

Human brain potentials indicate morphological decomposition in visual word recognition

Horacio Barber^{*}, Alberto Domínguez, Manuel de Vega

Departamento de Psicología Cognitiva, Universidad de La Laguna, 38205, S/C de Tenerife, Spain

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Abstract

Stem homographs are pairs of words with the same orthographic description of their stem but which are semantically and morphologically unrelated (e.g. in Spanish: *rata/rato* (rat/moment)). In priming tasks, stem homographs produce inhibition, unlike morphologically related words (*loca/loco* (madwoman/madman)) which produce facilitation. An event-related potentials study was conducted to compare morphological and stem homographic priming effects. The results show a similar attenuation of the N400 component at the 350–500 ms temporal window for the two conditions. In contrast, a broad negativity occurs only for stem homographs at the 500–600 ms window. This late negativity is interpreted as the consequence of an inhibitory effect for stem homographs that delays the stage of meaning integration. © 2002 Elsevier Science Ireland Ltd. All rights reserved.

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Many studies in psycholinguistics and cognitive neuropsychology have emphasized the crucial role played by the morphological structure of words in lexical access and representation [3]. A common result found when using the morphological priming paradigm is the faster recognition of a word when it is preceded by another morphologically related word. However, a problem associated with this facilitation is that morphological pairs of words overlap not only in their morphological structure but also in their orthographic, phonological and semantic features. Substantial effort has been devoted to separating these sources of variation [7,8,14].

Stem homograph inhibition provides one piece of evidence of morphological processing. Stem homographs are words that, despite sharing the orthographic description of the stem, are morphologically and semantically unrelated. Laudana, Badecker and Caramazza [10], in Italian, reported slower lexical decision times for pairs of stem homographs such as *port-are/port-e* (to carry/door) than for pairs of words with similar orthographic overlapping but different stem descriptions such as *coll-o* (neck)/*colp-o* (blow). Similar results were obtained in Spanish by Allen and Badecker [2]. This homographic stem inhibition cannot

be explained in terms of letter overlap but only in terms of morphological parsing.

Spanish allows the selection of pairs of words with a very good control of orthographic and morphological overlap. Gender is generally indicated by taking a root morpheme, e.g. *LOC-*, and adding an *-A* suffix to obtain a feminine word, *LOCA* (madwoman), or an *-O* suffix to obtain the masculine version, *LOCO* (madman). However, exceptions to this rule yield stem homographs, namely two words that share a stem orthographically identical but semantically and/or grammatically different, e.g. *RATA/RATO* (rat/moment). Domínguez, Cuetos and Seguí [5] used these two types of word pairs in order to compare the effects of morphological priming and stem homographs priming. When reaction times were analyzed, a facilitation effect for the stem homograph condition was found at short stimulus onset asynchronies (SOAs; 32 and 64 ms), whereas an inhibition effect was observed at 250 ms SOA. On the other hand, the morphological relationship condition resulted in a facilitation effect at all SOAs. These priming effects using reaction times can be supplemented with other dependent variables using event-related potential (ERP) measures. ERPs are voltage changes recorded from the scalp and extracted from the background electroencephalogram (EEG) by averaging response time locked to stimuli onset. When ERPs are collected for unprimed words, a negative deflection occurring around 400 ms after stimulus onset is typically observed. This nega-

^{*} Corresponding author. Tel.: +34-922-317508; fax: +34-922-317639.

E-mail address: hbarber@ull.es (H. Barber).

tivity is considerably attenuated for semantically primed words. The negative deflection is similar to the N400 component reported in the literature (see review in [11]). The same component is affected by repetition [15] and phonological priming [13]. It is generally assumed that the N400 component reflects conceptual integration processes, which are required to build high order representations. These processes would be affected by the information available in short-term memory (contextual information), and in addition, they would be sensitive to the ease of accessing information from long-term memory [9].

According to the literature [10], we assume that representations in the lexicon involve a single entry for morphological pairs, and two entries for stem homographs. Consequently, meaning integration is possible for morphological pairs but not for stem homographs. The N400 might be sensitive to meaning integration processes and also to lexical memory organization [9], therefore this component can be used to study how morphological and stem homograph stimuli are processed.

The present study uses pairs of words similar to those used by Domínguez, Cuetos and Seguí [5]. On two different lists, target stimuli were each paired with a related and an unrelated word. For instance, in the *morphological* category, the target *loc-o (madman)* was paired with *LOC-A (madwoman)* for the related condition, and with *CER-A (wax)* for the unrelated condition. Similarly, in the *stem homographs* category, the target *rat-o (moment)* was paired with *RAT-A (rat)* for the related condition, and with *PER-A (pear)* for the unrelated condition. In each of the stem homograph and morphological pairs, the primes and targets shared all but the final letter. Half of the experimental primes ended in *-a*, while their targets ended in *-o*, and vice versa. The inflection *-a* corresponds to feminine, while *-o* marks masculine gender. Sixty pairs of each type (morphological and stem homograph, related and unrelated) were generated. Thirty of these were presented in the related condition and the other 30 in the unrelated condition for half of the participants and the relations were reversed for the other half of the participants. Thus, each word occurred twice across subjects, once in the related condition and once in the unrelated condition, but within participants, each word appeared once during the experiment. The prime words had a lower printed lexical frequency than the target. This frequency relation was checked target by target, using a Spanish standard corpus [1]. The mean frequency and the standard deviation were similar for the morphological (57/million and 91, respectively) and the stem homograph targets (58/million and 88; $F_{(1,59)} = 0.81$, $MSE = 340.03$, $P = 0.372$). The target stimuli for the two experimental conditions were equated in length (four, five or six letters). Ninety non-words were also presented as targets, half of these sharing the same initial letters with the prime word. A list of fillers, word–word and word–non-word pairs were introduced, which reduced the percentage of orthographically related pairs to 35% of the initial set. Some fillers ended with different inflectional suffixes and were four, five,

six or seven letters long, which approaches the word length distribution of ordinary Spanish. Each participant received 300 pairs of stimuli, 180 word and 120 non-word targets; 120 of the word pairs were experimental word–word pairs and 60 were unrelated filler pairs.

Ten healthy volunteers aged 19–21 years (including five women), who were native Spanish speakers, were selected for this study. All of them were right-handed.

The sequence of events in each trial is described as follows. Firstly, a point of fixation appeared in the center of the screen and remained there for 1 s. Then the prime word in lower case letters was exposed for 200 ms. After a 50 ms blank interval, the target word appeared in upper case letters and remained there until the participant's response. Participants were instructed about this sequence and were requested to indicate whether or not the second letter string was a word by pressing one of the two assigned keys on the keyboard.

The EEG was recorded from 13 thin electrodes mounted on an electrode cap and amplified using a Medicid-4 system. The recording sites included F3, Fz, F4, F7, F8, T3, Cz, T4, T5, T6, P3, Pz and P4, according to the 10/20 system. All EEG channels were referred to linked mastoids. Inter-electrode impedances were kept below 5 K Ω . The biosignals were recorded in the 0.01–30 Hz band and digitized with 4 ms resolution. Eye movements and blinks were monitored via two bipolar montages. Baseline correction was performed using the average EEG activity in the 100 ms preceding the onset of the prime word as a reference signal value. After the baseline correction, trials with ocular artifacts were rejected. Averaging was conducted off-line using only samples recorded on trials in which correct responses had been made. Separate ERPs were formed for the four types of relationship, for each of the participants and for each of the electrode sites.

The analyses were carried out on the basis of calculations of mean amplitudes in two temporal windows: 350–500; and 500–600 ms. Three different analysis of variance (ANOVA) tests for each window were performed contrasting different conditions: (1), morphological relation with its control of non-related words; (2), stem homograph relation with its control of non-related words; (3), and finally, the morphological condition was subtracted from its control while the stem homograph condition was subtracted from its own control, the resulting differential waves being then contrasted. In all of these three ANOVA tests, electrode sites (Fz, Cz and Pz) were entered as another within-subject factor. Similar analyses were performed contrasting lateral sites and including the hemisphere as an additional factor. The results of these analyses are not reported because they did not show qualitative differences with respect to the midline analysis.

Inspection of the waveforms indicates the usual negativity, around 400 ms, for the targets of unrelated pairs. However, targets for the stem homographs and morphological pairs do not show this negativity and they start to differ from their respective controls at 300 ms. Since the two controls used for each priming condition did not differ—

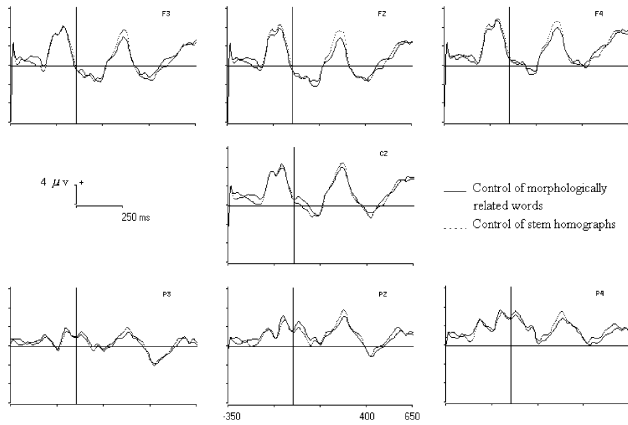


Fig. 1. Grand averages for the two unrelated words conditions in the central sites. A total overlap may be observed. Vertical line marks the onset of target words.

see Fig. 1 – the priming effects can be observed in Fig. 2 with respect to an average of the two controls of non-related words. Initially, there was no difference between stem homograph and morphological priming. Nevertheless, after this initial stage, stem homograph targets showed a broad negativity with a peak latency between 500 and 600 ms, while morphologically related pairs did not show this negativity.

At the 350–500 ms window, a reliable difference between morphologically related words and their unrelated controls was found ($F_{(1,9)} = 14.39$, $MSE = 330.12$, $P < 0.05$), as also happened with stem homographs and their unrelated controls ($F_{(1,9)} = 6.98$, $MSE = 64.33$, $P < 0.05$). However, there was not a reliable effect when the morphological differential wave and the stem homograph differential wave were compared. In the 500–600 ms window, no significant differences between morphologically related words and their controls were found, whereas there was a significant difference between stem homographs and their controls

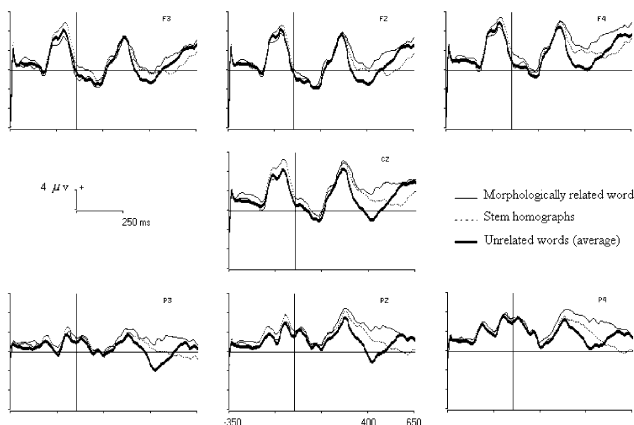


Fig. 2. Grand averages for the different experimental conditions. The line for the non-related words is the average of the two unrelated conditions that may be seen in Fig. 1.

($F_{(1,9)} = 5.23$, $MSE = 141.45$, $P < 0.05$). In addition, the contrast between the differential waves of morphological and stem homographs pairs was significant ($F_{(1,9)} = 6.71$, $MSE = 315.43$, $P < 0.05$). The effects of the electrode site factor are not described because their interaction with the other main factors (priming conditions) was not statistically significant.

To sum up, the N400 component was affected by both morphological priming and stem homographic priming. These conditions start to diverge from their controls at 300 ms. Later on, about 450 ms, the morphologically related waveform tends to approach that of the controls, whereas the stem homographs waveform shows a clear late negativity which extends into the 500–600 window.

Domínguez et al. [5] and also Rastle et al. [14], using a lexical decision task with a masking procedure, obtained a pattern of latencies which is compatible with the present ERP results. They found a facilitation for masked stem homographs at short SOAs (32 and 64 ms), and an inhibition with unmasked presentation at longer SOAs (250 ms). On the other hand, a sustained facilitation across SOAs (32, 64, and 250 ms) was observed for morphological stimuli. The inhibitory effect for stem homographs was explained as a consequence of the competition between two stem representations which share the same orthographic description [3]. The target cannot take advantage of the previous activation of the stem because, although the stem of prime and target have the same orthographic and phonological description, i.e. *RAT-*, the masculine realization of this root, the prime *RATO (moment)*, takes a different meaning in the feminine word, that is, the target *RATA (rat)*. This explanation of the inhibitory priming found for stem homographs could also be suitable for the current ERP results. In an early stage of processing, the similar attenuation of the N400 waveform for morphological and stem homograph pairs could be attributed to a facilitation produced by the orthographic overlapping between words (*RATO/RATA*, *LOCO/LOCA*). This facilitation (attenuation) then remains only for morphologically related words (*LOCO/LOCA*) because the orthographic code leads reliably to meaning. However, for stem homographs (*RATO/RATA*), the meaning integration is impossible and a late negativity waveform occurs.

Other priming studies support a modulation of the N400 in two stages. Doyle, Rugg and Wells [6] found that N400 is initially affected by priming with embedded words (i.e. scan- scandal), but differs from repetition priming at a later stage. There is, here, a degree of parallelism with the current experiment. Repetition priming shares some characteristics with morphological priming, and embedded words and stem homographs are, in fact, two formal priming paradigms. However, an important difference is that, unlike stem homographs in our experiment, embedded words are not expected to produce interference and they do not. On the other hand, Connolly and Philips [4] recorded ERPs from sentence terminal words that could be or could not be alliterated words (words that initially share phonetic—formal—

characteristics) with respect to the best sentence completion. They found that alliteration affects a component previous to the N400, and when alliterated words were inconsistent with the context, a delay of the N400 latency was observed. However, other authors consider that both effects or stages are modulations of the same component, namely the N400 [12].

The inhibitory priming obtained for stem homographs with respect to morphologically related pairs in reaction time experiments was confirmed and extended in this ERP experiment. The N400 component showed two different stages. In the first stage, orthographic and/or morphological (stem) elements of the words are processed, and in the second moment, the integration of meaning of the two words takes place. If prime and target are morphologically related, the integration is possible and the attenuation of the N400 is kept, but for stem homographs, this meaning integration is impossible and, consequently, a late negativity is obtained.

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- [1] Alameda, J.R. and Cuetos, F., *Diccionario de Frecuencias de las Unidades Lingüísticas del Castellano*, Servicio de Publicaciones de la Universidad de Oviedo, Oviedo, Spain, 1995.
- [2] Allen, M. and Badecker, W., Stem homograph inhibition and stem allomorphy: representing and processing inflected forms in a multilevel lexical system, *J. Mem. Lang.*, (1999) 105–123.
- [3] Badecker, W. and Caramazza, A., Morphology and Aphasia, In A. Zwicky and A. Spencer (Eds.), *Handbook of Morphology*, Blackwell, Oxford, 1998, pp. 390–406.
- [4] Connolly, J.F. and Phillips, N.A., Event-related potential components reflect phonological and semantic process of the terminal word spoken sentence, *J. Cogn. Neurosci.*, 6 (1994) 256–266.
- [5] Domínguez, A., Cuetos, F. and Segui, J., The time-course of inflexional morphological priming, *Linguistics*, (2002) in press.
- [6] Doyle, M.C., Rugg, M.D. and Wells, T., A comparison of the electrophysiological effects of formal and repetition priming, *Psychophysiology*, 33 (1996) 132–147.
- [7] Drews, E. and Zwitserlood, P., Morphological and orthographic similarity in visual word recognition, *J. Exp. Psychol. Hum. Percept. Perform.*, 21 (1995) 1098–1116.
- [8] Feldman, L.B. and Bentin, S., Morphological analysis in word recognition, In L. Katz and R. Frost (Eds.), *Orthography, Phonology, Morphology, and Meaning: An Overview*, Elsevier, Amsterdam, 1994, pp. 343–360.
- [9] Kutas, M. and Federmeier, K.D., Electrophysiology reveals semantic memory use in language comprehension, *Trends Cogn. Sci.*, 4 (12) (2000) 463–470.
- [10] Laudana, A., Badecker, W. and Caramazza, A., Priming homographic stems, *J. Mem. Lang.*, 28 (1989) 531–546.
- [11] Osterhout, L. and Holcomb, P.J., Event related potentials and language comprehension, In M.D. Rugg and M. Coles (Eds.), *Electrophysiology of Mind: Event Related Brain Potentials and Cognition*, Oxford University Press, Oxford, 1995, pp. 171–215.
- [12] Van Petten, C., Coulson, S., Rubin, S., Plante, E. and Parks, M., The course of word identification and semantic integration in spoken language, *J. Exp. Psychol. Learn. Mem. Cogn.*, 25 (1999) 394–417.
- [13] Radeau, M., Bensson, M., Fonteneau, E. and Luis-Castro, S., Semantic, repetition and rime priming between spoken words: behavioral and electrophysiological evidence, *Biol. Psychol.*, 48 (1998) 183–204.
- [14] Rastle, K., Davis, M.H., Marslen-Wilson, W.D. and Tyler, L.K., Morphological and semantic effects in visual word recognition: a time-course study, *Lang. Cogn. Process.*, 15 (4/5) (2000) 507–537.
- [15] Rugg, M.D. and Doyle, M.C., Event related potentials and stimulus repetition in direct and indirect test of memory, In H.J. Heinze, T.F. Münte and G.R. Magnum (Eds.), *Cognitive Electrophysiology*, Birkhäuser, Boston, MA, 1994, pp. 124–148.