
Experiment 2—overall ANOVAs

	Condition		Condition × Position		Condition × Hemisphere		Condition × Hemisphere × Position	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
350–550 ms								
Midline	3.5 <sup>a</sup>	0.018			Not applicable		Not applicable	
Parasagittal	2.7 <sup>a</sup>	0.051						
Temporal					3.1 <sup>a</sup>	0.03		
650–850 ms								
Midline	9.8 <sup>a</sup>	0.001	2.4 <sup>c</sup>	0.028	Not applicable		Not applicable	
Parasagittal	9.5 <sup>a</sup>	0.001	5.4 <sup>c</sup>	0.001			2.0 <sup>c</sup>	0.023
Temporal	9.0 <sup>a</sup>	0.001	5.3 <sup>c</sup>	0.001			2.1 <sup>c</sup>	0.047

Notes. Blank cells were not significant ( $p > .05$ ); degrees of freedom:

<sup>a</sup>3,96; <sup>a</sup>2,64; <sup>c</sup>6,192; <sup>d</sup>4,128; <sup>e</sup>12,384.

interactions with the topographical factors, additional pairwise analyses were performed in which the stem violations were compared to the baseline and to the other violation conditions.

#### 4.5. Effects in the early time-window

The comparison of stem violations to the no-violation condition in the early time-window revealed significant differences at MD ( $F(1, 32) = 8.8, p < .0056$ ), PS ( $F(1, 32) = 7.05, p < .012$ ), and TE ( $F(1, 32) = 5.6, p < .0245$ ), due to the reduced amplitude of the negative component for stem violations; at midline, the mean amplitude of the no-violation condition was  $-1.3 \pm 1.6 \mu\text{V}$ , and  $-0.58 \pm 1.4 \mu\text{V}$  for the stem-violation condition. When the no-violation condition was compared to suffix violations, significant differences were encountered only at midline locations ( $F(1, 32) = 6.8, < 0.014$ ), but not at PS ( $F(1, 32) = 2.8, p > 0.09$ ) or TE ( $F < 1$ ).

The direct comparison of stem and suffix violations in the 350–550 ms time range did not reveal any main effects for electrode sites (MD,  $F(1, 32) = 1.31, p > 0.26$ ; PS,  $F(1, 32) = 1.03$ ; TE,  $F < 1$ ), but a significant Condition × Hemisphere × Position interaction at PS ( $F(4, 128) = 2.52, p < .05$ ). This interaction reflects the increased negativity for suffix violations (when compared to stem violations) in left frontal and frontopolar locations. This effect is clearly seen in the waveforms and the corresponding scalp distribution in Fig. 3. Comparing the single (stem and suffix violations) to the double violation condition indicates an increased right anterior negativity for double violations at frontopolar, frontal and central locations with an onset near 400 ms and lasting until 650 ms (see Fig. 4). In the 350–550 ms time-window this effect was confirmed by a main effect of Condition at temporal locations (MD,  $F(1, 32) = 3.7, p > 0.06$ ; PS, ( $F(1, 32) = 4.06, p > .052$ ; TE ( $F(1, 32) = 4.61, p < .05$ )). In addition, a significant Cond × Hem interaction was found ( $F(1, 32) = 4.5, p < .05$ ). This effect reflects the increased negativity for double violations at right hemisphere lateral locations relative to left hemisphere lateral locations.

#### 4.6. Effects in the later time window

In the second time-window (650–850 ms), a clear difference was seen between the stem violations and the no-violation condition at MD ( $F(1, 32) = 9.9, p < .01$ ), PS ( $F(1, 32) = 14.7, p < .001$ ) and TE ( $F(1, 32) = 20, p < .001$ ), which is due to the increased amplitude of the P600 component in stem violations. The comparison of stem violations to suffix violations revealed Cond × Pos interactions at MD ( $F(2, 64) = 4.20, p < .02$ ), PS ( $F(4, 128) = 3.76, p < .028$ ) and TE ( $F(2, 64) = 3.6, p < .05$ ); these interactions reflect the enhanced positivity of the P600 component for the suffix condition at left central parieto-occipital locations (relative to stem violations). Comparing the stem violations to the double violation condition indicates an enhanced negativity for double violations at temporal locations, which was confirmed by a main effect of Condition at TE ( $F(1, 32) = 6.7, p < .0146$ ); there were no other main effects or interactions for this comparison.

#### 4.7. Discussion

The present study reported results from two experiments investigating how Spanish verbs with marked stems might be represented and processed. The first experiment showed that the marked *-i-* stem has restricted productivity and is only extended to nonce words if a given item can be assigned to the lexical template for existing 3rd conjugation verbs. Otherwise, participants fall back on the unmarked *-e* stem. The most interesting result of Experiment 2 is that *stem violations* produced an ERP component that was not seen for the other violation conditions, namely a reduced negativity in the 350–550 ms range relative to the baseline condition. In terms of its latency and amplitude, this waveform is reminiscent of a modulated N400, even though its topography is fronto-central, rather than centro-parietal (as is the case for the standard N400). It is unlikely that our participants processed the stem violations as if they were nonce words, because in that case we should have seen an increased (rather than a reduced negativity) for the stem violation condition (see, e.g., Federmeier,



Segal, Lombrozo, & Kutas, 2000). While no consensus has been reached as to the functional significance of the N400, its amplitude is generally found to be sensitive to lexical/semantic factors, and it has been argued that a reduced N400 amplitude signals relative ease of lexical access (see, e.g., van Petten, Kutas, & Mitchiner, 1991). With respect to morphological processing, two ERP priming studies, one on the English past tense (Münte et al., 1999) and one on Spanish verb forms (Rodríguez-Fornells et al., 2002), obtained reduced N400 effects in cases in which verb forms (*walk*, *andar*) were primed by regularly inflected forms (*walked* → *walk*, *ando* → *andar* ‘I walk → to walk’) compared to unprimed control conditions (*measured* → *walk*, *canto* → *andar*). This was interpreted as a (stem/root) repetition priming effect: The regular forms presented as primes are morphologically decomposed making the unmarked stem/root (e.g., *walk*, *and-*) available for priming, and this facilitates recognition of the same stems/roots in the target. Thus, the modulated N400 signals facilitated lexical access.

Following from these studies, we interpret the reduced negativity seen in the present experiment for pure stem violations as reflecting relative ease of lexical access. Recall that the baseline condition differs from the stem violation condition in that the former contains a marked stem and the latter the corresponding unmarked one (see (6a) vs. (6c)). Hence, the modulated negativity seen for stem violations reflects the fact that lexical access to an unmarked stem is easier than to a marked one, an interpretation that is consistent with the view that stem variants are represented in structured lexical entries, such as (4) above, with the *-e-* stem as the base and the *-i-* stem as a dependent form.

Further evidence for the idea that stems constitute lexical (sub)entries comes from the results of a series of lexical decision experiments examining frequency effects for marked stem forms of German (Clahsen et al., 2001). One experiment examined past-tense forms with marked stems and regular person and number affixes (e.g., *sangen* ‘sing-1st/3rd pl.-past’) that were similar in structure to the ones tested in the present experiments for Spanish. It was found that reaction times for verb forms with high stem frequencies were significantly shorter than for those with low stem frequencies, even though the critical items had the same mean word form and mean verb frequencies. These results suggest that marked stems are lexically represented and that stems are represented separately from the inflectional affixes with which they may occur (rather than being stored as wholes), hence the *stem*-frequency effects seen in the lexical decision task.

With respect to *suffix violations*, the results of Experiment 2 show that when incorrect person and number agreement suffixes are compared to the stem violation condition, the former yield a more negative-going waveform at left anterior sites in the early time-window and an enhanced positivity in the later time-window. These ERP responses are reminiscent of LAN/P600 effects seen in several previous violation studies and have been argued to be characteristic of combinatorial violations and to reflect rule-based

morpho-syntactic processing (see, e.g., Rodríguez-Fornells et al., 2001). An enhanced positivity was also seen for pure stem violations relative to the baseline condition. This finding suggests that the kinds of finite verb forms we tested, e.g., *\*med + en*, have decomposed stem + affix representations. Given decomposition, cases such as *\*med + en* in (6c) constitute (word-internal) combinatorial violations, i.e. incorrect pairings of the 3rd pl. ending with the unmarked stem, and elicit an enhanced P600, just like violations of syntactic agreement. Surprisingly, a LAN component was not observed when suffix violations were compared to the baseline or no-violation condition (see Fig. 1). The absence of a LAN in this contrast was unexpected given previous studies reporting LAN effects for subject–verb agreement violations (Coulson, King, & Kutas, 1998; Hagoort & Brown, 2000; Osterhout & Mobley, 1995, Exp. 1). However, there are also a number of reports in which LAN effects have not been found for agreement violations (Hagoort, Brown, & Groothusen, 1993; Kemmer, Coulson, De Ochoa, & Kutas, 2004; Osterhout, McKinnon, Bersick, & Corey, 1996; Osterhout & Mobley, 1995, Exp. 3). It has been argued that the absence of a LAN may be due to a superimposition of components with opposite polarity. Münte, Matzke, and Johannes (1997), for example, found a LAN in a grammaticality judgment task containing subject–verb agreement violations with nonce words, but not in a similar task with existing words. They attributed the lack of an LAN to the overlap of this component with a fast appearing P600 component associated with these violations. It is possible that the absence of a LAN for suffix violations (relative to the no-violation condition) in our study is also due to this reason.

With respect to the ERP responses to *double violations*, we found that they were not simply linear summations of the ERP responses to the single (suffix and stem) violation conditions. Instead, the difference waveforms shown in Fig. 4 indicate a right anterior negativity in the range of 300–500 ms for double violations. Previous ERP studies comparing double and single-violation conditions for syntactic and semantic violations also found that the ERP patterns for double violations did not represent direct superimpositions of the patterns seen for the two single (semantic and syntactic) violation conditions; see Gunter, Stowe, and Mulder (1997), Osterhout and Nicol (1999, Exp. 2). Note, in particular, that Osterhout and Nicol (1999) obtained the same right anterior negativity for double (semantic + syntactic) violations relative to the single violation conditions that we found for double (suffix + stem) violations. While Osterhout and Nicol (1999) do not offer an explanation for this effect, the similarity of their results on double violations to those of our study suggests that the right anterior component seen in both experiments might be related to the amount of effort required for processing double violations (relative to single violations), irrespective of whether these are semantic, syntactic, or morphological violations. It should be noted,

however, that further studies are needed to determine the exact neural source eliciting the pattern seen for double violations.

## 5. Conclusion

The results reported here indicate that stem allomorphy in Spanish verbs such as *pedir*—*vido* is lexically represented, rather than based on morphological rules. We found that the marked *-i-* stem is only extended to nonce verbs if a given item is perceived as falling into the relevant lexical template for existing verbs, which is indicative of a similarity-based generalization. The second experiment revealed an ERP signature for pure stem violations that was interpreted as an index of lexical processing and that was not seen for violations of rule-based morpho-syntactic processes.

More generally, our findings suggest that distinguishing between different morphological types can be useful for better understanding how the speaker/hearer processes inflected word forms. The results specifically demonstrate the significance of *stems* in morphological processing and suggest that in the Spanish mental lexicon, the kind of stem allomorphy we tested is lexically represented with marked stems forming subnodes of structured lexical entries.

## Acknowledgments

This work was supported by a grant of the Gran Mariscal de Ayacucho Foundation, Venezuela to Rafael Enrique Linares. We thank Anna Mestres and Laia Sartorius for running parts of the ERP experiment and David Eddington, Iggy Roca, two anonymous Brain and Language reviewers, and the audience at the 4th International Conference on the Mental Lexicon, Windsor (Canada) for helpful comments on an earlier version of the manuscript.

## Appendix A. Nonce verbs used in Experiment 1

ronteguir, pomegir, pentedir, entedir, intestir, invedir, tarnecir, fenteguir, trepecir, corteír, porcetir, sostebir, forpreñir, reletir, enegir, erpestir, peñir, femir, redir, fegir, len-dir, pervir, restir, pleír.

## Appendix B. Existing 3rd conj. verbs used in Experiment 2

bendecir (to bless), competir (to compete), concebir (to conceive), conseguir (to get/find), constreñir (to constrain), corregir (to correct), derretir (to melt), despedir → (to dismiss), elegir (to choose), embestir (to intentionally crash), expedir (to issue), freír (to fry), investir (to confer), impedir (to impede), maldecir (to damn), perseguir (to follow/pursue), predecir (to predict), repetir (to repeat), sonreír (to smile), gemir (to groan), medir (to measure), pedir (to request), regir (to govern), rendir (to surrender/give), reñir (to dispute), servir (to serve), teñir (to dye), vestir (to dress), ceñir → (to fit tightly).

## References

- Albright, A., Andrade, A., & Hayes, B. (2005). Segmental environments of Spanish diphthongization. UCLA, Unpublished ms.
- Allen, M., & Badecker, W. (1999). Stem homograph inhibition and stem allomorphy: Representing and processing inflected forms in a multilevel lexical system. *Journal of Memory and Language*, *41*, 105–123.
- Anderson, S. R. (1992). *A-morphous morphology*. Cambridge: CUP.
- Aronoff, M. (1994). *Morphology by itself*. Cambridge, MA: MIT Press.
- Brown, C. M., Hagoort, P., & Kutas, M. (1999). Postlexical integration processes in language comprehension: Evidence from brain-imaging research. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences*. Cambridge: MIT Press.
- Butterworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production* (Vol. 2). London: Academic Press.
- Bybee, J. L., & Pardo, E. (1981). On lexical and morphological conditioning of alternations: A nonce-probe experiment with Spanish verbs. *Linguistics*, *9*, 937–968.
- Clahsen, H., Eisenbeiss, S., Hadler, M., & Sonnenstuhl, I. (2001). The mental representation of inflected words: An experimental study of adjectives and verbs in German. *Language*, *77*, 510–543.
- Corbett, G., & Fraser, N. (1993). Network morphology: A DATR account of Russian nominal inflection. *Journal of Linguistics*, *29*, 113–142.
- Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes*, *13*, 21–58.
- Eddington, D. (1996). Diphthongization in Spanish derivational morphology: An empirical investigation. *Hispanic Linguistics*, *8*, 1–13.
- Federmeier, K. D., Segal, J. B., Lombrozo, T., & Kutas, M. (2000). Brain responses to nouns, verbs and class-ambiguous words in context. *Brain*, *12*, 2552–2566.
- Gunter, T. C., Stowe, L. A., & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology*, *34*, 660–676.
- Hagoort, P., Brown, C., & Groothusen, J. (1993). The Syntactic Positive Shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes*, *8*, 439–483.
- Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared to reading: The P600/SPS to syntactic violations in spoken sentences and rapid serial visual presentation. *Neuropsychologia*, *38*, 1531–1549.
- Harris, J. W. (1969). *Spanish phonology*. Cambridge, MA: MIT Press.
- Kemmer, L., Coulson, S., De Ochoa, E., & Kutas, M. (2004). Syntactic processing with aging: An event-related potential study. *Psychophysiology*, *41*, 372–384.
- Kutas, M., & Schmitt, B. M. (2003). Language in microvolts. In M. T. Banich & M. Mack (Eds.), *Mind, brain, and language*. Mahwah, NJ: Erlbaum.
- Laudanna, A., Badecker, W., & Caramazza, A. (1989a). Priming homographic stems. *Journal of Memory & Language*, *28*, 531–546.
- Laudanna, A., Badecker, W., & Caramazza, A. (1989b). Processing inflectional and derivational morphology. *Journal of Memory & Language*, *31*, 333–348.
- Manelis, L., & Tharp, D. A. (1977). The processing of affixed words. *Memory & Cognition*, *5*, 690–695.
- McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, *62*, 203–208.
- Münte, T. F., Matzke, M., & Johannes, S. (1997). Brain activity associated with syntactic incongruencies in words and pseudo-words. *Journal of Cognitive Neuroscience*, *9*, 318–329.
- Münte, T. F., Say, T., Schiltz, K., Clahsen, H., & Kutas, M. (1999). Decomposition of morphologically complex words in English: Evidence

- from event-related brain potentials. *Cognitive Brain Research*, 7, 241–253.
- Osterhout, L., & Mobley, L. A. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language*, 34, 739–773.
- Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the language specificity of the brain response to syntactic anomalies: Is the syntactic positive shift a member of the P300 family? *Journal of Cognitive Neuroscience*, 8, 507–526.
- Osterhout, L. (1997). On the brain response to syntactic anomalies: manipulations of word position and word class reveal individual differences. *Brain and Language*, 59, 494–522.
- Osterhout, L., & Nicol, J. (1999). On the distinctiveness, independence, and time course of the brain responses to syntactic and semantic anomalies. *Language and Cognitive Processes*, 14, 283–317.
- Penke, M., Weyerts, H., Gross, M., Zander, E., Münte, T., & Clahsen, H. (1997). How the brain processes complex words: An event-related potential study of German verb inflections. *Cognitive Brain Research*, 6, 37–52.
- Pinker, S. (1999). *Words and rules*. New York, NY: Basic Books.
- Rodriguez-Fornells, A., Clahsen, H., Lleo, C., Zaake, W., & Münte, T. F. (2001). Event-related brain responses to morphological violations in Catalan. *Cognitive Brain Research*, 11, 47–58.
- Rodriguez-Fornells, A., Münte, T., & Clahsen, H. (2002). Morphological priming in Spanish verb forms: An ERP repetition priming study. *Journal of Cognitive Neuroscience*, 14, 443–454.
- Rumelhart, D. E. & McClelland, J. L. (1986). On learning the past tenses of English verbs. In J. L. McClelland, D. E. Rumelhart & the PDP Research Group (Eds.), *Parallel distributed processing*. Vol. 2. Cambridge, MA: MIT Press.
- Sebastián-Gallés, N., Martí, M. A., Carreiras, M., Cuetos, F., (2000). LEXESP: Léxico informatizado del Español. Barcelona: Edicions Universitat de Barcelona.
- Taft, M. (1988). A morphological decomposition model of lexical representation. *Linguistics*, 26, 657–667.
- Taft, M., Hambly, G., & Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *The Quarterly Journal of Experimental Psychology*, 38, 357–366.
- van Petten, C., Kutas, M., & Mitchiner, M. (1991). Fractionating the word-repetition effect with event-related potentials. *Journal of Cognitive Neuroscience*, 3, 131–150.
- Weyerts, H., Penke, M., Dohrn, U., Clahsen, H., & Münte, T. (1997). Brain potentials indicate differences between regular and irregular German plurals. *Neuroreport*, 8, 957–962.
- Wunderlich, D. (1996). Minimalist Morphology: The role of paradigms. *Yearbook of Morphology*, 1995, 93–114.