Psicológica (2016), 37, 105-126.

The time-course of processing of grammatical class and semantic attributes of words: Dissociation by means of ERP

Carolina Yudes[a,*], Alberto Domínguez[b], Fernando Cuetos[c] and Manuel de Vega[b]

[a]*International University of La Rioja (Spain)*

[b]*University of La Laguna (Spain)*

[c]*University of Oviedo (Spain)*

This study explores the time-course of word processing by grammatical class (verbs vs. nouns) and meaning (action vs. non-action) by means of an ERP experiment. The morphology of Spanish words allows for a noun (e.g., *bail*-e [a dance]) or a verb (e.g., *bail*-ar [to dance]) to be formed by simply changing the suffix attached to the root. This facility results in a set of nouns and verbs that are nearly matched in meaning, because of their shared root. The results show that grammatical class of words is processed very early, around 200 ms after the word onset, with the effects remaining activated at left frontal regions until 800 ms. Later components show a focal LAN sensitive to the noun-verb distinction, and a broadly distributed N400-like waveform sensitive to meaning. The different components affected by grammar (P200 and LAN) and meaning (N400) and their topographical dissimilarity seem to indicate an independent neural processing of these two linguistic properties and support a lexical specification of grammatical class.

Words are complex linguistic units conveying morpho-syntactic and semantic information, among other things. How these facets of words are processed in the brain is an important research question, with theoretical implications for understanding the functional and brain architecture of

---

[*] **Acknowledgments**: This research was supported by the Canary Islands Agency for Research, Innovation and Information Society (Grant SolSubC200801000127 and NEUROCOG project to Manuel de Vega) and by the Spanish Ministry of Science and Innovation (Grant PSI2010-15184 to Alberto Domínguez). We would like to thank Catalina Llanos for her help in the elaboration of materials and data collection.
Corresponding author: Carolina Yudes. International University of La Rioja (UNIR). E-mail address: carolina.yudes@unir.net

language. There are two traditional responses to this question: one, the "autonomy of grammar" hypothesis, claims that the grammar and meaning of words are processed by independent mechanisms in the brain and may have different time-courses (e.g., Bedny & Caramazza, 2011), whereas the other, based on interactive models, suggests that these processes influence each other, indicating that they share brain networks and are processed in parallel (e.g., Pulvermüller, Mohr, & Schleichert, 1999). In this line of argument, Crepaldi, Berlingeri, Paulesu and Luzzatti (2011) propose that noun and verb processing should be functionally independent at certain levels but overlap at some others. Consequently, different brain areas should be also recruited (Crepaldi et al., 2013).

However, Crepaldi et al. (2011) also argue that the inconsistent picture between different theoretical approaches could be due to the variety of the tasks and methodologies used. In fact, Moseley and Pulvermüller (2014) suggest that matching the grammar and meaning of words can be an almost impossible task, since most verbs are action words whereas most nouns refer to objects. A recent review of this controversy, relating to an incorrect definition of the semantic and grammatical properties of words, can be seen in Kemmerer (2014), who suggests that much of the lack of consistency among results could be because the categories are not properly defined. Additionally, as discussed below, the methodologies employed in such studies are wide-ranging, covering everything from behavioral research and work with patients with brain lesions to neuroimaging or brain electrophysiological studies.

In addressing the subject of the time-course of processing of words, this paper will employ a very strict control of the linguistic material in order to prevent confounding of grammar and meaning, and apply the ERP technique, which provides an excellent temporal resolution that permits the dissociation of these two properties. But first, let us review some of the conclusions reported in the literature through the use of different methodologies.

A classical methodological approach for exploring whether nouns and verbs involve different neural networks is the study of patients with brain lesions. Selective impairments and double dissociation have allowed researchers to locate the processing of nouns in vision-related cortical areas, such as left temporal areas, and the processing of verbs in motor-related regions like the left prefrontal and frontal sites (e.g., Damasio & Tranel, 1993; Daniele, Giustolisis, Silveri, Colosimo, & Gainotti, 1994; Rapp & Caramazza, 2002; for reviews of the lesion data on noun/verb processing see Gainotti, Silveri, Daniel, & Giustolisi, 1995; Vigliocco, Vinson, Druks, Barber, & Cappa, 2011; for a review of action processing in damaged brain see Kemmerer, Rudrauf, Manzel, & Tranel, 2012). Unfortunately, the study of patients has not led to agreement on the relationships between brain lesions and functional problems (see Druks, 2002, for a review) and therefore, it has not been possible to establish a definitive model of verb and noun processing.

Neuroimaging studies have also provided some valuable evidence on the subject (e.g., Burton, Krebs-Noble, & Gullapalli, 2009; Tyler, Bright, Fletcher, & Stamatakis, 2004). Thus, some studies suggest that the semantic information of action words seems to be represented at the premotor and the primary motor cortex (e.g., Hauk & Pulvermüller, 2004) irrespective of their grammatical category. For instance, Oliveri et al. (2004) did not find any differences between motor verbs (e.g., to climb) and object nouns directly related to actions (e.g., the cup). On the other hand, Bedny, Caramazza, Grossman, Pascual-Leone, and Saxe (2008), using the fMRI method, proposed a multiple activation of the sensory-motor networks responsible for extracting word meaning. They noted that separate brain regions were activated in the left temporal, parietal and prefrontal cortices for conceptual and grammatical categories. Grammatical and semantic processes should consequently be interacting throughout the complex operations of eliciting a rich representation of meaning. In a previous study, Shapiro, Pascual-Leone, Mottaghy, Gangitano, and Caramazza (2001) used repetitive transcranial magnetic stimulation (rTMS) to inhibit the left prefrontal cortex, while participants were asked to produce singular or plural forms of verbs or nouns. They observed that latencies of production increased for verbs (or pseudo-verbs) but not for nouns (or pseudo-nouns). Consequently, contrary to Pulvermüller et al. (1999), Shapiro et al. (2001) claim that different neuroanatomical bases should support different grammatical categories regardless of the word meaning (see also Shapiro & Caramazza, 2003).

Finally, electrophysiological studies in this field have widely explored the cortical signatures associated with noun/verb grammatical classes (Federmeier, Segal, Lombrozo, & Kutas, 2000; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995; Pulvermüller, Harle, & Hummel, 2000, 2001; Rugg, 1984), as well as the influence of properties such as concreteness or imageability during semantic processing of both type of words (e.g., Kellenbach, Wijers, Hovius, Mulder, & Mulder, 2002; Kounios & Holcomb, 1994; Tsai, Yu, Lee, Tzeng, Hung, & Wu, 2009). In a pioneer study, Pulvermüller et al. (1999) manipulated the grammatical class of words in a lexical decision task, maintaining similar action meanings in verbs and nouns and introducing also a category of visual nouns. They found larger positivity for verbs than for visual-related nouns at frontal regions, peaking around 500 ms after the word onset, and no differences with action-related nouns. These results supported two main conclusions: the absence of systematic grammatical differences (nouns and verbs) in the brain responses, and the presence of a semantic effect consisting of the activation of motor cortical regions during processing of action verbs. However, this motor activation account of verb processing has been ruled out in subsequent studies. For example, Kellenbach et al. (2002) reported similar ERP patterns for visual and motor words, but different patterns for abstract words, which suggest that motor attributes did not influence the processing, and that the processing of grammatical class is also necessary. Similar conclusions were obtained when nouns and verbs were studied in a syntactic context such as minimal phrases (e.g., Lee & Federmeier, 2006).

From all these studies, it seems difficult to reach agreement about the interface mechanisms operating between grammar and meaning. There are at least two confounding factors complicating the interpretation of the experimental results: one is the overlap between grammatical categories and meaning (see Vigliocco et al., 2011) and the other is the confounding between morphological complexity and grammatical category (Tyler et al., 2004).

As suggested previously, verbs frequently have a *predicative* function and refer to functional features such as actions or body movements, whereas nouns have a *referential* function and generally refer to perceptual objects rather than motor functions; they are also thought to be more imaginable than verbs (Bird, Lambon-Ralph, Patterson, & Hodges, 2000; Kemmerer & Eggleston, 2010; Moseley & Pulvermüller, 2014). However, there are other possibilities that fall between these two extremes. For instance, there are nouns denoting concrete actions (e.g., '*patinaje*' [skating]), as well as verbs referring to emotional estates (e.g., '*deprimirse*' [to become depressed]), cognition (e.g., '*razonar*' [to reason]), perception (e.g., '*oler'* [to smell]), or some other abstract content not related to actions. To disentangle this possible confusion between semantics and grammatical class effects, Barber, Kousta, Otten, and Vigliocco (2010) performed an ERP study with Italian nouns and verbs differing in their meaning: motor verbs (e.g., '*scuote*' [s/he shakes]), motor nouns (e.g., '*giravolta*' [twirl]), sensory verbs (e.g., '*degustano*' [they taste]) and sensory nouns (e.g., '*ronzii*' [buzzes]). The authors expected to find ERP differences around N400 and in earlier components around 200 ms, as reported in previous studies (Kellenbach et al., 2002; Pulvermüller et al., 1999; Vigliocco et al., 2011). The results revealed significant ERP effects in the 300 to 450 ms time range for both grammatical category and meaning, with nouns and sensory words being more negative at posterior sites. Also, they obtained more negative amplitudes at the 450-1000 ms time window for verbs and motor words at frontal sites. The first component was considered a modulation of the N400 component, which would indicate the activation of semantic networks necessary to recover a word. The second effect was thought to be associated with working-memory operations required by the task (lexical decision). However, unlike in previous studies (Preissl et al., 1995; Pulvermüller et al., 1999) and in spite of the careful selection of the materials, grammatical effects were not found before 300 ms. This lack of early effects and the absence of differences in latency or topographic distribution for grammatical category and meaning compelled the authors to consider the results as evidence that word class is a second-order principle of lexical organization emerging from the pressure of semantic and pragmatic content of words (Vigliocco et al., 2011).

The second potential source of confounding is the morphological complexity of words. A near-universal linguistic principle establishes that nouns and verbs may be identified only by the suffixes added to their stems. Nouns add to their stems suffixes of gender, number, case, definiteness and possession, while verbs add tense, aspect, mood, modality and transitivity. Studies employing magnetic resonance imaging (Tyler et al., 2004; Longe, Randall, Stamatakis, & Tyler, 2007) have demonstrated that stems of nouns (e.g., snail) and verbs (e.g., hear) do not differ in their cerebral localization, but inflected forms of the same verbs (i.e., hears) yield more activation in the left frontotemporal areas than inflected nouns (i.e., snails). Nouns and verbs, therefore, could be linguistic categories that are indistinguishable by our brain when presented in isolation. Inflexions have a function when the word is included in a sentence, to establish agreement, but stems presented in isolation do not need to be identified for grammatical category. Given that grammatical category is the focus of our research, special care should be taken when selecting materials. We took advantage of the morphological structure of the Spanish language, which allows for an excellent manipulation and control of this critical variable. Thus, selecting different suffixes for a given root changes the word's grammatical category while maintaining other semantic features constant. For example, given the root /*patin-*/, we can add the suffix /*-ar*/ to obtain the infinitive form of the verb '*patinar*' (to skate), whereas choosing the suffix /*-aje*/ gives us the noun '*patinaje*' (the action of skating). This simple procedure reduces the semantic differences between nouns and verbs, allowing us to manipulate meaning and grammar orthogonally. Thus, in this study, two words of different grammatical class (a noun and a verb) could refer to the same action (*patinar*/*patinaje*) or to the same non-action concept (*dimitir/dimisión* [to resign/resignation]). In this way, we minimize grammatical class ambiguities in the stimuli, which frequently remain uncontrolled in single word recognition studies (see Vigliocco et al., 2011). In addition, Spanish plural nouns may be ambiguous because they adopt the same orthographic form as some conjugated verb forms. For instance, '*estrellas'* can be a plural noun, [*some stars*], but also a verb in the second person singular ['*you smash';* like in *'you smashed a glass against the wall'*]. To reduce these ambiguities, verbs and nouns in our experiment were presented only in infinitive and singular forms, respectively. This control will produce a more confident interpretation of the differences of grammatical class and meaning processing and representation.

In conclusion, the purpose of this study was to explore in detail whether word grammar and word meaning are independent mechanisms in the brain or whether they share neural networks. As in previous studies, the current experiment used ERPs to explore the time-course and the neural networks involved in the visual processing of nouns and verbs referring to either actions or non-action events. We tried to avoid, however, some of the methodological confusions of other experiments reported in the literature that sometimes make their results conflicting and difficult to interpret. In this way, we expected to provide more robust effects, allowing for stronger theoretical conclusions on whether grammar and meaning are processed independently or, on the contrary, they interact during word processing.

METHOD

Participants. Twenty-two undergraduate students (18 women) of the University of La Laguna (Spain) participated in the experiment for cash and/or credit. They had a mean age of 21.71 years (SD = 4.63, range from 18 to 30). All participants were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971; mean score = 0.72 on 1, SD = 0.39) and native Spanish speakers according to self-report. Prior to the experiment, participants signed a consent form in which they were informed in detail about the EEG procedure and the confidentiality of their personal data.

Materials and procedure. A set of 120 words was selected from Alameda and Cuetos' frequency dictionary (Alameda & Cuetos, 1995). Words were selected from two grammatical categories (nouns and verbs) and according to two different meanings (action and non-action words). Action words referred to events involving specific motor programs with different body parts (e.g., *patinar* [to skate]; *patinaje* [skating]; *brindar* [to toast]; *brindis* [a toast]), whereas non-action words referred mainly to sensorial events, excluding physical manipulations or body motions (e.g., *suspender* [to fail]; *suspenso* [a failing grade]; *alquilar* [to rent]; *alquiler* [a rent]). Therefore, there were four experimental conditions, with 30 words each: action verbs, action nouns, non-action verbs and non-action nouns. As explained previously, lexical factors were carefully controlled and manipulated, with pairs of nouns and verbs sharing the same root selected to increase the semantic similarity across grammatical class. Consequently, only the inflection of the word would determine the grammatical class (e.g., with the root /*empuj*/ we created the verb *'empujar'* [to push] and the noun *'empujón'* [a shove]). Nouns and verbs did not differ statistically in lexical frequency (Verbs mean = 17.39; *SD* = 24.86; Nouns mean = 19.14; *SD* = 25.05; $t(113) = -.372$; $p = 0.69$) or length in number of letters (Verbs mean = 7.15; *SD* = 1.19; Nouns mean = 7.43; *SD* = 1.83; $t(118) = -1.003$; $p = 0.31$), according to the Spanish frequency dictionary (Alameda & Cuetos, 1995). Likewise, no statistical differences were obtained when lexical frequency of action words (nouns and verbs) was compared to that of non-action words ($t(113) = 0.35$; $p = .72$). More detailed information on these values is shown in Tables 1 and 2.

Table 1. Use frequency and number of letters of the words used in the different conditions (standard deviations in parentheses).

	Action verbs	*Non-action verbs*	*Action nouns*	*Non-action nouns*
Lexical frequency	18.17 (26.89)	16.66 (23.16)	20.15 (32.29)	18.26 (16.83)
No. letters	7.00 (1.31)	7.29 (1.05)	7.09 (1.42)	7.76 (2.14)
Imageability	5.66 (0.53)	3.53 (0.82)	5.47 (0.54)	3.35 (0.76)
Concreteness	5.05 (0.54)	4.03 (0.86)	4.81 (0.67)	4.01 (0.67)

Nevertheless, statistical differences were found when comparing action words with non-action words in imageability and concreteness factors (see results in Table 2), where action words were found to have higher values. Curiously, no differences between action verbs and action nouns, or between non-action words, were found according to these dimensions (see Table 2). Values for concreteness and imageability dimensions were extracted from the *EsPal* database (Duchon, Perea, Sebastián-Galles, Martí, & Carreiras, 2013; http://www.bcbl.eu/databases/espal/index.php). We consider it relevant to indicate that a value was not available for each word: there were values of concreteness for 53.33% of the words (64 of 120) and values of imageability for 50.83% of the words (61 of 120).

Table 2. Results of the comparisons between different properties of words.

	Lexical frequency	*No. letters*	*Imageability*	*Concreteness*
Action vs. non-action verbs	$t(57) = 0.23$; $p = .81$	$t(58) = -0.97$; $p = .33$	$t(23) = 7.6$; $p < .001$	$t(31) = 8.34$; $p < .001$
Action vs. non-action nouns	$t(54) = 0.27$; $p = .78$	$t(58) = -1.41$; $p = .16$	$t(27) = 3.61$; $p < .001$	$t(30) = 4.01$; $p < .001$
Action nouns vs. action verbs	$t(53) = 0.24$; $p = .81$	$t(58) = 0.28$; $p = .77$	$t(23) = 0.83$; $p = .41$	$t(24) = -0.93$; $p = .35$
Non-action nouns vs. non-action verbs	$t(58) = 0.29$; $p = .76$	$t(58) = 1.06$; $p = .28$	$t(31) = 0.63$; $p = .63$	$t(33) = -0.09$; $p = .92$

The items were presented randomly to each participant to avoid morphological priming effects (Meyer & Schvaneveldt, 1971) associated with the orthographic similarity between nouns and verbs. In this way, some participants received '*empujón*' (noun) before '*empujar*' (verb), whereas for others this order was reversed.

The sequence of trials was controlled by E-prime 1.1 Experimental software (Schneider, Eschman, & Zuccolotto, 2002). Stimuli were displayed one at a time in lower-case black letters on a grey background in the center of the screen. Each trial began with a fixation point (+) for 1000 ms. After this fixation point, a blank screen was presented for 200 ms, then the word was displayed for 900 ms and a new blank screen was shown for 1000 ms. Five practice trials were presented prior to the 120 experimental trials. In addition, there were 24 probe trials, including nouns and verbs, in which a question was formulated after presenting the word. The general trial procedure only required participants to make a silent reading, but in the probe trials they also were prompted to indicate whether the word referred to an activity typical of people (e.g., *fumar* [to smoke]) or animals (e.g., *relinchar* [to neigh]). These 24 probe trials (not included in the analyses) appeared randomly to ensure participants' attention and prevent them from superficially processing the words throughout the task. The percentage of errors on these probe trials reached 5.78%. 99% of such errors were produced in those trials referring to the category of 'animals' (e.g., *embestida* [charge] or *incubar* [to incubate]), possibly due to their metaphoric use for persons in Spanish. Therefore, we could say that the intended purpose of this simple task was achieved, since participants maintained their attention and carried out a semantic processing of the stimuli during the task.

EEG recording parameters and analysis. Electroencephalographic activity (EEG) was recorded from 64 tin electrodes mounted on an elastic cap according to the international 10-20 system. The regions included midline and left/right hemisphere sites (anterior, central and posterior). Electrodes were placed on the left and right mastoids for a re-referencing offline of the data with Neuroscan Synamps[2] (Intelimed Ibérica, Madrid, Spain). The vertical and horizontal eye movements and blinks (EOG) were also recorded from a bipolar pair of electrodes placed above and below the left eye and on the external canthus of the right eye. EEG was digitized continuously at a sampling rate of 250 Hz and amplified with a band-pass filter of 0.15-40 Hz. Electrode impedances were kept below 5 KΩ by Electrogel conductant. For each stimulus word, EEG epochs were created starting at 100 ms prior to the word onset and ending at 800 ms after onset. Regression analyses and artifact averaging (spatial SVD transform) were performed to correct offline any trials with eye movements or other artifacts (Scan, 4.5). After this correction, a visual inspection was once again carried out. As a result of these visual checks, a total of 3.4% of trials were excluded. Artifact-free epochs were averaged for each participant for each experimental condition (action verbs, action nouns, non-action verbs and non-action nouns).

Based on theoretical considerations (Barber et al., 2010; Luck, 2005) and on the visual inspection of the grand average waveforms, statistical analyses among experimental conditions were computed within three latency windows: 170-300, 350-550 and 550-800 msec. In keeping with Luck (2005), although these amplitudes are not symmetrical, they do have the right size to capture main components while mitigating the effects of overlapping. Each set of window data was analyzed using general linear models (ANOVAs) on the mean amplitude of each time range. Greenhouse-Geisser (GG) corrections to *p*-values were performed if sphericity was violated (Greenhouse & Geisser, 1954). We carried out several analyses, including *Regions of interest (ROIs)* and *Hemisphere*, to assess the distribution of the effects across the scalp. There were 7 *ROIs* with 6 electrodes each: Left Anterior (AF3, F1, F3, F5, FC1, FC3), Right Anterior (AF4, F2, F4, F6, FC2, FC4), Left Central (C1, C3, C5, CP1, CP3, CP5), Right Central (C2, C4, C6, CP2, CP4, CP6), Left Posterior (O1, P3, P5, P7, PO3, PO7), Right Posterior (O2, P4, P6, P8, PO4, PO8) and Midline (Fz, FCz, Cz, CPz, Pz, POz). The left hemisphere (AF3, F1, F3, F5, Fc1, Fc3, C1, C3, C5, CP1, CP3, CP5, O1, P3, P5, P7, PO3, PO7) and the right hemisphere (AF4, F2, F4, F6, FC2, FC4, C2, C4, C6, CP2, CP4, CP6, O2, P4, P6, P8, PO4, PO8) were also contrasted in the analyses, although the results will be not reported because of their lack of statistical main effect or interactions with the other variables.

In sum, the analyses described below include 2 *Grammatical Class* (Nouns vs. Verbs) x 2 *Semantic Attribute* (Action vs. Non-action words) x 7 *ROI* (Left Anterior: LA; Right Anterior: RA; Left Central: LC; Right Central: RC; Left Posterior: LP; Right Posterior: RP and Midline: Mi).

RESULTS

Figure 1 shows the ERP grand averages for all the experimental conditions at Fz electrode. Figure 2 displays the specific grand averages for *Grammatical Class* (a) and *Semantic Attribute* (b).

From the visual inspection of these figures, two main peaks can be identified: a positive wave peaking around 200 ms in almost all regions immediately followed by a negative potential that peaked near 450 ms and remained for the rest of the epoch mainly at anterior and central regions. In the first peak, nouns elicited more positive amplitudes than verbs, regardless of the meaning (see Figures 1 and 2a). For the second peak, action words generated greater negativity as compared to non-action words (see Figures 1 and 2b).

170-300 ms time window

The general ANOVA of repeated measures performed on this early time window did not reveal any significant main effects of *Grammatical Class* or *Semantic Attribute*. However, a significant interaction *Grammatical Class x ROI* was found, $F(6, 126) = 4.01$, $p < .05$, GG: $p = .01$, $\eta^2_p = 0.16$. As can be seen in Figures 1 and 2a, the larger positive amplitudes for nouns, as compared to verbs, was located at left anterior (mean amplitude: 2.57 μV vs. 1.51 μV) and left central areas (mean amplitude: 3.06 μV vs. 2.21 μV).

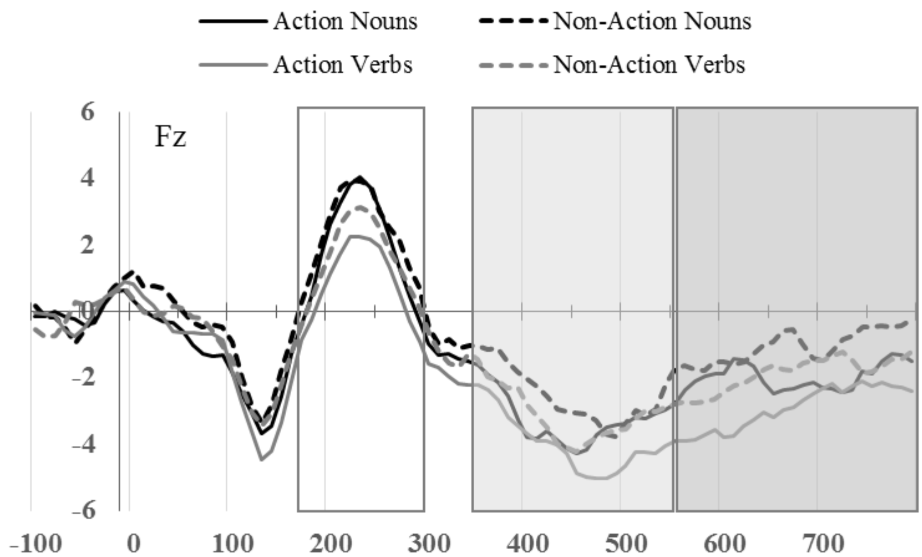

Figure 1. Grand average ERPs elicited by *Grammatical Class* (nouns and verbs) and *Semantic Attribute* (action word and non-action words) at the Fz. Time (ms) is represented on x-axis and amplitude (μV) on the y-axis. Different-colored windows represent each time interval analyzed.

In summary, in the 170-300 ms time window, nouns elicited larger positive amplitude values than verbs. By contrast, semantic effects were not found.

350-550 ms time window

Statistical analyses in this time window revealed no main effect of *Grammatical Class* ($F < 1$). By contrast, the main effect of *Semantic Attribute* was significant, $F(1, 21) = 7.55$, $p < .05$, $\eta^2_p = 0.26$, as well as the *Grammatical Class* x *ROI* interaction, $F(6, 126) = 8.02$, $p < .05$, $\eta^2_p = 0.27$. Post hoc comparisons (see Table 3) revealed that verbs elicited larger negativity than nouns in the left anterior and left central electrodes. On the other hand, action words were significantly more negative than non-action words at 5 out of 7 regions: left and right anterior, left and right central, and midline regions (at right anterior region *p*-value was 0.05). At the posterior region, the amplitude values of both types of words were more positive, although action words continued to elicit less positive amplitudes than non-action words. Consequently, the *Semantic Attribute* variable produced a less localized effect, obtaining significant differences in all regions (except at right anterior).

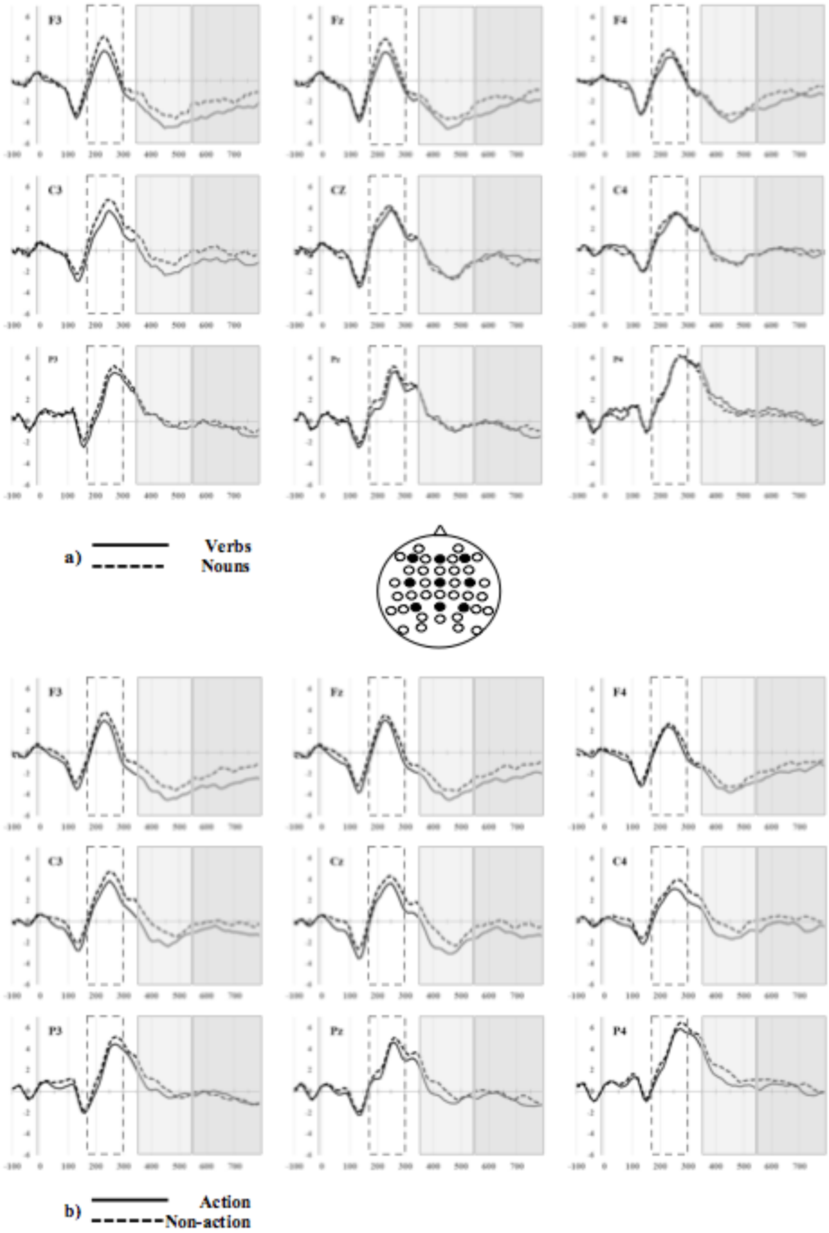

Figure 2. Specific Grand Average ERPs for *Grammatical Class* (a) and *Semantic Attribute* (b) at six representative electrodes. Waveforms for *Grammatical Class* (a) refer to voltage values collapsed across semantic attributes (action and non-action words). Waveforms for *Semantic Attribute* (b) refer to voltage values collapsed across grammatical class (verbs and nouns). Time (ms) is represented on *x-axis* and amplitude (µV) on the *y-axis*. Electrodes selected for each region of interest are shown on the map. Different-colored windows represent each time interval analyzed.

Table 3. Post hoc comparisons Grammatical Class-Semantic Attribute-ROI (350-550 ms time window).

	Verbs versus Nouns			***Action versus Non-Action***		
ROIs	**Means**	***F***	***p***	**Means**	***F***	***p***
Left Anterior	-3.24 vs. -2.34	9.81	.005	-3.25 vs. -2.33	5.91	.02
Right Anterior	-2.68 vs. -2.35	---	---	-2.87 vs. -2.16	---	0.5
Left Central	-0.91 vs. -0.26	4.04	.04	-0.99 vs. -0.17	7.51	.01
Right Central	0.04 vs. -0.09	---	---	-0.42 vs. 0.37	5.83	.02
Left Posterior	0.64 vs. 0.69	---	---	0.45 vs. 0.88	4.73	.04
Right Posterior	2.14 vs. 1.62	---	.06	1.51 vs. 2.25	8.51	.00
Midline	-1.34 vs. -1.24	---	---	-1.75 vs. -0.82	5.31	.03

To sum up, the analyses performed on the 350-550 ms time window showed that the *grammatical* effects (larger negativity for verbs than for nouns) are confined to the left anterior and left central regions. *Semantic* effects (larger negativity for action words than for non-action words), on the other hand, were extended to central and posterior regions bilaterally and at left anterior areas.

550-800 ms time window

Statistical analyses carried out in this late time window revealed *Grammatical Class* x *ROI* and *Semantic Attribute* x *ROI* interactions [$F(6, 126) = 3.56$, $p < .05$, GG: $p = .022$, $\eta^2_p = 0.14$ and $F(6, 126) = 3.73$, $p < .05$, GG: $p = .013$, $\eta^2_p = 0.15$, respectively]. In both cases, corresponding post hoc pairwise comparisons yielded significant differences only at left anterior regions. Namely, verbs elicited more negative waves than nouns, $F(1, 21) = 4.69$, $p < .05$, and action words elicited more negative waves than non-action words, $F(1, 21) = 5.42$, $p < .05$.

A graphic representation of these results can be seen in the following topographic map (Figure 3).

DISCUSSION

The study of semantic and grammatical properties of words has led to confounding results in the past, and it is still an open question whether different lexical categories and meanings activate the same neural networks.

Past findings suggest that the materials and tasks used in studies that explore the processing of words are not always carefully controlled, thus tarnishing the results. The motivation of the present study was to explore whether grammar and meaning are processed independently or whether they interact during word recognition. In contrast to previous studies, this was done by ensuring a strict control of variables while manipulating orthogonally the grammatical category and meaning of words. For the grammatical properties, we used pairs of Spanish words (nouns and verbs) sharing the same root but differing in the suffixes (e.g., '*patinaje'* [skating: action noun] vs. *'patinar'* [to skate: action verb]) in a word recognition task. This control was essential to minimize the semantic differences between verbs and nouns proposed by some authors (Moseley & Pulvermüller, 2014). Likewise, the semantic properties of the words (action vs. non-action) were also manipulated, by using different words (e.g., '*taconear*' [to click one's heels] vs. '*deducir*' [to deduce]).

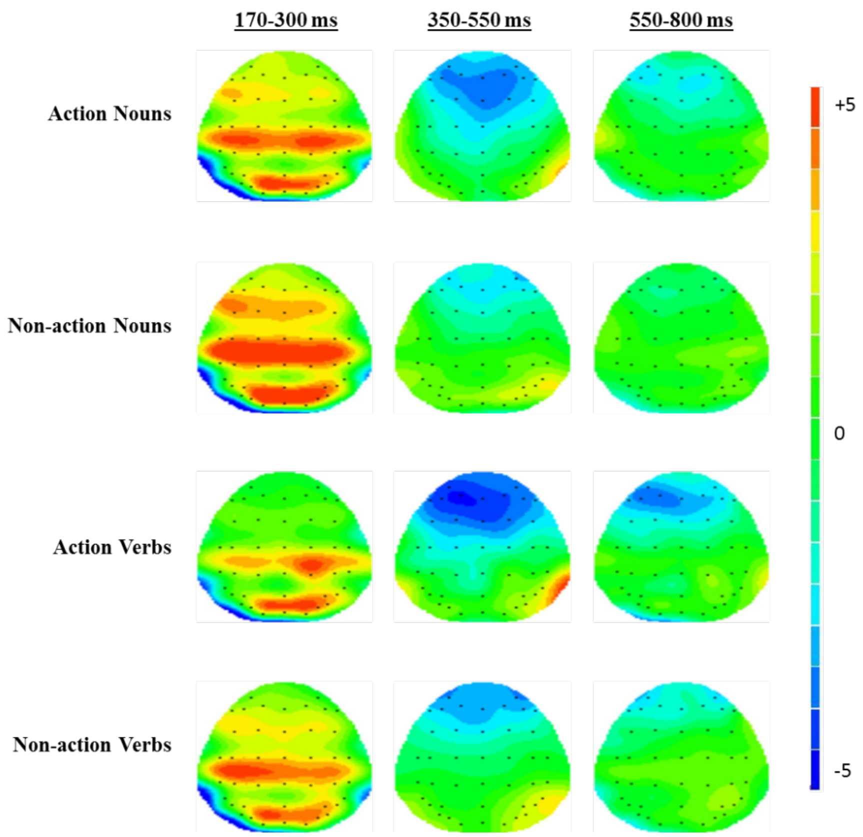

Figure 3. Topographic ERP maps for each time window analyzed in each condition.

The ERP results show several important findings. First, grammatical properties were processed at the early 170-300 ms time window, whereas semantic properties did not produce differences at this first stage. This initial processing suggests a P200 component, which will be defended later. Second, as processing progressed, in the 350-550 ms temporal window, both the grammatical and the semantic manipulations produced significant differential waves, albeit with a clear contrast in their topographical distribution. Thus, grammatical class elicited differences at the anterior regions, where verbs were more negative than nouns. This localization and polarity of grammatical class is reminiscent of a LAN (*Left Anterior Negativity*) component. On the other hand, the effects of meaning were much more extensive, with differences produced not only in the anterior regions, but also in central and posterior sites. In this case, action words generated more negative waves than non-action words. The distribution of this semantic effect resembles a classical N400. This difference of topographical distribution, as well as the different timing of meaning and grammar effects, suggests different neural assemblies are associated with the processing of these two properties of words. Finally, at the 550-800 ms window, both grammar and meaning ended up producing similar differential waves at the left frontal region, which is interpreted as a spreading of the previous effect, or to be more specific, a N700 effect. In sum, our data support the idea of an early processing of grammatical categories - which was not found in the study by Barber et al. (2010) - an intermediate independent processing of grammar and meaning at the medium stage, and a final common processing of both at the latest stage.

Previous ERP evidence suggests that grammatical category information about words begins to be available relatively quickly, from about 200 ms (Brown, Hagoort, & Keurs, 1999; Dehaene, 1995; Federmeier et al., 2000). Also, greater positive peaks at 200 ms have been found for words with shared roots (Barber, Domínguez, & de Vega, 2002), or in morphological priming tasks (Domínguez, de Vega, & Barber, 2004; Lavric, Clapp, & Rastle, 2007). Thus, the P200 component has been considered a marker of morphological suffix identification, reflecting morphological analysis at the orthographic level. Most of the aforementioned studies obtained P200 enhancement as a response to morphological violations in priming or agreement paradigms. The only difference between verbs and nouns in our experiment is found on the suffixes attached to the root. Therefore, the P200 effect obtained in our experiment indicates that readers are immediately sensitive to the grammatical category of words by detecting the specific suffixes which mark nouns and verbs (i.e. *patin*-/ar/ [to skate] vs. *patin*/-aje/ [the action of skating]). This first window analyzed shows precisely this process of suffixation for grammatical identification of the word. In other words, when the stem of the word is strictly controlled across the two levels of grammatical class, the early processing of this linguistic property continues to produce effects. Notice that this evidence of grammatical processing has been obtained in a word recognition task. This task could magnify, in any case, the semantic differences between words rather than their grammatical class, which was an incidental feature of the task. The anterior positivity, P200, is reminiscent of the effect obtained by Pulvermüller et al. (1999), Preissl et al. (1995) and Kellenbach et al. (2002) for noun and verb differences. However, it is worth noting that the possible confounding of grammar and meaning was not controlled for in those studies. But then Barber et al. (2010) solved this by distinguishing, in Italian, between motor verbs (e.g., '*scalano*' [hike]), motor nouns (e.g., '*piroetta*' [pirouette]), sensory verbs (e.g., '*annusano*' [sniff]) and sensory nouns (e.g., '*odore*' [smell]). They found that the grammatical class produced effects only at the N400 component, and did not find any topographical differences between grammar and meaning. The difference between Barber et al.'s results and those obtained in our experiment could stem from the control of the grammatical factors, whereby the same roots are used for different lexical categories. This manipulation perhaps forced the reader to be especially sensitive to the morphological composition of words and thereby of their grammatical class.

Continuing with the results of our study, it was found that after 300 ms the processing of meaning and grammar strongly diverges, as the effects of the two properties were statistically independent and showed different distributions. Grammatical effects were limited to the left anterior region, whereas a negative-going potential, peaking near 450 ms and with a broad frontal, central and posterior distribution, was observed for semantic features. Looking first at the grammatical effects, we see that the waveform focal distribution, latency and polarity correspond to the LAN effect, which is sensitive to morpho-syntactic manipulations, according to the literature (e.g., Krott, Baayen, & Hagoort, 2006; Linares, Rodríguez-Fornells, & Clahsen, 2006; Mancini, Molinaro, Rizzi, & Carreiras, 2011; Rodríguez-Fornells, Clahsen, Lleo, Zaake, & Münte, 2001; Rodríguez-Fornells, Münte, & Clahsen, 2002, Tanner & Van Hell, 2014). This effect, associated with grammatical class, differs markedly from the broadly distributed negativity characterizing the semantic effects observed in the same time window. The polarity and latency of the negativity linked to the semantic properties was similar to that of the classical N400, but with a different distribution on the scalp. Whereas the typical N400, obtained in response to semantic inconsistency at the sentence level, has a central-parietal distribution, the negativity related to the semantic effects in the present study has a more fronto-central distribution. On the one hand, this indicates that the effect could be relying on different neural assemblies than the classical N400. On the other hand, a similar frontal distribution of N400-like waves has been reported for words given out of context, such as for example concrete versus abstract words, or difficult recognition processes (Adorni & Proverbio, 2012; Barber & Kutas, 2007; Holcomb, Kounios, Anderson, & West, 1999; Kounios & Holcomb, 1994).

In our experiment, and in contrast to Barber et al. (2010), action-related words elicited larger negativity than non-action words, independently of their grammatical class, suggesting that their processing involves greater neural activity or cognitive load (Bentin, McCarthy, & Wood, 1985; Kellenbach et al., 2002; Kutas & Federmeier, 2000). We think this may be linked to the generally accepted assumption that a greater cognitive load is involved in the processing of concrete (vs. abstract) words because more information is activated (Barber, Otten, Kousta, & Vigliocco, 2013; Kiehl, Liddle, Smith, Mendrek, Forster, & Hare, 1999). Specifically, it is thought that concrete words have a dual coding, being represented in memory through both verbal and non-verbal codes, while abstract words are only represented by the verbal code. In this way, if concrete words, which usually are highly imageable, are compared with abstract concepts, a frontal N400-like component can be observed (Holcomb et al., 1999; Swaab et al., 2002). In our experiment, we could say that action words produced similar results to the concreteness effect found across studies. Thus, action words involved the activation of a greater amount of meaning-related information and therefore more memory demands (Barber et al., 2010).

Finally, the effect found between 550-800 ms could be considered a spreading of the previous semantic effect. Just as in the 350-550 ms time window, verbs and action words produced a greater negativity in the late time window. In fact, some authors support that the frontal N400 concreteness effect continues beyond this time window (Huang, Lee, & Federmeier, 2010). Specifically, this effect is thought to be sustained between 500 and 1000 ms and has been labeled as an N700 effect (Welcome, Paivio, McRae, & Joanisse, 2011). Barber et al. (2013) proposed that this effect, which is greater for concrete words than for abstract words, involves a processing of meaning in which multiple information is activated and integrated.

In closing, our results highlight differences in both latency and topography for grammar and meaning processing. As mentioned previously, the main cause of the lack of consistency of results across studies appears to be the overlapping between grammatical categories and meaning (Vigliocco et al., 2011). We think that our task resolves this problem, such that our results, which show independent processing for grammar and meaning at different temporal intervals, support the "autonomy of grammar" hypothesis (Bedny & Caramazza, 2011).

Conclusions

This study demonstrated that the processing of a word's grammatical class (noun/verb) starts very early, around two hundred milliseconds after the word onset, and that the effects extend until 800 ms after the word onset, at left frontal regions. These results support a Lexicalist model, which assumes that grammatical class is specified at the lexical level and can be retrieved during the process of word comprehension (Vigliocco et al., 2011). Semantic features, related to the action meaning of words, are codified later and their effects are broadly distributed.

In conclusion, the different components affected by grammar (P200 and LAN) and meaning (N400) and their topographical dissimilarity would seem to speak for an independent neural processing of the two linguistic properties.

RESUMEN

El curso temporal del procesamiento de la categoría gramatical y las propiedades semánticas de las palabras: Disociación mediante potenciales evocados. Esta investigación examina el curso temporal del procesamiento de palabras en función de su clase gramatical (verbos vs. nombres) y su significado (acción vs. no acción) mediante potenciales evocados. La morfología de palabras en español permite formar un nombre (ej. *bail*-e) o un verbo (ej. *bail*-ar) únicamente cambiando el sufijo unido a la raíz. Este hecho permitió la elaboración de un conjunto de nombres y verbos, igualados en significado y con una misma raíz, referidos a acciones y no acciones. Los resultados obtenidos ponen de manifiesto que la clase gramatical de las palabras es procesada muy pronto, alrededor de 200 ms tras la presentación de la palabra, manteniéndose sus efectos activados en regiones frontales izquierdas hasta los 800 ms. Igualmente se encontró un componente LAN sensible a esta distinción nombres-verbos, y una onda similar al N400, ampliamente distribuida, sensible al procesamiento del significado (acción-no acción). Estos diferentes componentes afectados por la gramática (P200 y LAN) y el significado (N400) parecen indicar la existencia de un procesamiento neuronal independiente de ambas propiedades lingüísticas y apoyan una especificación léxica de la clase gramatical.

REFERENCES

Adorni, R., & Proverbio, A. M. (2012). The neural manifestation of the word concreteness effect: An electrical neuroimaging study. *Neuropsychologia, 50*, 880–891.

Alameda, J. R. & Cuetos, F. (1995). *Diccionario de frecuencias de las unidades lingüísticas del castellano*. Oviedo: Servicio de Publicaciones de la Universidad de Oviedo.

Barber, H., Domínguez, A. & de Vega, M. (2002). Human brain potentials indicate morphological decomposition in visual word recognition. *Neuroscience Letters, 318*(3), 149-152.

Barber, H., Kousta, S., Otten, L. & Vigliocco, G. (2010). Event-related potentials to event-related words: Grammatical class and semantic attributes in the representation of knowledge. *Brain Research, 1332,* 65-74.

Barber, H. A., Otten, L. J., Kousta, S. T., & Vigliocco, G. (2013). Concreteness in word processing: ERP and behavioral effects in a lexical decision task. *Brain and language, 125*(1), 47-53.

Bedny, M. & Caramazza, A. (2011). Perception, action, and word meaning in the human brain: the case from action verbs. *Annals of New York Academy of Sciences, 1224*(1), 81-95.

Bedny, M., Caramazza, A., Grossman, E., Pascual-Leone, A. & Saxe, R. (2008). Concepts are more than percepts: The case of action verbs. *The Journal of Neuroscience, 28*(44), 11347-11353.

Bentin, S., McCarthy, G. & Wood, C. (1985). Event-related potentials, lexical decision and semantic priming. *Electroencephalography and Clinical Neurophysiology, 60*(4), 343-355.

Bird, H., Lambon-Ralph, M. A., Patterson, K., & Hodges, J. R. (2000). Why is a verb like an inanimate object? Grammatical category and semantic category deficits. *Brain and Language, 72*(3), 246-309.

Brown, C., Hagoort, P. & Keurs, M. (1999). Electrophysiological signatures of visual lexical processing: Open- and closed-class words. *Journal of Cognitive Neuroscience, 11*(3), 261-281.

Burton, M., Krebs-Noble, D. & Gullapalli, R. (2009). Functional neuroimaging of grammatical class: Ambiguous and unambiguous nouns and verbs. *Cognitive Neuropsychology, 26*(2), 148-171.

Chiarello, C., Liu, S., Shears, C. & Kacinik, N. (2002). Differential asymmetries for recognizing nouns and verbs: Where are they? *Neuropsychology, 16*(1), 35-48.

Crepaldi, D., Berlingeri, M., Paulesu, E., & Luzzatti, C. (2011). A place for nouns and a place for verbs? A critical review of neurocognitive data on grammatical class effects. *Brain and Language, 116*, 33-49.

Crepaldi, D., Berlingeri, M., Cattinelli, I., Borghese, N. A., Luzzatti, C., & Paulesu, E. (2013). Clustering the lexicon in the brain: a meta-analysis of the neurofunctional evidence on noun and verb processing. *Frontiers in Human Neuroscience, 7, 303*.

Damasio, A. & Tranel, D. (1993). Nouns and verbs are retrieved with differently distributed neural systems. *Neurobiology, 90*(11), 4957-4960.

Daniele, A., Giustolisi, L., Silveri, M. C., Colosimo, C. & Gainotti, G. (1994). Evidence for a possible neuroanatomical basis for lexical processing of nouns and verbs. *Neuropsychologia, 32*(11), 1325-1341.

Dehaene, S. (1995). Electrophysiological evidence for category-specific word processing in the normal human brain. *NeuroReport, 6(16),* 2153-2157.

Domínguez, A., De Vega, M., & Barber, H. (2004). Event related brain potentials elicited by morphological, homographic, orthographic and semantic priming. *Journal of Cognitive Neuroscience, 16*(4), 598-608.

Druks, J. (2002). Verbs and nouns: A review of literature. *Journal of Neurolinguistics, 15*(3), 289-315.

Duchon, A., Perea, M., Sebastián-Gallés, N., Martí, A., & Carreiras, M. (2013) EsPal: One-stop Shopping for Spanish Word Properties. *Behavior Research Methods, 45*, 1246-1258.

Federmeier, K., Segal, J., Lombrozo, T. & Kutas, M. (2000). Brain responses to nouns, verbs and class-ambiguous words in context. *Brain, 123*(12), 2552-2566.

Gainotti, G., Silveri, M. C., Daniel, A. & Giustolisi, L. (1995). Neuroanatomical correlates of category-specific semantic disorders: A critical survey. *Memory, 3*(3-4), 247-263.

Greenhouse, S. W. & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*(2), 95-112.

Hauk, O. & Pulvermüller, F. (2004). Neurophysiological distinction of action words in the fronto-central cortex. *Human Brain Mapping, 21*(3), 191-201.

Holcomb, P. J., Kounios, J., Anderson, J. E. & West, W. C. (1999). Dual coding, context-availability and concreteness effects in sentence comprehension: An electrophysiological investigation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(3), 721-742.

Huang, H., Lee, C., & Federmeier, K. D. (2010). Imagine that ERPs provide evidence for distinct hemispheric contributions to the processing of concrete and abstract concepts. *NeuroImage, 49*, 1116–1123.

Kauschke, C. & Stenneken, P. (2008). Differences in noun and verb processing in lexical decision cannot be attributed to word form and morphological complexity alone. *Journal of Psycholinguistic Research, 37*(6), 443-452.

Kellenbach, M., Wijers, A., Hovius, M., Mulder, J. & Mulder, G. (2002). Neural differentiation of lexico-syntactic categories or semantic features? Event-related potential evidence for both. *Journal of Cognitive Neuroscience, 14*(4), 561-577.

Kemmerer, D. & Eggleston, A. (2010). Nouns and verbs in the brain: Implications of linguistic typology for cognitive neuroscience. *Lingua, 120*(12), 2686-2690.

Kemmerer, D., Rudrauf, D., Manzel, K. & Tranel, D. (2012). Behavioral patterns and lesion sites associated with impaired processing of lexical and conceptual knowledge of actions. *Cortex*, 48(7), 826-848

Kiehl, K. A., Liddle, P. F., Smith, A. M., Mendrek, A., Forster, B. B., & Hare, R. D. (1999). Neural pathways involved in the processing of concrete and abstract words. *Human brain mapping, 7*(4), 225-233.

Kounios, J. & Holcomb, P. (1994). Concreteness effects in semantic processing: ERP evidence supporting dual-coding theory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20*(4), 804-823.

Krott, A., Baayen, R. H. & Hagoort, P. (2006). The nature of anterior negativities caused by misapplications of morphological rules. *Journal of Cognitive Neuroscience, 18*(10), 1616-1630.

Kutas, M. & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Science, 4*(12), 463-470.

Lavric, A., Clapp, A. & Rastle, K. (2007). ERP evidence of morphological analysis from orthography: A masked priming study. *Journal of Cognitive Neuroscience, 19*(5), 866-877.

Lee, C. L. & Federmeier, K. D. (2006). To mind to mind: An event-related potential study of word class and semantic ambiguity. *Brain Research, 1081*(1), 191-202.

Linares, M. E., Rodríguez-Fornells, A. & Clahsen, H. (2006). Stem allomorphy in the Spanish mental lexicon: evidence from behavioral and ERP experiments. *Brain and Language, 97*(1), 110-120.

Longe, O., Randall, E. A., Stamatakis & Tyler, L.K. (2007). Grammatical categories in the brain: The role of morphological structure. *Cerebral Cortex, 17*(8), 1812-1820.

Luck, S. J. (2005). *An Introduction to Event-Related Potential Technique*. MIT Press

Mancini, S., Molinaro, N., Rizzi, L., & Carreiras, M. (2011). When persons disagree: an ERP study of unagreement in Spanish. *Psychophysiology, 48*(10), 1361-1371.

Meyer, D. & Schvaneveldt, R. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*(2), 227-234.

Moseley, R. L., & Pulvermüller, F. (2014). Nouns, verbs, objects, actions, and abstractions: Local fMRI activity indexes semantics, not lexical categories. *Brain and language, 132*, 28-42.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*(1), 97-113.

Oliveri, M., Finocchiaro, C., Shapiro, K., Gangitano, M., Caramazza, A. & Pascual-Leone, A. (2004). All talk and no-action: A transcranial magnetic stimulation study of motor cortex activation during action word production. *Journal of Cognitive Neuroscience, 16*(3), 374-381.

Preissl, H., Pulvermüller, F., Lutzenberger, W. & Birbaumer, N. (1995). Evoked potentials distinguish between nouns and verbs. *Neuroscience Letters, 197*(1), 81-83.

Pulvermüller, F., Harle, M. & Hummel, F. (2000). Neurophysiological distinction of verb categories. *Neuroreport, 11*(12), 2789-2793.

Pulvermüller, F., Harle, M. & Hummel, F. (2001). Walking or talking: Behavioral and neurophysiological correlates of action verb processing. *Brain and Language, 78*(2), 143-168.

Pulvermüller, F., Mohr, B. & Schleichert, H. (1999). Semantic or lexico-syntactic factors: What determines word-class specific activity in the human brain? *Neuroscience Letters, 275*(2), 81-84.

Rapp, B. & Caramazza, A. (2002). Selective difficulties with spoken nouns and written verbs: A single case study. *Journal of Neurolinguistics, 15*(3-5), 373-402.

Rodríguez-Fornells, A., Clahsen, H., Lleo, C., Zaake, W. & Münte, T.F. (2001). Event-related brain responses to morphological violations in Catalan. *Cognitive Brain Research, 11*(1), 47-58.

Rodríguez-Fornells, A., Münte, T. & Clahsen, H. (2002). Morphological priming in Spanish verb form: An ERP repetition priming study. *Journal of Cognitive Neuroscience,* 14(3), 443-454.

Rugg, M. (1984). Event-related potentials and the phonological processing of words and non-words. *Neuropsychologia, 22*(4), 435-443.

Swaab, T. Y., Baynes, K., & Knight, R. T. (2002). Separable effects of priming and imageability on word processing: an ERP study. *Cognitive Brain Research, 15*(1), 99-103.

Schneider, W., Eschman, A. & Zuccolotto, A. (2002). *E-prime user´s guide*. Pittsburgh, PA: Psychology Software Tools.

Shapiro, K. & Caramazza, A. (2003). Looming a loom: evidence for independent access to grammatical and phonological properties in verb retrieval. *Journal of Neurolinguistics 16*(2-3), 85-111.

Shapiro, K., Pascual-Leone, A., Mottaghy, F., Gangitano, M. & Caramazza, A. (2001). Grammatical distinctions in the left frontal cortex. *Journal of Cognitive Neuroscience, 13*(6), 713-720.

Tanner, D., & Van Hell, J. G. (2014). ERPs reveal individual differences in morphosyntactic processing. *Neuropsychologia, 56*, 289-301.

Tsai, P., Yu, B., Lee, C., Tzeng, O., Hung, D. & Wu, D. (2009). An event-related potential study of the concreteness effect between Chinese nouns and verbs. *Brain Research, 1253*(9), 149-160.

Tyler, L. K., Bright, P., Fletcher, P. & Stamatakis, E. A. (2004). Neural processing of nouns and verbs: The role of inflectional morphology. *Neuropsychologia, 42*(4), 512-523.

Vigliocco, G., Vinson, D., Druks, J., Barber, H. & Cappa, S. (2011). Nouns and verbs in the brain: A review of behavioral, electrophysiological, neuropsychological and imaging studies. *Neuroscience and Biobehavioral Reviews, 35*(3), 407-426.

Welcome, S. E., Paivio, A., McRae, K., & Joanisse, M. F. (2011). An electrophysiological study of task demands on concreteness effects: evidence for dual coding theory. *Experimental brain research, 212*(3), 347-358.

(Manuscript received: 4 June 2015; accepted: 3 November 2015)