ERP correlates of letter-case in visual word recognition

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1 Introduction

Visual word recognition is a key element of language comprehension. The vast majority of current models assume that the recognition of a printed word is based on the activation of abstract letter identity representations. The hierarchical neural accounts of letter/word recognition of Dehaene, Cohen, Sigman, and Vinckier (2005) and Grainger, Rey, and Dufau (2008) posit that, early in the process of lexical access, there are neuronal assemblies that respond to the word's case-specific letters (e.g., they respond to 'e' but not to 'E'). Later in processing, there are neuronal assemblies that respond to the abstract representation of the letter identity (e.g., they respond to the same degree to 'e' and to 'E').

Behavioral evidence using masked priming (i.e., a paradigm that taps onto early word processing; Forster & Davis, 1984; see Grainger, 2008, for review) has revealed that there is a rapid access to case-invariant letter representations. Specifically, the advantage of the identity condition over the unrelated condition is independent of the letter-case (similar advantage for kiss-KISS and EDGE-edge; see Bowers, Vigliocco, & Haan, 1998). Furthermore, response times to matched-case identical prime-target pairs (EDGE-EDGE) are virtually similar as the response times to mismatched-case identical prime-target pairs (edge-EDGE; see Jacobs, Grainger, & Ferrand, 1995; Perea, Jiménez, & Gómez, 2014).

To our knowledge, only a previous experiment investigated the temporal processing of letter-case using event-related potentials in an unmasked paradigm (Lien, Allen, & Crawford, 2012). Lien et al. compared the processing of lowercase-printed vs mIxEd-cAse-printed words of different frequency (high and low). They found that the N170 amplitude, related to structural encoding, was sensitive to case mixing, but the P3, related to stimulus categorization, was sensitive to lexicality and word frequency. They proposed that case mixing affects early processing stages of visual word recognition.

The Lien et al. experiment is important, but it does not respond to the question of whether letter-case plays a role during visual-word recognition with visually familiar words –note that mIxEd-cAsE stimuli are visually unfamiliar and difficult to process. In contrast, lowercase and uppercase words are the usual format when reading words. Indeed, experiments on visual-word recognition employ either lowercase or uppercase words with no explicit justification.
Importantly, there is one account that does assume that letter-case information may form an integral part of a word's lexical representation. Specifically, Peressotti, Cubelli, and Job (2003) claimed that 'while size, font and style (cursive or print) affect the visual shape of letters, the uppercase–lowercase distinction is abstract in nature as it is an intrinsic property of letters' (p. 108). In the framework of Peressotti et al.'s 'orthographic cue' account, a given lexical unit would not be retrieved only on the basis of the letter identity and letter position, but also on the basis of letter-case information. Given that most printed words are presented in lowercase, this should provide an advantage for the processing of lowercase vs. uppercase words (see Mayall & Humphreys, 1996; Perea & Rosa, 2002, for behavioral evidence of a lowercase advantage in visual-word recognition).

The main aim of this study is to examine the time course of letter-case on lexical access. The ERPs may help to disentangle whether letter case is an attribute that is only relevant in early perceptual

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processing or whether it is also relevant in the retrieval of lexical representations. To attain this goal, we examined whether the effects of letter-case (lowercase vs. UPPERCASE) are modulated by word-frequency (a factor that indicates lexical/semantic activation; see Vergara-Martínez, Perea, Gómez, & Swaab, 2013) tracking the ERP waves in well-studied time windows (N/P150: 100-170 ms; P200: 170-250 ms; N400: 255-450 ms) in a lexical decision task.

2 Method

Twenty-two healthy, right-handed, native Spanish-speaking Valencia University students, naïve to the manipulation of the stimuli, participated in the study in exchange for a small gift.

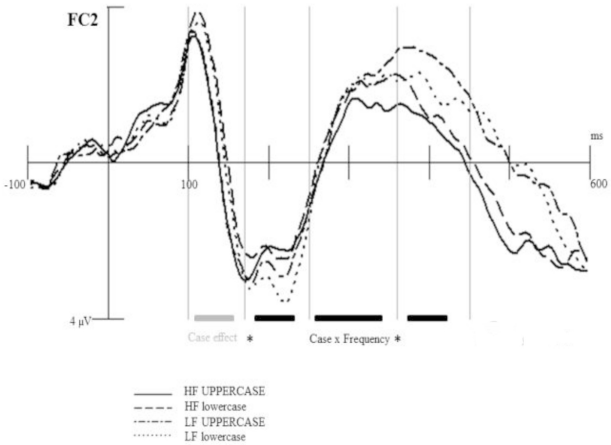
We selected a set of 160 words from the Web-accessible EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). Half of the words were of high frequency and half were of low frequency. The two groups of words were matched in relevant psycholinguistic factors (length, orthographic neighborhood, concreteness, imageability…). Half of the words were presented in uppercase and half in lowercase (MOTHER; mother). In addition, a list of 160 pseudowords (half in lowercase, half in uppercase) was included for the purposes of the lexical decision task.

Participants were instructed to decide as accurately and rapidly as possible whether or not the stimulus was a Spanish word. They pressed one of two response buttons (YES/NO). The electroencephalogram (EEG) was recorded from 29 electrodes, averaged separately for each of the experimental conditions, each of the subjects and each of the electrode sites. For each time window, we conducted ANOVAs with word-frequency (high, low), case (lowercase, UPPERCASE), and AP (anterior, central-anterior, central, central-posterior and posterior) as factors in the design.

Results and Conclusions

The behavioral data revealed significantly faster responses for high-frequency than for low-frequency words (656 vs. 702 ms) and significantly faster responses for lowercase than for uppercase words (675 vs. 683 ms). There were no signs of an interaction between the two factors. The error data revealed the same pattern as the response time data.

In the N/P150, larger negative values were observed for lowercase than for uppercase words, with a central scalp distribution, whereas the effect of word-frequency was not significant. In the P200, and only for low-frequency words, larger positive values were observed for the lowercase than for uppercase words in frontal/central scalp areas. With respect to the N400, the ERP waves revealed a dissociation of the letter-case effect for low- and high-frequency words. High-frequency words showed an effect of letter-case in an early stage of the N400, whereas low-frequency words showed an effect of letter-case (in the opposite direction; see Figure 1) in a later stage of the N400.



As expected, there was an early pre-lexical effect of letter-case that did not interact with word-frequency. Importantly, we found an interaction between letter-case and word-frequency not only in the N400 time window –which is commonly associated to lexical-semantic processing, but also the P200 time window, thus supporting the hypothesis that letter-case may affect the mapping of visual-orthographic information onto word representations. Taken together, the present ERP data provide empirical support to the hypothesis that letter-case information may be stored in the abstract word representations (Peressotti et al., 2003), thus posing some problems for current computational and neural models of visual-word recognition.

"Figure 1. Grand average ERP waves to Frequency and case manipulations in one representative electrode. Different columns mark the four epochs under analysis"

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