

Brain potentials for derivational morphology: An ERP study of deadjectival nominalizations in Spanish

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ABSTRACT

This study investigates brain potentials to derived word forms in Spanish. Two experiments were performed on derived nominals that differ in terms of their productivity and semantic properties but are otherwise similar, an acceptability judgment task and a reading experiment using event-related brain potentials (ERPs) in which correctly and incorrectly formed derived words were presented in sentence contexts. The first experiment indicated productivity differences between the different nominalization processes in Spanish. The second experiment yielded a pattern of ERP responses that differed from both the familiar lexical-semantic and grammatical ERP effects. Violations of derivational morphology elicited an increased N400 component plus a late positivity (P600), unlike gender-agreement violations, which produced the biphasic LAN/P600 ERP pattern known from previous studies of morpho-syntactic violations. We conclude that the recognition of derived word forms engages both word-level (lexical-semantic) and decompositional (morpheme-based) processes.

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1. Introduction

The psycholinguistic study of morphologically complex words has received interest from a wide audience within the cognitive sciences in recent years, owing particularly to the so-called ‘past-tense’ debate (McClelland & Patterson, 2002; Pinker & Ullman, 2002). The linguistic phenomenon this controversy has focused on is the sharp contrast in English between regular *-ed* forms (e.g. *walked*, *looked*) and corresponding irregular ones (e.g. *ran*, *saw*). Whilst irregular past-tense forms represent a restricted set of morphologically unstructured lexical items, regular ones are potentially unrestricted, highly productive, and internally structured, consisting of the basic lexical root and a segmentable affix ([walk]+ed). This phenomenon seems to be an ideal test case to investigate fundamental issues, such as the role of combinatorial computation of abstract (rule-like) operations as opposed to associative processing of forms stored in memory. Although this debate has stimulated a lot of empirical research, it has also led to some unfortunate simplifications, misconceptions, and partly inconclusive findings.

One problem is that the sharp contrast between rule-based regular and memory-based irregular inflection familiar from the English past tense does not straightforwardly generalize to other

languages and other morphological systems. The English past tense is a highly unusual inflectional system cross-linguistically, in that it comprises an almost perfect complementary distribution of affixation and stem allomorphy: regular forms contain unchanged stems plus a segmentable affix whereas irregular ones are unaffixed with common stem changes. These (idiosyncratic) properties raise doubts as to the general significance of empirical findings on the English past tense for morphological processing. Furthermore, findings from inflectional morphology do not necessarily generalize to other morphological systems. Derivational processes, for example, are sensitive to selectional constraints, which are specific to individual languages. In English, for example, *-ity* nominalizations are restricted to adjectives of Latin or Greek origin. It is likely that language-particular properties of this kind influence morphological processing, but due to a shortage of cross-linguistic psycholinguistic research the details of how individual languages shape morphological processing are largely unknown.

Another point of concern is that much experimental work on morphological processing relies on broad categories or conditions such as ‘regular vs. irregular’, ‘transparent vs. opaque’, or ‘inflected vs. derived’, that a range of different morphologically complex words are assigned. Although special care is usually taken to match the materials for frequency, length, orthographic neighborhood and the like, materials used in experimental studies may be surprisingly diverse in linguistic terms, yielding uncontrolled possibly confounding factors. Consider, as an example, a recent priming

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study on derived word forms in English (Kielar & Joanisse, 2011). For their ‘fully transparent’ condition, they included items representing 10 different derivational processes as target words (*-ness, -er, -ly, -able, -ment, -ful, -ity, -ation, -ion, -y*), and as prime words both simplex (*farm, nice*) and morphologically complex words, the latter including both prefixed and suffixed word forms (*discover, lonely*). Furthermore, in contrast to the label for this condition, some of the derived words have additional meanings (*debatable–debate*) which are not transparently related to their base forms. Finally, some of the prime-target pairs included derived prime words which involved simple affixation (*bitter → bitter + ness*) and others additional stem changes (*intense → intensity*). Collapsing diverse linguistic processes into broad categories in this way is perhaps not the optimal way of designing experimental conditions, particularly for derivational morphology. A more promising approach would be to directly compare closely related derivational processes that minimally differ in a small number of parameters.

The aim of the present study is to contribute to a better understanding of the lexical representation and processing of derived word forms. We specifically ask to what extent derived words show experimental effects that are characteristic of lexical entries and/or of combinatorial word forms. The linguistic phenomenon under study is deadjectival nominalizations in a Romance language, Spanish, comparing two linguistically closely matched derivational processes.

1.1. Psycholinguistic studies of derivational morphology

Although much research on morphological processing has focused on inflection, there are also many experimental studies investigating derivational morphology using lexical decision times or other behavioral measures. As noted by Marslen-Wilson (2007), however, the outcomes of these studies have not always been clear and systematic.

One major aim of the psycholinguistic study of derivational morphology is to determine to what extent derived words show experimental effects that are characteristic of lexical entries and/or of combinatorial word forms. Experimental evidence showing that the lexical representations of some (but not all) derived word forms maintain their morphological structure comes, for example, from priming experiments in different Indo-European languages. In English, pairs like *darkness → dark* or *unhappy → happy* yielded significant stem-priming effects in cross-modal priming tasks, signaling morphological (stem + affix) decomposition processes during processing (Marslen-Wilson, Tyler, Waksler, & Older, 1994; among others). Similar findings have been reported for French (Longtin, Segui, & Hallé, 2003) and Polish (Reid & Marslen-Wilson, 2003).

Another line of experimental research demonstrates language-particular differences in the processing of derived words. Whilst in Indo-European languages only transparent but not opaque derived word forms yielded robust stem priming in cross-modal and other overt priming experiments, experimental studies of Arabic and Hebrew showed priming effects for both types of derived words (Boudelaa & Marslen-Wilson, 2005; Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000). In Arabic, for example, opaque derived words such as *katiibatun* ‘squadron’ were found to prime root-related word forms such as *kaataba* ‘correspond’ in the same way as transparently related derived words such as *maktabatun* ‘library’. Thus in Semitic languages, the lexical representations of both opaque and semantically transparent derived words appear to maintain their morphological structure. In contrast to that, several experimental studies of derived word forms in Finnish suggested a strong influence of whole-word properties on processing, despite their largely agglutinating structure. Results from unprimed lexical decision experiments, for example, showed weak

base frequency effects and strong word-form frequency effects for different kinds of derived words in Finnish (Vannest, Bertram, Järvikivi, & Niemi, 2002). Likewise, results from eye-movement experiments (Hyönä, Laine, & Niemi, 1995) and patient studies (Laine, Niemi, Koivuselkä-Sallinen, & Hyönä, 1995) did not reveal any differences between productively derived word forms and monomorphemic control words. These results could mean that unlike in Indo-European languages, derived words in Finnish are stored and accessed as full forms irrespective of their morphological structure or productivity.

Despite the wealth of psycholinguistic studies on derivational morphology, the processing and mental representation of derived word forms is still not well understood and questions remain as to the role of morphological decomposition and lexical storage.

1.2. Event-related brain potential studies of derivational morphology

In addition to behavioral methods, psycholinguistic research on derivational morphology has begun to make use of physiological measures, such as eye movements and event-related brain potentials (ERPs). ERPs represent small changes in the brain’s electrophysiological responses to particular stimuli or events that are recorded from a participant’s scalp. Due to their excellent temporal resolution, ERPs have been used successfully to investigate real-time language processing (see e.g. Kutas & Federmeier, 2007; Otten & Rugg, 2005). This research has led to the identification of different components involved in lexical-semantic and morpho-syntactic (combinatorial) processing, which makes ERPs particularly suited to investigate the controversial issues surrounding the processing of derived word forms.

The present study relies on three ERPs components, N400, P600 and the left anterior negativity (LAN), that in previous research have been reported to be related to language processing across a wide range of languages. The N400 component, a negative going waveform that peaks at around 400 ms after stimulus onset has been related to lexical processing and semantic integration processes (Kutas & Hillyard, 1984; see for a review Friederici and Weissenborn (2007), Kutas and Federmeier (2011)). This component is sensitive to factors such as word frequency, cloze probability and semantic relatedness amongst words but is typically not sensitive to grammatical (in)correctness, for example incorrect subject-verb agreement, and other morpho-syntactic violations. The P600 component is a late centro-parietal positivity, starting at about 500 ms and typically extending up to at least 800–900 ms, which has often been related to syntactic processing and shows an increased amplitude in response to different kinds of syntactic violations, e.g. subject-verb agreement violations, verb-inflection errors, case inflection violations, etc.; see for a review, van Herten, Kolk, and Chwilla (2005). Although an enhanced P600 component is typically found for syntactic violations, several studies have reported P600 modulations during the processing of semantically anomalous sentences as well (Friederici & Weissenborn, 2007; van Herten, Kolk, & Chwilla 2005; Bornkessel-Schlesewsky & Schlesewsky, 2008; Frenzel et al. 2010). For example, grammatically correct sentences with a semantically implausible distribution of thematic roles such as *The fox that hunted the poachers* elicited a P600 but no N400 effect, which suggests that sentence-level semantic (im)plausibility affects the amplitude of the P600 component; see Kuperberg (2007) for further discussion. Finally, the LAN component is an early anterior negativity with a left frontal maximum that has been elicited as a response to morphological and morpho-syntactic violations (Osterhout, 1997; Penke et al. 1997; reviewed in Friederici & Weissenborn, 2007; Rodriguez-Fornells, Clahsen, Lleo, Zaake, & Münte, 2001; Weyerts, Penke, Dohrn, Clahsen, & Münte, 1997).

Previous ERP studies of derivational morphology have used two experimental designs, the priming and the violation paradigm. The priming design has been applied to derived word forms of English in a number of studies (Kielar & Joanisse, 2011; Lavric, Clapp, & Rastle, 2007; Morris, Frank, Grainger, & Holcomb, 2007; Morris, Grainger, & Holcomb, 2008). The results from these studies are broadly consistent in that they all found a reduction of the N400 component on target words preceded by morphologically related primes, e.g. *hunter–hunt*, relative to unrelated control primes. Additional conditions, however, produced mixed results leading to conflicting interpretations. Lavric et al. (2007) interpreted the attenuated N400 as an indication of morphological decomposition of the prime word, e.g. [hunt]+-er, by which the stem is isolated. Consequently, a target word such as *hunt* is easy to process, by virtue of its overlap with the memory trace formed by the corresponding prime, hence leading to a reduced N400. Kielar and Joanisse (2011), on the other hand, argued that the N400 modulation is not determined by morphological relatedness, but instead depends on the amount of semantic and phonological overlap between primes and targets. Note, however, that – as pointed out above – the materials used by Kielar and Joanisse (2011) were not ideally matched in terms of their linguistic properties, which could be the reason for why they did not find a clear *morphological priming effect*.

The ERP violation paradigm has also been used to examine derived word forms in different languages. Two studies examined prefixed word forms. For English, McKinnon, Allen, and Osterhout (2003) obtained an increased N400 for pseudowords (e.g. **flermuf*) relative to existing monomorphemic words, but not for pseudowords such as **inceive* relative to existing prefixed words (e.g. *receive*). The lack of a pseudoword effect for forms such as **inceive* is taken as an indication of morphological decomposition, by which two existing component parts are identified. Yet, the question of why a morphological violation, such as the incorrect combination of **in + ceive* does not elicit any kind of ERP effect remains unclear. Another ERP violation study of prefixed word forms comes from Palmović and Maričić (2008). They observed a LAN followed by a P600 for illegal prefix-verb combinations in Croatian, comparable to English non-words such as **underhold* or **overstand* (as opposed to *withhold/understand*). These results differ from those of McKinnon et al. (2003), possibly reflecting processing differences between individual languages. Palmović and Maričić (2008) interpreted the biphasic LAN/P600 ERP pattern they obtained as reflecting morphological parsing processes for prefix violations in Croatian.

Derivational processes involving suffixes have been examined for Finnish and German using the ERP violation paradigm. Leinonen, Brattico, Järvenpää, and Krause (2008) tested illegal combinations of denominal suffixes with verbal roots in Finnish (e.g. **juokselli-linen* – ‘run-owning’ instead of *talo + llinen* ‘house-owning’) in a sentence-judgement task, for which they obtained an increased N400 followed by a P600. This partially replicates earlier findings from Janssen, Wiese, and Schlesewsky (2006) who examined comparable materials for German in a lexical decision task. They obtained an enhanced N400 (albeit no P600) for illegal combinations of the deverbal suffix *-ung* with adjectival roots (**Mildung* ‘mild-ing’). Finally, Bölte, Jansma, Zilverstand, and Zwitserlood (2009), also testing derivational word forms of German, reported a small LAN-type negativity without a P600 for illegal adjective formations (e.g. **freund-haft* instead of *freund-lich* ‘friendly’) presented in sentential contexts, which they interpreted as reflecting structural problems due to morphological parsing (p. 336).

In summary, the picture that emerges from previous ERP research on derivational morphology is far from consistent. Different ERP patterns were found across experiments, both for priming and

violation studies. This may be due to the particular linguistic materials used, or to the specific tasks assigned to participants, or to differences between individual languages.

1.3. The present study

In order to contribute to the experimental study of derivational morphology across typologically different languages, we investigated derivational processes in Spanish, a member of the family of Romance languages, which have rich derivational morphology. We specifically examined deadjectival nominalizations comparing formations with *-ez(a)* and *-ura*, two derivational processes that are closely matched with respect to their form properties, but differ in terms of their productivity and semantic properties. Whilst both *-ez(a)* and *-ura* produce abstract nouns with segmentable stems and affixes and without any kind of stem or affix allomorphy, suffixation with *-ez(a)* is more productive according to Lacuesta and Gisbert (1999, p. 4563) and can apply to a wide variety of adjectives including neologisms and borrowings from other languages; see also Rainer (1993, pp. 504–506). By contrast, *-ura* formations are unproductive, ‘regressive’ according to Lüdtke (1978, p. 380), particularly in Castilian Spanish; see also Lacuesta and Gisbert (1999, p. 4591). Furthermore, *-ez(a)* formations typically have compositional meanings denoting the degree of X-ness or the state of being X of a given adjective X, for example, *robustez* denoting the state of being robust. Formations with *-ura*, on the other hand, tend to have additional sometimes unpredictable meanings expressing concrete, visible, palatable or tactile sensations, shapes, or dimensions (Dworkin 1989, p. 338), for example, *verdura* (compare *verde* ‘green’) means ‘vegetables’, and not simply the state of being ‘green’.

The present study investigates the role of whole-word knowledge and of their morphological constituents for the recognition of derived word forms in Spanish. Two experiments were performed. Experiment 1 was an offline acceptability judgment task to compare productivity differences between different deadjectival nominalization processes in Spanish, and more specifically, to test the (above-mentioned) intuitions from the linguistic literature regarding productivity with a group of native speakers of Spanish. Experiment 2, the main experiment, employed the ERP violation paradigm to determine whether (incorrect) forms with *-ez(a)* and *-ura* produce ERP patterns typical of lexical/semantic violations and/or of combinatorial/grammatical violations. To properly assess potential violation effects in the critical (derivational) conditions, a morpho-syntactic control condition was added to the main ERP experiment. This control condition tested gender-agreement violations in Spanish, which from previous research are known to elicit LAN/P600 effects and are thought to be indicative of combinatorial, morpho-syntactic processing (Barber & Carreiras, 2005; Hagoort, Groothusen, & Brown, 1993; Wicha, Moreno, & Kutas, 2004).

Due to the hybrid linguistic properties of derivational word forms, we expect that violations of derivational processes elicit ERP patterns different from those of grammatical violations. Assuming that existing derived word forms constitute entries with particular meanings stored in the mental lexicon, incorrect derived word forms (unlike pure morpho-syntactic violations) should produce ERP signatures characteristic of lexical-semantic violations, i.e. N400-like responses. Furthermore, in terms of their morphological properties, the derivational processes under study yield combinatorial word forms, and thus incorrect formations may also produce LAN and/or P600 effects. Finally, corresponding to their different linguistic properties, we also expect to find differences in the ERP patterns of *-ez(a)* and *-ura* formations, with the former showing more prominent combinatorial and the latter more prominent lexical-semantic violation effects.

2. Method

2.1. Participants

Experiment 1, the acceptability judgment task, tested 104 healthy participants of whom 32 were monolingual in Spanish, 70 bilingual in Spanish and Catalan, and 2 bilingual in Spanish and Basque (61 women, age range 18–59 years, mean 22.4). Experiment 2, the ERP study, had 26 healthy right-handed participants of whom 6 were monolingual in Spanish and 20 bilingual in Spanish and Catalan (13 women and 13 men, age range 18–35 years, mean 24.4). In case of the bilingual participants at least one of the two parents had Spanish as his/her L1 and used Spanish from birth. The data of four of the participants of experiment 2 had to be excluded due to excessive eye-movements, which led to the rejection of more than 30% of the trials for these four participants. All participants gave their informed consent and were paid for their participation.

2.2. Materials and design

2.2.1. Experiment 1: acceptability judgment task

The purpose of this experiment was to assess the productivity of *-ura*, *-ez(a)*, and *-dad* derivations which represent the main deadjectival nominalization processes in Spanish. Participants were shown a list of 60 nonce adjectives and were asked to choose one of the three nominalization suffixes (*-ura*, *-ez(a)*, *-dad*) to create a derived noun. Three types of nonce word were presented to participants: (i) *-ura* rhymes, (ii) *-ez(a)* rhymes, (iii) non-rhyming nonce words. Rhyming nonce adjectives differ from the corresponding existing ones in their onsets. For example, the existing adjective *negro* 'black' which takes *-ura* as its nominalizer (*negrura* 'blackness') was used to construct the nonce word *tegro* in condition (i), likewise the existing adjective *grande* 'great' (which takes *-eza*, *grandeza*) to construct the nonce word *trande*. Non-rhyming nonce adjectives were constructed so as not to rhyme with any existing adjective in the language but to be phonotactically legal words in Spanish. The existing adjectives used to construct the nonce items for conditions (i) and (ii) were matched in terms of their derived word form frequencies in the LEXESP database (Sebastian-Galles, Marti, Carreiras, & Cuetos, 2000). The mean frequencies (per million) were 3.00 for *-ura* and 4.36 for *-ez(a)* rhymes, a non-significant difference ($t(31) = 1.39$, $p > 0.18$). In addition, the non-rhymes in condition (iii) were matched to the rhyming nonce adjectives in terms of length; the mean numbers of letters were 8.34 in condition (i), 7.84 in condition (ii), and 8.03 in condition (iii), a non-significant difference ($F(93,2) = 1.26$, $p > 0.29$).

2.2.2. Experiment 2: event-related potentials

This experiment employed the ERP violation paradigm using a design similar to that of previous ERP studies of morphological violations (Linares, Rodriguez-Fornells, & Clahsen, 2006; Penke et al., 1997; Rodriguez-Fornells et al., 2001). The critical derived words were presented in short two-sentence paragraphs. Each paragraph began with a simple introductory sentence to provide an appropriate context for the derived word form followed by a second sentence that was always seven words in length with the critical nominalized adjective as the subject of the sentence preceded by a definite article; see (1) below. The second sentence was presented using a word-by-word presentation sequence with each word shown for 500 ms (stimulus-onset-asynchrony 500 ms) in black letters against a white background in the middle of a video monitor. Participants were instructed to carefully read all sentence pairs for their meaning. To make sure that participants followed

these instructions, a yes/no question referring to the contents of one of the 20 previous sentences appeared after each block of 10 sentence pairs, which they were asked to answer as accurately as possible by pressing one of two response buttons. The yes/no question was presented for 3000 ms after which the screen again went blank for 5000 ms before the next sentence pair was presented. Taking into account the demands on memory and attention required to answer these content questions, the overall response accuracy to the questions was high and significantly above chance level (mean: 0.77, SD: 0.09), indicating that participants carefully read the experimental materials for content.

To reduce the number of conditions and because *-dad* turned out to be the least productive of the three deadjectival nominalizers tested in experiment 1, the ERP experiment focused on the comparison between *-ura* and *-ez(a)* nominalizations. For word forms containing existing stems, there were two conditions: (i) adjectives that require *-ura*, either correctly presented with *-ura* (see (1a)) or incorrectly with *-ez(a)* (see (1b)); (ii) adjectives that require *-ez(a)*, either correctly presented with *-ez(a)* or incorrectly with *-ura*. As in experiment 1, we also tested three kinds of nonce words, *-ura* rhymes, *-ez(a)* rhymes, and non-rhyming nonce words. Parallel to existing word stems, the three kinds of nonce word stems were presented both with *-ura* and *-ez(a)*, yielding three nonce word conditions (see Table 1). The nonce word conditions were included to determine how potential productivity differences between derivational processes affect the electrophysiological responses. Assuming that *-ura* forms are less productive than *-ez(a)* forms, we expect nonce words with *-ura* to be perceived as more unusual or deviant than those with *-ez(a)*, particularly for *-ez(a)* rhymes and for non-rhyming nonce words, which should be reflected in corresponding ERP violation effects, i.e. enhanced N400 and/or LAN/P600 components.

- (1) (a) Las montañas estaban nevadas. La **blancura** de la nieve era deslumbrante.
'The mountains had snow. The whiteness of the snow was dazzling.'
(b) Pintaron de nuevo el edificio. La **blanqueza** del edificio era muy notable.
'They repainted the building. The whiteness of the building was outstanding'

To ensure that an appropriate number of items was available for each condition, a number of relatively uncommon existing *-ura* and *-ez(a)* word forms had to be included in the stimulus lists. We therefore pretested all critical items with respect to their familiarity of use. Sixty-nine Spanish-speaking adults were asked to rate 200 words (100 with *-ura*, 100 with *-ez(a)*) on a 7-point scale for familiarity (1-not familiar at all, 7-very familiar). On the basis of this pretest, 32 critical items for each of the two conditions ('existing *-ura*' and 'existing *-ez(a)*') were chosen that were matched with respect to familiarity of use (mean *-ura* = 5.68, mean *-ez(a)* = 5.78, $t(31) = 1.71$, $p > 0.10$), length (number of letters: mean *-ura* = 8.34, mean *-ez(a)* = 7.84, $t(31) = 1.37$, $p > 0.20$) and lemma frequency (mean *-ura* = 3.00, mean *-ez(a)* = 4.36, $t(31) = 1.39$, $p > 0.18$); see Appendices A and B. In addition, there were 32 items each for the three nonce word conditions; see Appendices C–E.

The pool of 32 items per condition was divided into two lists for two ERP sessions with each participant using a Latin-square design in which participants saw a particular *-ura* or *-ez(a)* word form only once per session. A participant, for example, who (for 'existing *-ura*') saw 16 sentence pairs with correct *-ura* forms (e.g., (1a)) and 16 different sentences with incorrect *-ura* forms in the first session, was presented in a second ERP session (1 week after the first one) with the remaining 16 correct and 16 incorrect *-ura* forms. Thus, at the end of the two sessions data were available from 32

Table 1
Experimental conditions for the ERP study.

Words with existing stems		
Correct form	Words that take <i>-ura</i> blanco → <i>blancura</i> [§] 'white' → 'whiteness'	Words that take <i>-eza</i> gigante → <i>gigantez</i> [§] 'huge' → 'hugeness'
Incorrect form	blanco → <i>blanqueza</i> [§]	gigante → <i>gigantura</i> [§]
Rhyming nonce words		
Expected ending	<i>-ura</i> rhymes encho → <i>enchura</i> [§] (from 'ancho - anchura' - wide - 'width')	<i>-eza</i> rhymes nirme → <i>nirmeza</i> [§] (from firme - firmeza - firm - firmness)
Unexpected ending	encho → <i>encheza</i> [§]	nirme → <i>nirmura</i> [§]
Non-rhymes		
Non-rhymes with <i>-ura</i> ending	tampid → <i>tampidura</i> [§]	
Non-rhymes with <i>-eza</i> ending	tamped → <i>tampidez</i> [§]	
Control condition		
Correct definite article	la bondad [§] (the goodness)	
Gender-agreement violation	el bondad [§]	

This table shows one example for each of the 12 conditions of the ERP experiment. The words marked with § are the target words that appeared in the second sentence of the two-sentence paragraph and for which ERP waveforms were analyzed.

correct/expected and 32 incorrect/unexpected *-ez(a)/-ura* forms in each of the five experimental conditions.

An additional control condition was included to determine how ERP signatures for the two critical derivational processes differ from those elicited by standard morpho-syntactic violations. There were 64 trials for this *gender-agreement* condition, 32 with correct and 32 with incorrect gender agreement. The trials had the same structure as those of the other five conditions, consisting of a sentence pair and a deadjectival nominalization in the subject position of the second sentence. In (2b), for example, the gender-agreement violation results from the combination of a masculine article with a feminine noun.

- (2) (a) Esta mañana han presentado un nuevo videojuego para niños. La realidad virtual del juego es convincente.
'This morning a new video game for children was presented. The virtual reality of the game is compelling.'
(b) Hubo una manifestación delante del ayuntamiento. El_[+masc] sociedad_[+fem] exige respuestas con esta manifestación.
'There was a demonstration in front of City Hall. The_[+masc] society_[+fem] requires answers to this event.'

2.3. Electrophysiological recording and analysis

The electroencephalogram (EEG) was recorded from the scalp using tin electrodes mounted in an elastic cap (Electro-Cap International) and located at 29 standard scalp locations (Fz, Cz, Pz, Fp1/2, F3/4, Fc1/2, C3/4, Cp1/2, P3/4, O1/2, F7/8, FC5/6, T3/4, T5/6, Cp5/6, PO1/2) and was referenced on-line to the right ocular canthus. All scalp electrodes were referenced off-line to the average of both mastoids. Vertical eye movements were monitored with an electrode below the right eye (vertical EOG). All electrode impedances were kept below 5 k Ω . The electrophysiological signals were filtered with a bandpass of 0.01–70 Hz (half-amplitude cutoffs) and digitized at a rate of 500 Hz. Thereafter, data were converted to 250 Hz off-line. The trials in which base-to-peak electrooculogram (EOG) amplitudes exceeded 75 μ V, amplifier saturation occurred, or the baseline shift exceeded 200 mV/s were automatically rejected off-line; the mean percentage of rejections was 17%. EEG recordings of both sessions were pooled together before averaging the data for the different conditions. All clean trials in each condition (max. 32 trials) were included into these averages. The EEG signal was averaged separately for each condition for epochs of

1024 ms including a 100 ms prestimulus baseline before the onset of the target word or non-word.

After visual examination of the main effects and in accordance with what has been reported in previous studies, we chose two time windows for the statistical analysis of the mean amplitudes, 250–500 ms and 700–800 ms for the five derived word conditions (existing *-ez(a)/-ura*, nonce rhymes (*-ez(a)/-ura*), non-rhymes), and 250–500 ms and 700–900 ms for the gender-agreement condition. The two time windows were selected to examine the data with respect to well-known language-related ERP components, the early time window to test for LAN and N400, the later time window for potential P600 effects. A larger time-window for the P600 was selected for the gender-agreement condition because visual inspection of the effects (see results below) indicated that the gender-agreement modulation had long-lasting effects (at least until 900 ms), which were not evident in the other conditions of the study; see Erdocia, Laka, Mestres-Misse, and Rodriguez-Fornells (2009) for a similar approach. To analyze the data statistically, we used repeated measures analyses of variance. Whilst all ERP waveforms presented in figures were digitally filtered using a low-pass filter with an 8 Hz half-power cutoff, the statistical analyses were computed with the unfiltered waveforms. For all statistical effects involving two or more degrees of freedom in the numerator, the Huynh–Feldt epsilon was applied even though the exact *p*-values after correction are shown.

3. Results

3.1. Experiment 1: acceptability judgments

In this experiment, participants were asked to form nominalizations with *-ez(a)*, *-ura*, or *-dad* for three kinds of nonce adjectives, those rhyming with existing adjectives that take *-ura*, those rhyming with existing ones that take *-ez(a)*, and non-rhymes. Fig. 1 shows mean percentages of the forms produced in these three conditions. Statistical comparisons revealed a significant preference for the expected form in the two rhyme conditions, (63% *-ura* forms for *-ura* rhymes: $F(171,2) = 374.48$, $p < 0.001$; 63% *-ez(a)* forms for *-ez(a)* rhymes: $F(172,2) = 256$, $p < 0.001$). For non-rhymes, participants showed a small but significant preference for *-ez(a)* forms overall ($F(206,2) = 27.63$, $p < 0.001$), as well as for *-ez(a)* compared to *-ura* ($F(103,1) = 5.276$, $p < 0.02$) and for *-ez(a)* compared to *-dad* forms ($F(103,1) = 7.327$, $p < 0.002$). In addition to similarity-based generalizations for both *-ez(a)* and *-ura* forms, the results for

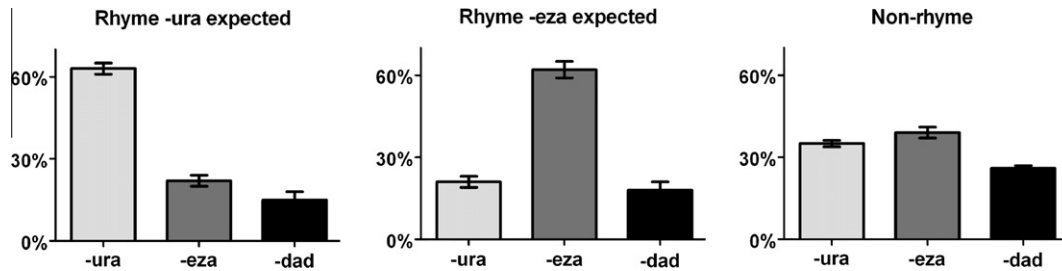


Fig. 1. Mean percentages of *-ura*, *-ez(a)*, and *-dad* forms produced for three types of nonce word, *-ura* rhymes, *-ez(a)* rhymes, and non-rhymes in the offline acceptability judgment task (Experiment 1). Condition ‘*-ura* rhymes’ refers to nonce words that rhyme with existing Spanish adjectives that take the *-ura* nominalizer, ‘*-ez(a)* rhymes’ to nonce words that rhyme with existing Spanish adjectives that take *-eza* and ‘Non-rhymes’ to nonce words that are phonotactically legal but do not rhyme with any existing adjective in Spanish.

non-rhymes are indicative of *-ez(a)* formations being a more productive deadjectival nominalization than both *-ura* and *-dad* forms in Spanish, confirming observations made in the linguistic literature.

3.2. Experiment 2: ERPs

Table 2 shows the results of an overall analysis for word forms with existing and rhyming nonce word stems, which includes the factors Condition (‘existing’, ‘rhyming nonce’), Correctness (‘correct/expected’, ‘incorrect/unexpected’), and Electrode (15 levels). As these analyses yielded significant interactions between Correctness and Condition and Correctness, Condition and Electrode, separate analyses were performed for the different morphological conditions. Furthermore, since visual inspection of the waveforms showed differences between specific electrode sites, more focused additional analyses were conducted for different electrode sites (midline (ML): Fz, Cz, Pz; parasagittal (PS): Fp1/2, F3/4, C3/4, P3/4; temporal (TE): F7/8, T3/4, T5/6).

Fig. 2 shows the grand-average ERPs for the two conditions of existing word stems, separately for stems that require *-ura* and for those that take *-ez(a)*, and Table 3 the statistical results for specific electrode sites.

3.2.1. ‘Words with existing stems that require *-ez(a)*’

The ERP waveforms for this condition (see right panel in Fig. 2) show a pronounced fronto-central negativity and a broadly distributed late positivity for the incorrect cases, i.e., for incorrect *-ura* forms, for example, for the nominalization **grandura* instead of the correct form *grandeza* derived from the adjective *grande* ‘big,

great’. Statistically, the observed negativity for the early time-window is reflected in a main effect of Correctness at temporal locations, Correctness by Hemisphere at parasagittal regions, and significant interactions of Correctness-by-Hemisphere-by-Anterior/Posterior at parasagittal and temporal electrodes (see Table 3). Decomposition of these interactions for the temporal electrode locations showed a significant Correctness-by-Anterior/Posterior interaction in the left hemisphere ($F(2, 42) = 3.65, p < 0.04$).

With respect to the late positivity, a significant main effect of Correctness was obtained at the PS, TE and ML electrode sites that was not modulated by the factors Hemisphere or Ant/Post in the 700–800 ms time window (see Table 3), reflecting the increased late positivity for the incorrect forms.

3.2.2. ‘Words with existing stems that require *-ura*’

For existing adjectives that require *-ura* nominalizations, the grand-average ERPs in Fig. 2 show a late posterior positivity for the incorrect (*-ez(a)*) forms (e.g. **bordadeza* instead of *bordadura* ‘embroidery’) and an early more negative-going waveform for correct (*-ura*) forms. As can be seen from Table 3, the latter is reflected in a significant interaction of the factors Correctness, Hemisphere, and Anterior/Posterior in the early time window. Note, however, that when the interaction was decomposed, no significant differences were found, either for Correctness or for the interaction between Correctness and Anterior/Posterior, indicating that the differences in the 250–500 ms time window are not reliable.

By contrast, the positivity is not only reflected in a marginally significant interaction of Correctness and Anterior–Posterior at midline locations but also in a significant three-way interaction of Correctness, Hemisphere, and Anterior–Posterior at parasagittal regions (see Table 2). Direct pairwise comparisons at specific midline electrodes showed a significant effect of Correctness at Pz ($F(1, 21) = 5.01, p < 0.04$). To further assess this late positivity we carried out a repeated measures ANOVA analysis to the parietal region of interest that included CP1/2, Pz and PO1/2 electrodes. At this site we found a significant main effect of condition ($F(1, 21) = 4.17, p < .05$) reflecting the increased late posterior positivity for incorrect forms at parietal regions.

3.2.3. Nonce word conditions

The ERP waveforms for these conditions are shown in Figs. 3 and 4, and the statistical results in Table 4.

With respect to *-ez(a)* rhymes, Fig. 3 (see right panel) suggests a more negative-going waveform for the (unexpected) *-ura* forms relative to the (expected) *-ez(a)* forms. Statistical analyses (see Table 4), however, showed that even though there was a significant interaction for the factors Suffix, Hemisphere, and Anterior–Posterior for the parasagittal electrodes in the later time window, decomposition of this interaction did not produce any significant differences. Furthermore, analyses for the early time window did

Table 2
Overall analyses.

	Cond F=	C F=	Cond × C F=	Cond × E F=	C × E F=	Cond × C × E F=
A. Words with existing stems						
250–500 ms	0.15 ^a	1.71 ^a	4.39 ^{a**}	0.39 ^b	1.22 ^b	1.78 ^{b**}
700–800 ms	0.02 ^a	6.50 ^{a**}	0.42 ^a	0.59 ^b	1.27 ^b	0.64 ^b
B. Rhyming nonce words						
250–500 ms	0.58 ^a	0.17 ^a	0.00 ^a	0.98 ^b	1.03 ^b	1.80 ^{b**}
700–800 ms	0.89 ^a	0.36 ^a	4.21 ^{a**}	2.21 ^{b*}	1.60 ^b	1.35 ^b

Notes. A. Factors: Condition (Cond) – two levels (*-ura*, *-ez(a)*); Correctness (C) – two levels (correct, incorrect); Electrodes (E) – 15 levels (F7/8, F3/4, T3/4, C3/4, T5/6, P3/4, Fz, Cz, Pz). B. Factors: Condition (Cond) – two levels (*-ura*, *-eza*); ‘Correctness’ (C) – two levels (expected/unexpected); Electrodes (E) – 15 levels (F7/8, F3/4, T3/4, C3/4, T5/6, P3/4, Fz, Cz, Pz).

^{*} $p < 0.01$.
^{**} $p < 0.05$.
^{***} $p < 0.07$.
^a Degrees of freedom: 1 and 21
^b Degrees of freedom: 14 and 294.

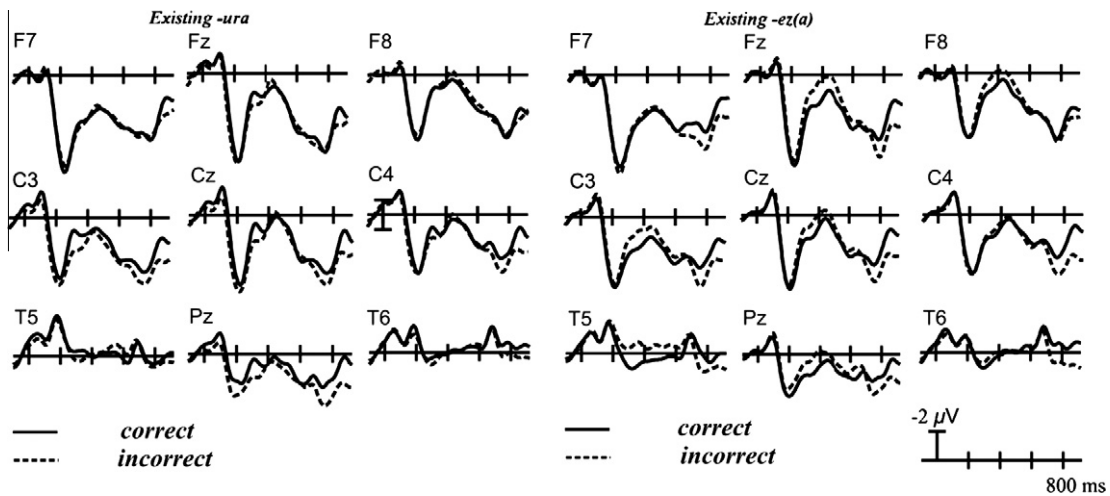


Fig. 2. Grand-average ERPs for word forms containing existing *-ura* and *-ez(a)* stems for specific electrode locations. The left panel shows waveforms for existing Spanish adjectives that require *-ura*, the right panel for those that require *-ez(a)* nominalizations. Incorrect forms in the *-ura* condition are with *-ez(a)* and incorrect forms in the *-ez(a)* condition are with *-ura*.

Table 3
Words with existing stems that require either *-ura* or *-ez(a)*.

	250–500 ms			700–800 ms		
	ML F=	PS F=	TE F=	ML F=	PS F=	TE F=
<i>-ura</i>						
C	0.35 ^a	0.14 ^a	0.08 ^a	2.26 ^a	1.36 ^a	0.46 ^a
C × H	–	0.00 ^a	0.07 ^a	–	0.17 ^a	0.06 ^a
C × A	0.57 ^b	0.26 ^c	0.16 ^b	3.10 ^{b***}	0.24 ^c	1.04 ^b
C × H × A	–	2.57 ^{c**}	0.26 ^c	–	2.48 ^{c**}	0.20 ^b
<i>-ez(a)</i>						
C	4.39 ^{a**}	3.87 ^{a***}	4.50 ^{a**}	3.95 ^{a***}	5.26 ^{a**}	5.70 ^{a**}
C × H	–	5.28 ^{a**}	2.44 ^a	–	0.13 ^a	0.01 ^a
C × A	0.23 ^b	0.51 ^c	1.09 ^b	0.06 ^b	0.19 ^c	1.96 ^b
C × H × A	–	2.96 ^{c**}	7.47 ^{b*}	–	0.61 ^c	1.69 ^b

Factors: Correctness (C) – two levels (correct, incorrect); Hemisphere (H) – two levels (left, right); anterior–posterior (A) – three levels on ML (Fz, Cz, Pz) and TE (F7/4, T3/4, T5/6) sites and five levels on PS (Fp1/2, F3/4, C3/4, P3/4, O1/2) site.

^a $p < 0.01$.

^{**} $p < 0.05$.

^{***} $p < 0.07$.

^a Degrees of freedom: 1 and 21.

^b Degrees of freedom: 2 and 42.

^c Degrees of freedom: 4 and 84.

not yield any reliable statistical differences either, as can be seen from Table 4.

For the *-ura* rhyme condition, the waveforms in Fig. 3 (see left panel) indicate a late positivity for (unexpected) *-ez(a)* in comparison to the (expected) *-ura* forms in this condition. Statistically, this is reflected in main effects of Suffix for the parasagittal and temporal electrodes and a significant Suffix-by-Hemisphere interaction for the late time window (see Table 4). Decomposition of this interaction yielded a significant effect of the factor Suffix for the LH ($F(1,21) = 15.50$, $p < 0.001$) but not for the RH electrodes. The waveforms in Fig. 3 also suggest a small early positivity for *-ez(a)* at approximately 200 ms, and Table 4 does indeed show interactions of Suffix-by-Hemisphere and Suffix-by-Anterior–Posterior for the temporal and parasagittal electrodes in the early time window. Decomposition of these interactions, however, did not produce significant effects, indicating that this early difference between *-ura* and *-ez(a)* forms is not reliable.

With respect to the non-rhyme condition, given the productivity differences between *-ez(a)* and *-ura* in Spanish and the results of

experiment 1, *-ura* nominalizations for non-rhyming adjectives are expected to be perceived as more unusual or even deviant than forms with *-ez(a)*. Fig. 4 confirms this in that *-ura* forms elicited an enhanced fronto-central negativity after 250 ms. The main statistical analysis in Table 4 revealed significant effects for the later time window only, namely a main effect of Suffix for the medial central and a Suffix-by-Hemisphere interaction for the temporal electrodes. Decomposition of this interaction yielded a marginally significant effect of Suffix for RH ($F(1,21) = 3.91$, $p < 0.06$) but not for LH electrodes.

To examine the earlier time window more carefully, we defined a fronto-central region of interest consisting of five electrode pairs (F7/8, F3/4, Fc5/6, Fc1/2, C3/4) and performed a corresponding repeated-measures ANOVA with the factors Suffix, Hemisphere, and Electrode. With the same 250–500 ms time-window as for the other conditions, a marginally significant main effect of Suffix was encountered ($F(1,21) = 4.01$, $p < 0.058$) that was not modulated by either Hemisphere, or Electrode (all $F_s < 1$). For a slightly narrower time-window (250–350 ms), however, this main effect became statistically reliable ($F(1,21) = 4.62$, $p < 0.05$). These results reflect a tendency for *-ura* forms of non-rhymes to develop a larger negativity at fronto-central sites during a relatively narrow early time-window when compared to *-ez(a)* forms (*-ura*: $1.15 \mu\text{V} \pm 2.3$, *-ez(a)*: 1.99 ± 2.2).

3.2.4. Gender-agreement condition

The ERP waveforms for this condition are shown in Fig. 5, and the statistical analysis in Table 5.

The waveforms in Fig. 4 indicate a biphasic ERP pattern for the violation condition, with an early left-lateralized negativity (LAN) followed by a late posterior positivity (P600). The statistical analysis for the early time window yielded a marginally significant Correctness-by-Hemisphere interaction for the temporal electrodes (see Table 5), which after decomposition led to a significant (correct vs. incorrect) difference at T5 ($F(2,42) = 4.52$, $p < 0.05$) and more pronounced (correct vs. incorrect) differences at left than at right hemisphere sites (Correctness/LH: $F(1,21) = 2.63$, $p < 0.12$ Correctness/RH: $F(1,21) = 0.06$, $p < 0.81$). The reliability of this LAN effect was further inspected using a narrower time-window of 60 ms centered around the peak of the effect, which was found at 420 ms. Using this narrower time window, the interaction between Correctness and Hemisphere at temporal locations (see Table 5) was significant ($F(1,21) = 7.6$, $p < 0.011$), which confirms

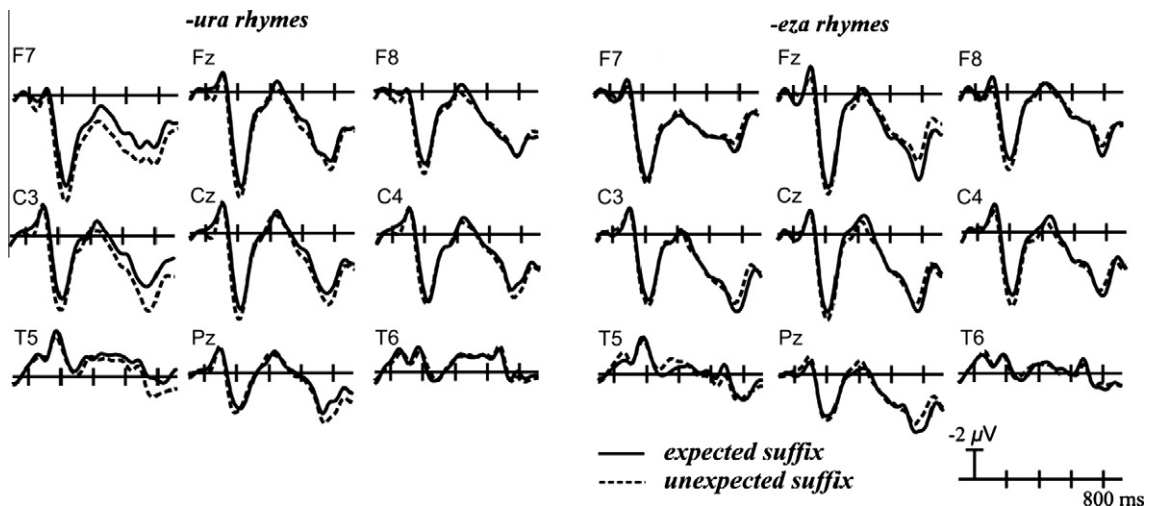


Fig. 3. Grand average ERPs for rhyming nonce adjectives for specific electrodes. The left panel shows waveforms for nonce adjectives that rhyme with existing ones that require *-ura*, the right panel those that rhyme with existing ones that require *-ez(a)* nominalizations. Unexpected forms in the *-ura* condition are with *-ez(a)* and, vice versa, with *-ura* in the *-ez(a)* condition.

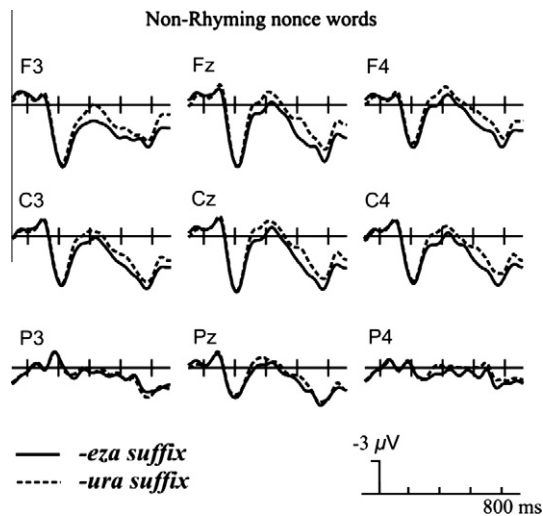


Fig. 4. Grand average ERPs for non-rhyming nonce words for specific electrodes.

the lateralization of the LAN effect observed in Fig. 5 (as well as Fig. 6C below). Further pairwise comparisons between correct and incorrect gender conditions at the three lateral left hemisphere electrodes and using this narrower time window revealed significant differences at T3 ($F(1,21) = 5.4, p < 0.03$) and T5 ($F(1,21) = 6.7, p < 0.017$), marginally significant at F7 ($F(1,21) = 3.4, p < 0.08$).

For the later time window (700–900 ms), significant interactions were obtained for Correctness and Anterior–Posterior for all electrode sites (see Table 5) without any effect of Hemisphere, confirming that the late positivity for gender-agreement violations is stronger for posterior than for anterior electrode sites.

3.2.5. Topographical comparisons between conditions

The results for the critical nominalization conditions reported above showed (i) reliable fronto-central negativities after 250 ms for incorrect *-ura* forms of existing adjectives that require *-ez(a)* and for *-ura* forms of non-rhymes; (ii) late posterior positivities for incorrect (*-ura* and *-ez(a)*) nominalizations of existing adjectives and for (unexpected) *-ez(a)* forms of nonce adjectives that rhyme with existing *-ura* forms. Whilst the late posterior positivities can be identified as P600-like effects, both in terms of their

latencies and distributions, the fronto-central negativities obtained for the early time window require further exploration. To this end, we compared the negativities seen in the nominalization conditions to the gender-agreement condition using the topographical distribution of the LAN effect for gender-agreement violations as a control; see Fig. 6 for the topographical distribution of the difference waveforms.

The maps in Fig. 6 show a more central distribution for the nominalization conditions (see Fig. 6A and B) compared to a more left-oriented one for the gender-agreement violations. Statistically, a comparison of the broad distribution of the negativities depicted in map A (for incorrect *-ura* nominalizations) relative to the gender-agreement violations (map C) for all 29 electrodes revealed a significant Condition-by-Electrode interaction ($F(28,588) = 1.9, p < 0.0037$), confirming the distributional differences of these two negativities. In addition, a more stringent analysis focusing on frontal vs. central electrodes (F7/F3/Fc5/Fc1/T3/C3/F8/F4/Fc6/Fc2/T4/C4) only and in a narrow time window of 40 ms centered on the peak of each difference waveform (370–390 ms for the nominalization and 420–440 ms for the gender-agreement condition) produced a significant three-way interaction for Condition, Anterior–Posterior, and Hemisphere ($F(5,105) = 3.0, p < 0.0143$), again confirming the topographical differences between maps A and C.

Concerning the non-rhyme condition (map B), the contrasts are less pronounced, and the same topographical analyses did not yield any reliable differences for the non-rhyme condition, either in comparison to the gender-agreement condition (maps B vs. C: $F(28,588) < 1$) or in comparison to incorrect *-ura* nominalizations (maps B vs. A: $F(28,588) < 1$).

4. Discussion

The present study revealed a pattern of experimental results for derivational morphology that indicates the involvement of both lexical (word-level) and combinatorial (morpheme-level) processes. Two experiments were performed on derived word forms in Spanish, specifically deadjectival nominalizations with the suffixes *-ura* and *-ez(a)*. The first experiment tested how nominalization processes generalize to different kinds of nonce adjectives in an offline acceptability judgment task. The results showed associative (word-form based) generalizations for both *-ura* and *-ez(a)* formations, with *-ura* forms preferred for nonce words that were

Table 4
-ura and -ez(a) forms for nonce words.

Rhymes		250–500 ms			700–800 ms		
		ML	PS	TE	ML	PS	TE
		F=	F=	F=	F=	F=	F=
-ura rhymes	S	0.06 ^a	0.01 ^a	1.08 ^a	1.74 ^a	4.45 ^{a**}	5.11 ^{a**}
	S × H.	–	3.95 ^{a***}	3.08 ^a	–	6.54 ^a	6.15 ^{a**}
	S × A	0.76 ^b	1.66 ^c	3.24 ^{b**}	0.68 ^b	0.28 ^c	0.03 ^b
	S × H × A	–	0.22 ^c	0.49 ^b	–	0.57 ^c	1.27 ^b
-ez(a) rhymes	S	0.64 ^a	0.06 ^a	0.18 ^a	0.57 ^a	1.84 ^a	0.33 ^a
	S × H	–	0.87 ^a	2.79 ^a	–	1.16 ^a	0.11 ^a
	S × A	1.08 ^b	1.51 ^c	0.61 ^b	0.50 ^b	1.17 ³	0.89 ^b
	S × H × A	–	0.41 ^c	2.17 ^b	–	2.97 ^{c**}	0.72 ^b
Non-rhymes	S	1.85 ^a	1.63 ^a	2.35 ^a	3.97 ^{a***}	2.46 ^a	1.51 ^a
	S × H	–	0.01 ^a	0.01 ^a	–	0.83 ^a	4.69 ^{a**}
	S × A	0.37 ^b	0.31 ^c	0.70 ^b	1.35 ^b	1.10 ^c	1.70 ^b
	S × H × A	–	0.49 ^c	0.68 ^b	–	0.57 ^c	0.32 ^b

Factors: Rhymes: Suffix (S) – two levels (expected, unexpected); Hemisphere (H) – two levels (left, right); anterior–posterior (A) three levels on ML (Fz, Cz, Pz) and TE (F7/4, T3/4, T5/6) sites and five levels on PS (Fp1/2, F3/4, C3/4, P3/4, O1/2) site. Non-rhymes: Suffix (S) – two levels (-ura, -eza); Hemisphere (H) – two levels (left, right); anterior–posterior (A) three levels on ML (Fz, Cz, Pz) and TE (F7/4, T3/4, T5/6) sites and five levels on PS (Fp1/2, F3/4, C3/4, P3/4, O1/2) site.

^{*} $p < 0.01$.

^{**} $p < 0.05$.

^{***} $p < 0.07$.

^a Degrees of freedom: 1 and 21.

^b Degrees of freedom: 2 and 42.

^c Degrees of freedom: 4 and 84.

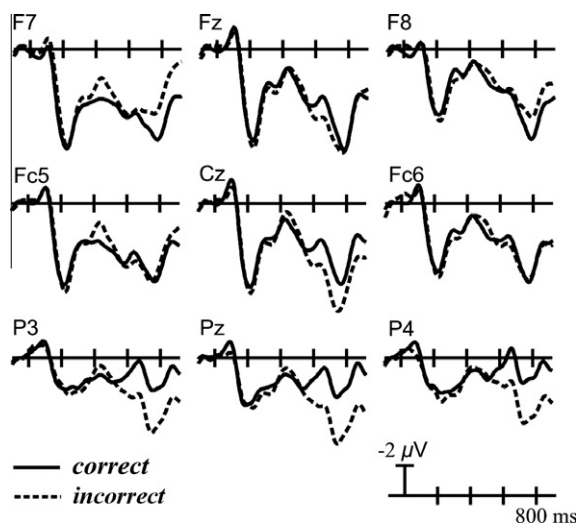


Fig. 5. Grand average waveforms for the gender-agreement condition.

Table 5
Sentences with and without gender-agreement violations.

	250–500 ms			700–900 ms		
	ML	PS	TE	ML	PS	TE
C	0.07 ^a	0.08 ^a	0.47 ^a	5.07 ^{a*}	0.44 ^a	0.02 ^a
C × H	0.28 ^a	0.28 ^a	3.60 ^{a***}	1.18 ^a	0.83 ^a	0.83 ^a
C × A	0.20 ^b	0.15 ^c	1.64 ^b	7.76 ^{b*}	9.90 ^{c*}	5.40 ^{b*}
C × H × A	–	1.15 ^c	0.69 ^b	–	0.95 ^c	0.17 ^b

Factors: Correctness (C) – two levels (correct, incorrect); Hemisphere (H) – two levels (left, right); anterior–posterior (A) – three levels on ML (Fz, Cz, Pz) and TE (F7/4, T3/4, T5/6) sites and five levels on PS (Fp1/2, F3/4, C3/4, P3/4, O1/2) site.

^{*} $p < 0.01$.

^{**} $p < 0.05$.

^{***} $p < 0.07$.

^a Degrees of freedom: 1 and 21.

^b Degrees of freedom: 2 and 42.

^c Degrees of freedom: 4 and 84.

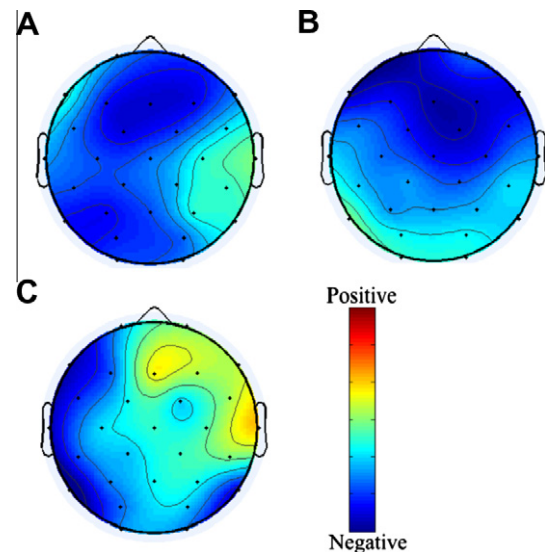


Fig. 6. Spherical spline-interpolated isovoltage maps derived from the following difference waveforms for the early time window: (A) 'Existing -ez(a)': (incorrect) -ura minus (correct) -ez(a), early (350–450 ms) time window (scale: most positive $-0.01 \mu\text{V}$, most negative $-1.29 \mu\text{V}$). (B) 'Non-rhymes': -ura minus -ez(a), early (350–450 ms) time window (scale: most positive $-0.03 \mu\text{V}$, most negative $-1.5 \mu\text{V}$). (C) 'Gender-agreement': incorrect minus correct; early (400–450 ms) time window (scale: most positive $0.46 \mu\text{V}$, most negative $-1.48 \mu\text{V}$).

similar to existing adjectives that take -ura, and -ez(a) forms for those similar to existing -ez(a) adjectives. However, for non-rhyming nonce adjectives, which do not allow for any similarity-based associations, -ez(a) forms yielded a small but significant preference, indicating that -eza is more productive than other deadjectival nominalizations in Spanish.

The second experiment showed that incorrect or unexpected forms with -ez(a) and -ura elicited a hybrid pattern of ERP responses. Incorrect forms with -ura (but not those with -ez(a)) elicited an increased fronto-central negativity with a peak latency of approximately 400 ms, an ERP effect which in terms of its distribution could be distinguished from the LAN-type effect observed for

gender-agreement violations in the morpho-syntactic control condition. We interpret the enhanced fronto-central negativity as an N400 response caused by incorrect *-ura* forms. The second main finding from the present ERP experiment was that incorrect or unexpected derived word forms, both with *-ura* and with *-ez(a)*, elicited an increased late posterior positivity compared to the correct or expected suffixed word forms, which in terms of its timing and distribution could be identified as a P600 component. In addition, an enhanced late posterior positivity (P600) was also seen for gender-agreement violations (relative to correct gender forms) in the morpho-syntactic control condition.

In much previous ERP research, N400 effects, specifically modulations of the amplitude of this component, have been found to be sensitive to lexical-semantic factors, and it has been suggested that N400 amplitudes vary with ease of lexical access and/or integration processes (e.g. Kutas, 2003). Although the topography of the visual N400 component is usually central-parietal, several studies have also reported N400 components with a fronto-central and more anterior distribution for visually presented words (McCarthy & Nobre, 1993), similar to the ones obtained here for incorrect or unexpected *-ura* forms. For non-words in particular, fronto-centrally distributed N400 components have been previously observed in both sentence contexts (Penke et al., 1997) and as isolated word forms (Bentin, 1987; Bentin, McCarthy, & Wood, 1985; Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Nobre & McCarthy, 2004). Furthermore, a fronto-central N400 distribution has been reported in word-learning studies for initial exposures to visually presented new forms (e.g. Frishkoff, Perfetti, & Collins-Thompson, 2010; Mestres-Missé, Rodríguez-Fornells, & Münte, 2007). Numerous studies have been conducted to localize the neural substrate(s) of this component using the techniques of functional MRI, magnetoencephalography and intracranial recordings (amongst others) with similar designs as those familiar from ERPs studies; see Lau, Phillips, and Poeppel (2008) for review. Although results are far from clear-cut, there are several sites (anterior medial temporal lobe, middle temporal gyrus and anterior ventral and posterior inferior frontal gyrus) that consistently showed modified activation depending on the experimental manipulation. Taken together, it is plausible to assume that anterior-medial-temporal lobe sites and other frontal neural sources are responsible for eliciting the N400 component (on the scalp) in response to the processing of phonologically and orthographically legal non-words (Mestres-Missé, Camara, Rodríguez-Fornells, Rotte, & Münte, 2008; Nobre & McCarthy, 1995), possibly reflecting associative activations of the lexical representations of similar existing words. Following from this research, we interpret the increased N400 seen in the present experiment for *-ura* violations as an index of word-level lexical-semantic processing.

The second ERP component elicited by violations of nominalization processes was a late posterior positivity identified as a P600 component, which was found for both incorrect or unexpected *-ura* and *-ez(a)* forms. In language-related ERP research, P600 effects are thought to be indicative of combinatorial linguistic processes, specifically with respect to morphological and syntactic violations. Assuming that this interpretation of the P600 is correct, our results show that violations of derivational processes involve not only word-level but also combinatorial processing. This is confirmed by the finding that nominalization violations elicited the same P600 component as straightforward morpho-syntactic (gender-agreement) violations.

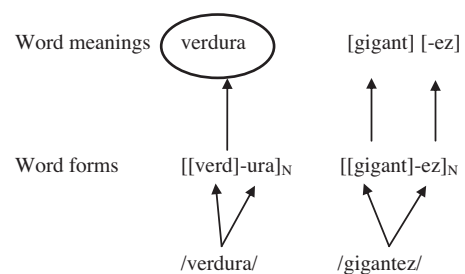
4.1. The representation of *-ez(a)* and *-ura* forms in the Spanish mental lexicon

The present set of findings raise the question of how it is possible that derived words are processed both as whole words and via

their constituent morphemes. We address this question from a linguistic perspective, in terms of the lexical representations created by derivational processes.

Derived words have linguistic properties of both lexical entries and combinatorial grammatical processes. On the one hand, derivational processes produce new lexemes with new lexical entries, which (much like morphologically simplex words) have their own grammatical properties, selectional restrictions, and particular meanings. On the other hand, many derived words have internal morphological structure, which arguably results from rule-like grammatical operations. Consider, for example, deadjectival nouns with *-ura* in Spanish, e.g. *verdura* 'vegetables'. Although these derived words forms are largely unproductive and may express unpredictable meanings, *-ura* derivation yields morphologically structured word forms consisting of adjectival stems and a segmentable derivational suffix. To capture the linguistic properties of derived words, several linguistic accounts assume distinct morpholexical representations for derived words that distinguish them from the products of inflectional or paradigmatic processes. Realization-based approaches to morphology, for example, (Anderson, 1992; Matthews, 1991; Stump, 2001, among others) argue that the outputs of all derivational processes 'constitute lexical stems' (Anderson, 1992, p. 184), i.e. word-form entries stored in the lexicon. Consequently, the outputs of two derivational processes may have the same (potentially structured) word-form-level entries irrespective of their semantic properties. Experimental evidence for this hypothesis comes from masked priming experiments which reported significant priming effects for derived word forms irrespective of their semantic transparency; see Marslen-Wilson (2007) and Davis and Rastle (2010) for reviews of this literature. Applying the distinction between word-form and word-meaning level representations to *-ez(a)* and *-ura* nominalizations in Spanish, we suggest that they both have the same kind of (morphologically structured) word-form-level representations but different ones at the meaning level. This is illustrated in (3) for the derived words *gigantez* 'hugeness' and *verdura* 'vegetables'.

(3) Lexical representations for *-ura* and *-ez(a)* forms:



Derived words with *-ez(a)* and *-ura* are proposed to have the same morphologically structured word-form level representations, both consisting of a stem and a derivational affix, but different meaning-level representations, dedicated entries for *-ura* forms that encode their specific meanings, and no separate entries for *-ez(a)* forms, due to their largely compositional meanings. We suggest that the observed pattern of experimental results for deadjectival nominalizations in Spanish can be explained in these terms. The finding from experiment 1 that *-ura* is less productive than *-ez(a)* can be attributed to their different semantic properties, specifically the fact that due to the specific meanings of existing *-ura* forms, *-ura* generalizes to nonce words less easily than *-ez(a)*. Likewise, the finding from experiment 2 that incorrect or unexpected *-ura* forms, but not those with *-ez(a)*, elicited an

increased N400 is also a likely result of their different semantic properties. Assuming that *-ura* forms have specific meaning-level entries in the Spanish mental lexicon, unexpected forms such as **gigantura* (instead of the existing *gigantez* ‘hugeness’) cannot be mapped onto any of these existing entries and fail to denote any of the particular sensations, shapes, or dimensions that *-ura* forms normally express. Thus, *-ura* forms such as **gigantura* may be perceived as highly unfamiliar forms or even as non-words, yielding a fronto-central N400. By contrast, incorrect *-ez(a)* forms did not produce an increased N400 (relative to the correct *-ura* forms), due to the fact that *-ez(a)* forms are more familiar and do not have any specific lexical-semantic requirements.

Experiment 2 also showed enhanced P600 effects, for both violations of *-ura* and *-ez(a)*. We attribute this to the internal morphological structure of the word-form-level representations of both *-ura* and of *-ez(a)* forms; see (3) above. Thus, incorrect pairings of *-ez(a)* with stems that normally take *-ura* and, conversely, of *-ura* with stems that require *-ez(a)* are perceived as combinatorial violations, producing an increased P600, similarly to gender-agreement violations and other grammatically incorrect sequences of words and morphemes. Yet, P600 effects were found to be more common for incorrect or unexpected *-ez(a)* forms than for those with *-ura*, in that for nonce words, a P600 was only found for (unexpected) *-ez(a)*, i.e. in cases in which *-ez(a)* appeared on a derived nonce word that rhymed with an existing adjective that takes *-ura*. We attribute this contrast to the fact that *-ez(a)* is more familiar and productive as a deadjectival nominalizer than *-ura*, and thus more easily recognizable as a derivational suffix, even in nonce words, yielding a P600 in cases of unexpected combinations. Nonce words with the unproductive *-ura*, on the other hand, are more likely to be recognized as unanalyzed rather than as morphologically structured words, and as a result do not produce a P600 effect.

Summarizing, we proposed a linguistic account of derived nominals in Spanish according to which *-ura* and *-ez(a)* have the same (morphologically structured) word-form-level entries, but the representations of *-ura* words include an additional pointer to meaning-level entries that specify their particular semantic properties. For *-ez(a)* nominals, such additional entries or pointers are not required, corresponding to their largely compositional meanings. We explained the present set of experimental findings in terms of these representations. We also note that the proposed account for derived nominals in Spanish is consistent with previous psycholinguistic research on other languages indicating that knowledge of both the whole-word properties and the component parts of derived words affect their processing; see Marslen-Wilson (2007) for a review. To take one example from German, Clahsen, Sonnenstuhl, and Blevins (2003) showed that productive (*-ung*) nominalizations produce efficient stem priming in cross-modal priming experiments paired with word-form frequency effects (in unprimed lexical decision), with the former indicating decompositional and the latter whole-word-level processing. At a more general level, these experimental findings as well as the ones reported in the present study indicate that understanding derivational morphology and the way derived word forms are processed requires more complex notions that go beyond the simple opposition between ‘regular’ and ‘irregular’ inflection that has been the focus of the controversy between connectionist and symbolist accounts of the English past-tense (McClelland & Patterson, 2002; Pinker & Ullman, 2002).

4.2. Cross-linguistic comparisons

Consider finally, in the light of the proposed interpretation, how the present set of ERP results on Spanish compare with those of

previous ERP violation studies of derivational processes in other languages.

Two previous ERP studies investigated *prefixed* derived words in which incorrect derived word forms produced either no effect (McKinnon et al., 2003) or a LAN/P600 pattern (Palmović & Maričić, 2008), but not the enhanced N400 component that was found in the present ERP experiment for derivational suffixes in Spanish. Rather than reflecting differences between the particular languages involved (English, Croatian, Spanish), we suggest that these contrasting findings are due to more general processing differences between prefixed and suffixed words. In behavioral experiments using cross-modal priming, for example, prefixed words tend to yield strong decomposition effects (Marslen-Wilson et al., 1994; among others), which may reflect mechanisms specific to these kinds of words (‘prefix stripping’; see Taft & Forster, 1975). The results of the two ERP studies mentioned above are consistent with the idea that incorrect prefixed word forms are primarily perceived as combinatorial (rather than lexical-level) violations.

Derivational *suffixes* were examined in three previous ERP violation studies, Leinonen et al. (2008) for Finnish, and Janssen et al. (2006) and Bölte et al. (2009) for German. The results on Finnish yielded ‘an N400-like negativity effect, followed by a P600 effect for derivational violations’ (p. 181), parallel to the present set of findings for Spanish. Yet, Leinonen et al. (2008) interpreted the enhanced N400 differently, as reflecting ‘a morphological parsing process’. Leinonen et al. believe that because the stimulus words they used do not represent existing words in the language, the increased N400 for the violation condition cannot signify any kind of lexical processes. Note, however, that the violations were constructed by combining adjectival suffixes with a verb stem (**juoksello-linen* ‘run-owning’) which are not only grammatically ill-formed, but also semantically hard to interpret. Hence, it is conceivable that the N400 obtained in such cases is due to lexical-semantic factors, rather than signifying morphological decomposition processes.

For German, the results are less clear. Two studies examined suffixed derivational forms, Janssen et al. (2006) and Bölte et al. (2009), and both of them obtained enhanced negativities for the violation conditions. However, whilst Janssen et al. (2006, p. 477) reported an ‘N400-like component rather than a LAN’, Bölte et al. (2009, p. 350) claimed to have found ‘LAN effects rather than N400 effects’. Nevertheless, despite these apparently different ERP results, both studies managed to offer the same functional interpretation, arguing that the ERP responses to the violation conditions reflect morphological parsing processes. These accounts can obviously not both be correct. With respect to the description of the ERP components, the negativity reported by Janssen et al. (2006) does indeed show the characteristics of an enhanced N400. By contrast, Bölte et al.’s (2009) characterization of their ERP results is much less straightforward. The time window for which the effect occurred was unusually small (450–500 ms), and the signal-to-noise ratio of the effect seemed to be very low, with Fig. 3 (Bölte et al., 2009, p. 348) showing partly larger amplitudes in the control than the experimental conditions. Furthermore, the mean negativity was strongest at central, less so at left electrode sites. Portraying these results as a LAN effect seems unwarranted. Concerning the functional interpretation of the negativities, both studies concentrate on the *grammatical* illformedness of their critical materials. Yet, these materials are also *semantically* odd in that word forms such as **Mild-ung* are difficult to interpret with respect to their meaning, especially when presented in isolation without context, as was the case in Janssen et al.’s (2006) lexical decision experiment. Consequently, the enhanced N400 in such cases may reflect lexical-semantic processing, rather than purely grammatical violations. Finally, it should be noted that a P600 effect such as the one seen for both Finnish from

Leinonen et al. (2008) and for Spanish from the present study was not reported in either of the two German studies. This may be due to the fact that words were tested in isolation (as was the case in Janssen et al., 2006) and/or that the time windows chosen were unsuitable to detect a late positivity.

5. Conclusion

The main finding from the present study is a pattern of brain potentials for derivational morphology that differs from those reported for both purely lexical-semantic and grammatical phenomena. We found that violations of derivational morphology elicited an increased (fronto-central) N400 component plus a late positivity (P600), in contrast to morpho-syntactic (gender-agreement) violations which produced the biphasic LAN/P600 ERP pattern known from previous studies of inflectional and syntactic phenomena. An increased N400 component was found for incorrect forms with *-ura* (but not those with *-ez(a)*), and an increased late posterior positivity was found for incorrect or unexpected derived word forms, both with *-ura* and with *-ez(a)*. These results correspond to the hybrid nature of derivational processes, suggesting that derived words such as the ones tested are represented and processed in terms of *combinatorial entries* (Clahsen et al., 2003), i.e. as lexical items that maintain their internal morphological structure. Finally, one caveat should be noted, however. The present study represents the first ERP study of derived word forms in Spanish that compares a specific, narrowly constrained set of deadjectival nominalizations which only differ with respect to their productivity and are otherwise similar. Yet, this design meant that the final amount of data for analysis, i.e. minimally 28 items per condition per participant after artifact rejection, was moderate and causing a potentially low signal-to-noise ratio for some of the ERP components evaluated. Although our results for Spanish are similar to earlier findings for Finnish (Leinonen et al., 2008), we concede that further studies are required to test the ERP effects reported in the present study and to determine whether the combination of N400 and P600 effects is characteristic of violations of derivational morphology across different languages.

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Appendix A. Existing *-ura* forms

tersura 'smoothness', bordadura 'embroidery', chifladura 'craziness', tachadura 'deletion', embestidura 'attack', negrura 'blackness', guapura 'good looks', ligadura 'tying', abolladura 'buckling', rasgadura 'tearing', tomadura 'teasing', salpicadura 'spray', armadura 'armor', sabrosura 'tastiness', rotura 'broken', atadura 'bond', frescura 'freshness', gordura 'fat', fritura 'fried', bravura 'bravery', hendidura 'cleavage', espesura 'density', soldadura 'welding', picadura 'pitting', dulzura 'tenderness', locura 'madness', quemadura 'burn', desembocadura 'mouth', blancura 'whitening', hermosura 'beauty', cerradura 'lock', anchura 'width'.

Appendix B. Existing *-ez(a)* forms

impavidez 'fearlessness', gigantez 'hugeness' vileza 'cowardice', altivez 'arrogance', viudez 'widowhood', sordidez 'sleaze', robustez 'strength', tibieza 'warmth', ligereza 'lightness', exquisitez 'deli-

cacy', avidez 'greed', flacidez 'sagging', insipidez 'dullness', simpleza 'simplicity', extrañeza 'surprise', impureza 'impurity', tirantez 'tightness', honradez 'honesty', grandeza 'grandeur', brillantez 'brilliance', agudeza 'wit', viveza 'vivacity', candidez 'candor', firmeza 'firmness', palidez 'pallor', nitidez 'sharpness', calidez 'warmth', delicadeza 'delicacy', inmediatez 'immediacy', sensatez 'wisdom', madurez 'maturity', sencillez 'simplicity'.

Appendix C. Nonce adjectives: *-ura* rhymes

epochado, encho, ermado, itado, planco, pordado, cravo, dellado, lliblado, tefemdosado, mucle, imesivo, usbeso, tresco, drito, mordo, zuapo, hintido, horposo, dicado, soco, tegro, sipado, guetado, paslado, goto, bacroso, talminado, bolmado, varrado, cerso, socado.

Appendix D. Nonce adjectives: *-ez(a)* rhymes

efudo, uldivo, étido, trichante, gápido, jánfido, temibado, axguifito, ixbraño, nirme, bláfido, cipante, trande, henpado, embáfido, emnuro, andefiato, ontívido, mitero, hamuro, mílido, tájido, nodusto, lenmillo, penfato, vimple, fírboda, jubio, julante, zil, piudo, mivo.

Appendix E. Nonce adjectives: non-rhymes

tampid, betanil, rontal, ropog, meguer, tagol, zavar, cergu, zongor, oldavon, hambis, catalom, belud, ciger, cutra, nalota, darabol, deluran, adomentes, ajanl, aldas, bosit, fobegu, belemar, tancos, vasut, utalas, tomban, ruborin, fuvar, mampan, mutat.

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