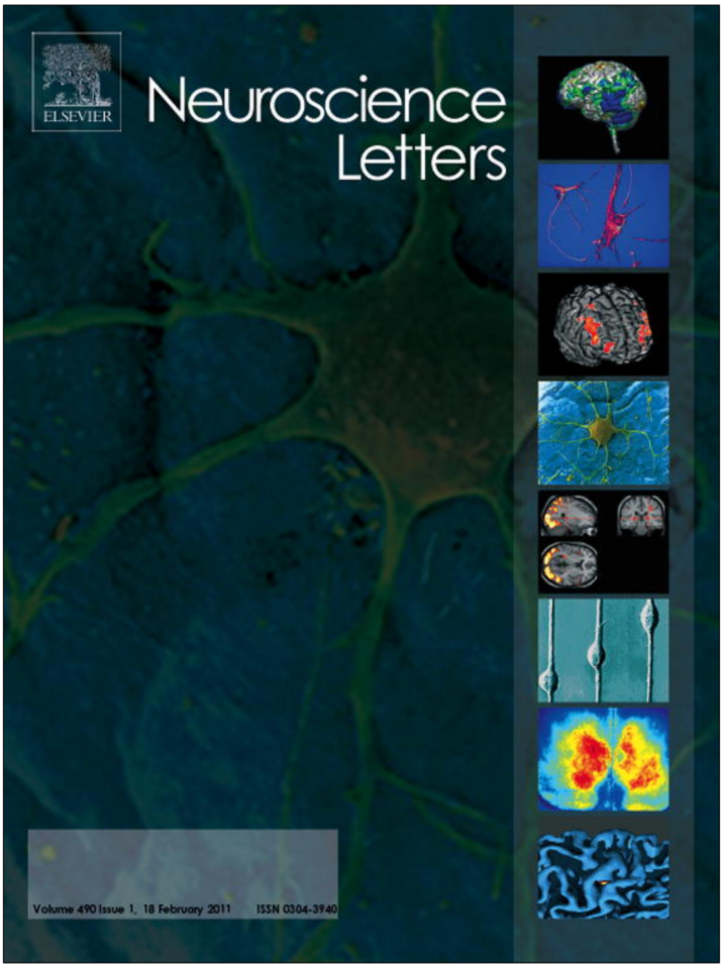
ELSEVIER
Neuroscience Letters
Volume 490 Issue 1, 18 February 2011 ISSN 0304-3940

Neuroscience Letters 490 (2011) 6–10

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Processing inflectional and derivational morphology: Electrophysiological evidence from Spanish

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ARTICLE INFO

Article history:
Received 27 July 2010
Received in revised form
25 November 2010
Accepted 8 December 2010

Keywords:
Morphology
Inflection
Derivation
Spanish

ABSTRACT

The goal of this paper is to study possible differences between the processing of inflectional vs. derivational morphology in Spanish word recognition using electrophysiological measures. A lexical decision task to target words preceded by morphological-related (or unrelated) primes was used. The orthographic and phonological overlap and the grammatical class for the two experimental conditions were exactly the same. Examples of the related conditions were, for inflection, NIÑO-NIÑA ("girl"-"boy"), and for derivation, RAMO-RAMA ("bunch"-"branch"). These conditions were compared with unrelated pairs without orthographic, phonological or semantic relationships. An attenuation of the N-400 component was found for both related conditions from 300 ms until 450 ms (until 500 ms for inflections only). In addition, different locations were suggested by the source analysis. These findings are consistent with accounts that argue for differences between the processing of inflections and derivations.

Attempts to answer empirically whether words are processed at a morphological level have led to contrasting points of view. But the weight of evidence so far certainly seems to argue for morphological decomposition.

Most of this evidence has been obtained using morphological priming in tasks that require lexical access, such as lexical decision. In general, morphologically related primes facilitate target recognition compared to other non-morphological conditions (see, for instance [10,15] for reviews). Findings from ERP studies are particularly interesting and generally show that morphological overlap between prime–target pairs affects the N400 component [6,10], traditionally related to semantic processing, with the amount of amplitude reduction associated with the degree of relatedness between words. Some other components such as the Left Anterior Negativity or P600 also reflect morphological processing but only for agreement situations in sentence contexts, e.g., [16].

Inflectional and derivational morphology constitute two types of morphological relationships where related words share letters (orthographic overlap) and meanings (semantic relationship), but differ in several important aspects: inflections (gender, number and verbal) have syntactic functions facilitating the agreement between words (e.g., "the boy plays" vs. "the boys play"), without changing the basic meaning of the base. On the other hand, derivations contribute to thematic role (for example, transforming nouns into agents, "walk"-"walker"), do not have syntactic function and are specially implicated in the semantic variation of words.

Some previous studies have found that both inflected and derived primes produce similar effects, while others have reported larger effects for inflections than for derivations (see [7,15,17] for reviews). Neuropsychological studies have also suggested that "inflectional and derivational processes constitute autonomous subcomponents" [13, p. 24]. The lexicon would include three different components: a set of root morphemes and two affix components, one derivational and the other inflectional. However, equivalent effects for both inflected and derived primes have been found in English [15]. Similar results with priming manipulation were found in Spanish, showing that these effects could not be attributed simply to orthographic overlap or semantic relationships, since appropriate control pairs for these two factors were included in the experiments [17].

Our main goal is to investigate further the priming effects produced by these two types of morphological relationships, using ERPs in order to track in a more precise way the time-course of possible effects and differences. To this end, morphologically related prime–target pairs (inflected or derived words) were compared to unrelated control pairs in a lexical decision task in Spanish, following a previous study [17]. Spanish allows, at least for some kinds of words, an ideal and powerful control of orthographic similarity. Thus, in our stimuli, the orthographic similarity and overlap was the same for both kinds of morphological relations (inflections and derivations): three out of four letters.

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0304-3940/$ – see front matter
doi:10.1016/j.neulet.2010.12.015

ERPs also allow localization of the internal source of the electrical differences registered at the scalp by means of source analysis software. Recent studies of neuroimaging using fMRI or magnetoencephalographic measures have shown that left inferior frontal areas and left superior temporal areas are particularly active when inflected words are processed in comprehension tasks [20,22]. The evidence is not so clear with derivational morphology, but activation at the inferior frontal cortex has also been found [4,5]. When inflected and derived words have been compared directly, specific bilateral activation at the inferior frontal gyrus and parietal activation for derived words have been detected [11]. This difference could be due to the wider meaning variation in derived words with respect to inflected relatives. These internal source localizations were also a main goal of the present research.

Twenty right-handed psychology students from the University of La Laguna (15 women and 5 men, age range between 18 and 28 years old, mean 22.5), with normal or corrected-to-normal vision participated voluntarily in the experiment, receiving course credit for it. Their native language was Spanish, and none of them had a clinical history of neurological or psychiatric abnormality.

Sixty inflected words (e.g., NIÑO, "boy") and 60 derived words (e.g., BARCA, "small boat") were selected as targets, all of them being from 4 to 6 letters long (mean: 5). For the inflected targets, two kinds of words were selected as primes: inflected-related words (e.g., NIÑA, "girl") and unrelated words (from an orthographic, phonological and semantic point of view) (e.g., JEFE "boss"). Similarly, for the derived words, the primes were a derived-related word (e.g., BARCO, "ship") or an unrelated word (e.g., LÍDER "leader"). The 60 inflected target words were gender inflected words: words that can have variable gender in Spanish (i.e., masculine, finishing with an "o", or feminine, ending with an "a") and they were matched in the relatedness condition with a word sharing the root and having the alternative gender suffix (e.g., GATA-GATO). The 60 derived words also had a gender marking but these words do not allow variable gender, and their related primes shared the same root but had the other gender suffix (e.g., BARCO-BARCA). In all the relatedness condition, primes and targets were of the same grammatical class (i.e., nouns), they had the same length both in letters and number of syllables and shared all but the last letter that was always "o" and "a". In the non-related condition, the primes were of the same length as the target and they did not share any letters in the same position. Primes and targets were equated in frequency and number of orthographic neighbors as much as possible according to the LEXESP database [18]. In the case of the inflected words: targets had a mean frequency of 19 per million and a mean number of neighbors of 7.8; for related primes, the mean values were 15 and 7.3, and for non-related primes, 18 and 8, respectively. For derived words: for targets, the mean frequency was 19 and the mean number of neighbors 6.4; for related primes, 19 and 6.8 and non-related primes 24 and 5, respectively. In addition, the relation in frequency between primes and targets was equivalent across conditions. Approximately half of the related and the unrelated primes were of a higher frequency than the corresponding targets: for the inflected targets, 31 related and 30 unrelated, and for derived words, 35 and 36, respectively.

Each participant viewed 30 word pairs in each of the two experimental conditions; thus, all participants completed all conditions but viewed each target only once. An additional 120 word–pseudoword pairs were selected. Each prime word finished in "a" or "o" (as in the experimental pairs) and its target pseudoword shared all the letters but the last one with the prime word, that always was an "a" or an "o" (e.g., MESA, "table" – MESO). The order of presentation of the stimulus pairs was randomized for each participant. The stimuli are available at http://webpages.ull.es/users/calvarez.

Each trial consisted of the following sequence: a fixation point displayed for 200 ms; a 500 ms blank screen; the prime word presented for 200 ms; a new 100 ms blank screen and finally a target that remained on the screen until the participant responded. After 1 s, the word "parpadeo" [*blink*] appeared for 700 ms to allow the participant to blink between trials, and then a new trial started. All prime words were presented in lowercase and all targets in uppercase letters. Participants were instructed to attend to the two words and respond only to the second. They had to indicate, as quickly as possible, whether the target was a word or a nonword by pressing, respectively, the "p" key with the right hand index finger, or the "q" key with the left hand index finger, labeled with "SI"("yes") and "NO", respectively.

Sixty-four Ag/AgCl electrodes were employed, 58 of them incorporated in an elastic-cap fitted to the size of participants' heads following the 10/20 system. Two spoon electrodes (10 mm of diameter) were placed on the inferior canthus of the left eye and on the left area of the canthus of the right eye. Both electrodes were applied to measure the electrical voltage produced by ocular movements and blinking. Two other electrodes were placed on the mastoid bones (behind both ears) as an average off-line monopolar reference. The inter-electrodes impedance was kept below the 5 kΩ. The brain electrical biosignals registered at the scalp were digitized with a sampling rate of 200 Hz, processed by a Neuronic amplifier and filtered into a frequency band of 0.05–30 Hz. Averaging was carried out on a line-base of 100 ms previous to the presentation of the target, just at the inter-stimulus interval.

Reaction times (RTs) more than 2.5 standard deviations above or below the mean for each participant and for each condition were excluded from the analyses as well as incorrect responses. In total, 20% of the data was removed. In addition, two participants were removed from the analyses because of excessive number of incorrect responses and motor artefacts (blinks).

The mean RTs for inflected words were submitted to separate analyses of variance (ANOVAs), both by-participants and by-items, with type of priming (related vs. non-related) and counterbalance group as factors. A facilitation effect was obtained for inflection-related pairs (675 ms) in comparison with the inflected target words preceded by non-related primes (792 ms), $F_1(1, 16) = 22.35$, $p < .001$; $F_2(1, 59) = 108.56$, $p < .001$. Neither the counterbalance group factor nor the interaction was significant. In the case of derived words, we proceeded similarly and a facilitation effect was observed for the derivation-related pairs (730 ms) in comparison with their control condition (832 ms) $F_1(1, 16) = 17.85$, $p < .001$; $F_2(1, 59) = 48.38$, $p < .001$. No other effect was significant. In the error rate analyses no effect yielded significance.

First, statistical analyses were conducted for mean amplitude of the waves in microvolt recorded in a broad window (261–502 ms). The selection of this concrete window was based on a non-parametric statistical method of permutations that allows empirical estimations of interesting ERPs segments in terms of significant differences among conditions [2].

Then, and more importantly, 50-ms time epochs were analyzed (all the analyses were carried out on the mean amplitude in each window), starting from 100 ms and finishing at 600 ms, in order to capture possible small differences in the temporal locus between the two kinds of morphological relations. Repeated measures ANOVAs were performed separately for inflected and for derived targets, including the factor priming condition (related vs. unrelated) and cranial region with three different levels: left (FP1, F3, C3, P3, F7, T7, P7, AF3, P5, FC5, C5, TP7, PO5, PO3, CP3, F5, FC3, CP5), middle (FZ, CZ, PZ, F1, F2, P1, P2, FPZ, FCZ, CPZ, POZ, OZ, CP1, CP2, C1, C2, FC1, FC2) and right (FP2, F4, C4, P4, F8, T8, P8, AF4, P6, FC6, C6, TP8, PO6, PO4, CP4, F6, FC4, CP6). In order to test the possible interactions between Priming × Region effects the Geisser-Greenhouse correction was used. In the case of the 50 ms epochs,

Table 1
Significantly activated regions for each category of stimuli and Talairach *X*, *Y* and *Z* coordinates.

	Region	Coordinates			BA
		X	*Y*	*Z*	
Inflected words	Right lingual gyms	7	−91	1	17
	Rigth cuneus	7	−89	4	17
	Right occipital cuneus	6	−77	10	23
Unrelated inflected words	Left cingulate gyms	−3	−11	38	24
	Left medial frontal gyms	−3	−11	52	6
Derived words	Right anterior cingulate	8	42	5	32
	Left medial, frontal gyms	7	47	−17	
Unrelated derived words	Right cingulate gyms	7	−47	32	31
	Right parietal precuneus	7	−51	33	31
	Right parietal precuneus	7	−54	38	7

the Benjamin–Hochberg procedure was employed in the analyses to control for the false discovery fate due to multiple tests. Due to the number of statistical values, we will only report those effects that yielded significance.

In the case of inflected words, the interaction Priming × Region yielded significance, $F(1, 18) = 5.92$, $p = .026$. Post hoc analyses showed that words preceded by inflection-related primes produce more positivity than the same words preceded by unrelated words, both in the midline region, $F(1, 18) = 9.72$, $p = .006$, and in the right region, $F(1, 18) = 8.34$, $p = .010$. Similarly, the same interaction was significant for derived words, $F(1, 18) = 6.15$, $p < .005$, showing the same effects in the midline region, $F(1, 18) = 6.25$, $p = .022$ and in the right region, $F(1, 18) = 6.56$, $p = .020$.

For inflected words, the interaction Priming × Region reached significance, $F(1, 18) = 15.02$, $p = .003$. Post hoc analyses revealed that inflection-related words produced more positivity than the non-related control condition, both in the midline region, $F(1, 18) = 5.99$, $p = .025$, and in the right region, $F(1, 18) = 5.74$, $p = .028$. For derived words the interaction with the region was also significant, $F(1, 18) = 6.19$, $p = .02$, showing that there was a difference in positivity in related primes comparing with unrelated primes only in the right region, $F(1, 18) = 4.54$, $p = .047$.

For inflected words, reliable interactions Priming × Region were found in the two windows, $F(1, 18) = 9.15$, $p = .007$ and $F(1, 18) = 5.34$, $p = .024$, respectively. The difference between related and unrelated pairs was restricted to two regions: midline, for both the 350–400 window, $F(1, 18) = 13.23$, $p = .006$, and for the 400–450 window, $F(1, 18) = 9.26$, $p = .01$; and right, $F(1, 18) = 9.82$, $p = .02$ (in the 350–400 window) and $F(1, 18) = 8.07$, $p = .02$ (in the 400–450 window).

For derived words, the interaction Priming × Region was reliable: $F(1, 18) = 7.85$, $p = .025$ (350–400 ms window) and $F(1, 18) = 7.64$, $p = .02$ (400–450 ms window). The differences between the two priming condition occurred in the midline region, $F(1, 18) = 8.12$, $p = .011$, for the first window, and $F(1, 18) = 12.14$, $p = .006$ for the 400–450 window, as well as in the right region, $F(1, 18) = 9.82$, $p = .009$ in the 350–400 window and $F(1, 18) = 10.89$, $p = .009$ in the 400–450 ms region.

In the 450–500 window, inflection-related words produced more positivity that the non-related control condition, $F(1, 18) = 6.42$, $p = .021$. No effect was significant for derived words. In the case of the 500–550 ms and 550–600 ms windows, no main effect or interaction reached significance for either type of words.

The analyses were based on the coordinates proposed by Talairach, using the VARETA (Variable Resolution Electromagnetic Tomography) localization model. See [3,19] for methodological details and Table 1. The statistical significance of both types of relationship (inflection and derivation) recommends searching for sources at the 350–500 ms window. Fig. 1 shows the main activated areas for each of the experimental conditions, based on the *t*-test contrasts between early inflectional priming and the base line and derivational priming and the base line, using the Worsley correction [23]. These contrasts showed different localizations for inflected words and for derived words. However, the two unrelated conditions present a similar activation at the frontal areas, specifically in cingulate gyrus; inflected words presented a particular area of activation at the right cuneus and lingual gyrus. Usually this area is associated with visual processing of words. Activation in frontal areas has not been usually reported for this type of words. However derived words produced activation at right medial frontal gyrus and right anterior cingulate.

As expected and as previously observed when RTs are taken into account, both morphologically related primes (derived and inflected) produced a facilitation effect for the targets in comparison with the non-related conditions. In addition, the results for both kinds of morphology showed a clear modification of the N400, starting approximately at 300 ms, according to our 50 ms window analyses. This positivity for the related conditions is maintained later clearly for both morphological conditions, supporting previous findings [6,10]. However, the positivity is still significant at 500 ms only for inflections but not for derivations, where it seems to disappear at approximately 450 ms. To sum up, and looking the whole pattern of amplitude data, it appears that the impact of the attenuation in N400 lasts longer also for inflections. The longer duration of the attenuation in N400 for inflections is likely to be produced by the obvious differences with derivations. Whereas inflectional suffixes mark features like gender or number (different forms of the same word or lexical entry), derivational morphology is related to the "creation" of different but related words from a base word [11]. Thus, from a semantic point of view, our derivational pairs were much less related than the inflectional ones.

Regarding the source analyses, differences in location were also found for the two types of morphological relations, providing additional support for the existence of relevant differences between the processing of these, as indicated by the amplitude data. Whereas inflections seem to be located in areas commonly related to visual word recognition (right cuneus and lingual gyrus), activation for derivations was found at the left medial frontal areas as well as at the anterior cingulate cortex.

These findings are in contrast to previous studies where, on the one hand, no difference was obtained between morphologically simple and complex words [5], and on the other hand, the same frontal areas were found to be activated by either of the two types of morphology [21]. The activation for derivation, in general, has been reported at left inferior frontal cortex [4] as well as parietal areas [11] or as including a large bilaterally organized neural network [12]. This activation in left inferior frontal areas is consistent with our findings in the case of derivations. Activation effects in inflections have been mainly reported in the left frontal/basal ganglia circuits [21] and in left temporal or inferior parietal regions [11] (see [22] for a review).

However, there are important differences between both the stimuli and the task used in previous experiments and in the current experiment. In Ref. [11] a generation task was used: words had to be produced silently from a morphologically related word that was presented auditorily. The derivational morphology condition involved changes of grammatical class (as in many other previous experiments), whereas inflections (in one condition) only varied in gender, maintaining the same grammatical class (nouns). In the case of derivational morphology, nouns had to be generated from derivationally related verbs or adjectives. Thus, the task required a change of grammatical category, and the form (orthographic) overlap of both kinds of words (the presented word and the generated word) was much smaller than in our stimuli (where all letters but one were shared by primes and targets). In the current experi-

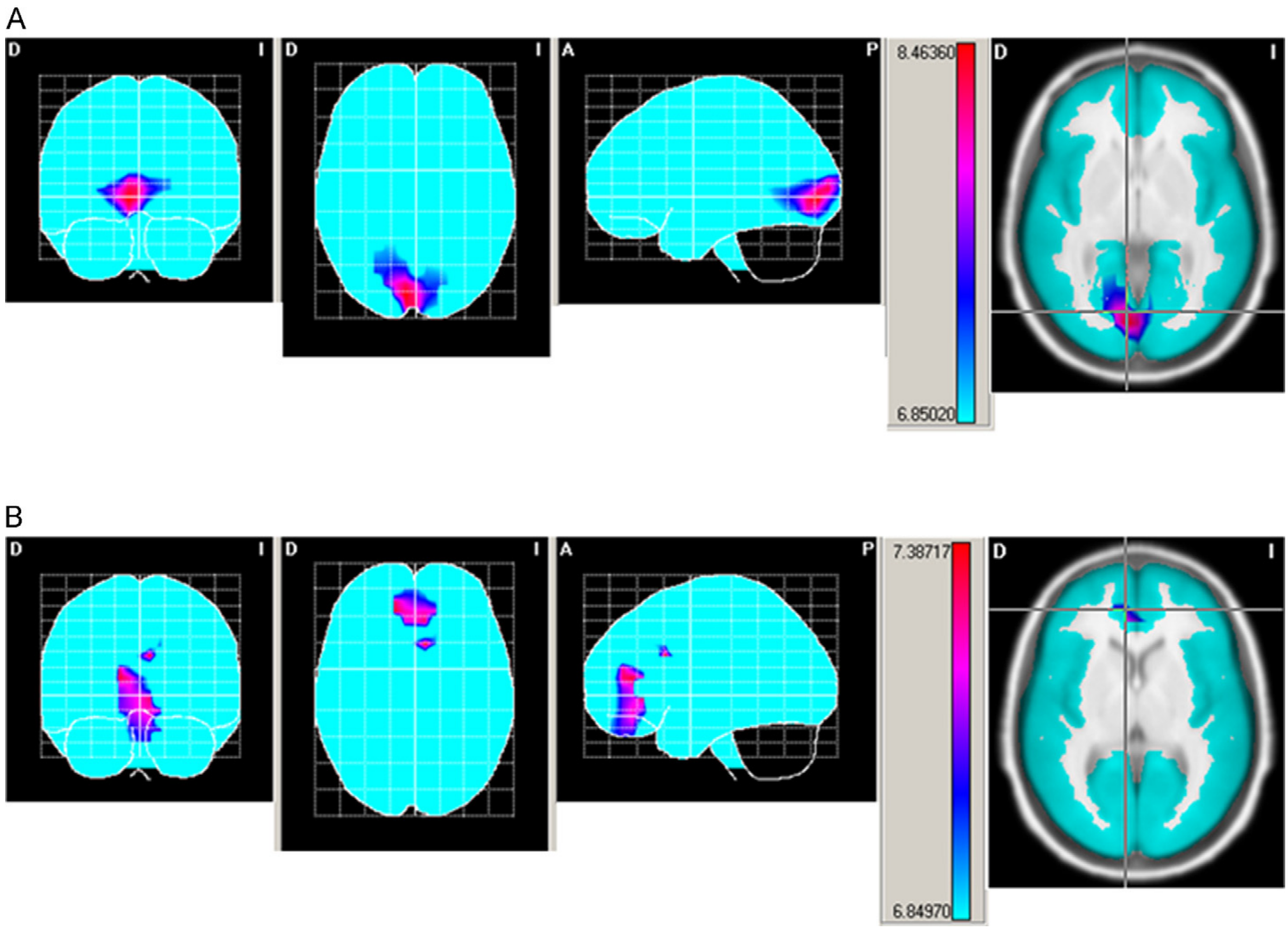

Fig. 1. Location of activated sources for (A) inflected pairs of words (gato-GATA; *male cat-female cat*), and (B) derived pairs of words (reino-REINA; *kingdom-queen*) according to the VARETA method. Red areas correspond to regions reaching a significant level of activation ($p < .05$ Worsley corrected) at the 350–500 ms window. The images on the left represent the three different planes of the image (*X*; *Y*; *Z*) and the image on the right represents the axial angle at which the maximum activation was observed, *Z*: 5. Scales represents *Z* scores between 6.8 and 8.4. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

ment, we used a very different task: a reading (lexical decision) task using primes and targets differing in the last letter, that was always an *a* or an *o*. Therefore, the activation in the lingual gyrus, the cuneus and the occipital areas for inflectionally related pairs in our experiment was likely produced by the phonological and lexical mechanisms implicated in visual word recognition [1], since the visual/orthographic overlap was much greater than in previous research and we used a strictly visual task. It should be borne in mind that lexical decision is based on our experiment on the identification of a target non-word differing also in one letter from the prime (vena-VENO –vein-nonword-, for example).

On the other hand [11], obtained activation at the right anterior cingulate and the ventrolateral frontal cortex for verbs derived from nouns and for adjectives derived from nouns. The anterior cingulate cortex had been related to executive control, conflict monitoring, response selection and also semantic processing [8,14]. General activation in prefrontal cortex has been associated with independent processing between form (e.g., orthography) and meaning [4]. In our study, the orthographic overlap between primes and targets was exactly the same in derivational and inflectional conditions. However, the distinction between meaning and superficial cues is much greater for our derivational pairs because primes and targets could be semantically unrelated, although there was no change of grammatical class (both derivational-related words of each pair were nouns, which was not the case in previous studies). However, in the case of our inflectional condition pairs which differed only in gender, the semantic relationship was much closer. Thus, we consider that, given the large orthographic overlap in the derived pairs as well as the null change of grammatical class, and together with the smaller semantic relationship, the activation of the cingulate cortex in our derived pairs makes sense.

The activation in the cingulate area of the unrelated conditions is consistent with the above assumptions as it was probably due to some task requirements, among which is executive control. It is noticeable that in all conditions different cingulate areas were activated: left cingulate for unrelated derivational pairs, right cingulate for unrelated inflectional pairs and right anterior cingulate for inflectional pairs. In the case of the unrelated inflectional condition, activation in left medial frontal gyrus might be associated with the identification of the word [9], whereas the right precuneus activation in unrelated derivational words could be associated with orthographic and morphological word-form processing.

In sum, the majority of the findings reported here could be related to the task-related requirements of visual discrimination. Adequate discrimination allows correct access to the word meaning. We consider that the differences in the semantic relation of the two morphological categories manipulated also explain the differences in amplitude and latencies of the ERP waves and in the localization of sources.

Acknowledgements

This research was supported by Grants SEJ2007-66860/PSIC (to Carlos J. Álvarez and Alberto Domínguez), PSI2009-12616 (to Rosa Sánchez-Casas) and SEJ2007-66916 (to Mabel Urrutia), all of them from the Spanish Ministry of Education and Science. We express our gratitude to Margaret Guillon and to three anonymous reviewers for their helpful comments.

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