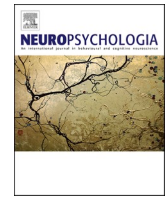
Neuropsychologia 146 (2020) 107556

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: http://www.elsevier.com/locate/neuropsychologia



The time course of the lowercase advantage in visual word recognition: An ERP investigation☆

Marta Vergara-Martínez [a,*], Manuel Perea [a,b], Barbara Leone-Fernandez [c]

[a] Universitat de València, Valencia, Spain
[b] Universidad Nebrija, Madrid, Spain
[c] Università di Torino, Torino, Italy

ARTICLE INFO

Keywords:
Visual word recognition
Letter-case
Lexical decision
ERPs

ABSTRACT

Previous word identification and sentence reading experiments have consistently shown faster reading for lowercase than for uppercase words (e.g., table faster than TABLE). A theoretically relevant question for neural models of word recognition is whether the effect of letter-case only affects the early prelexical stages of visual word recognition or whether it also influences lexical-semantic processing. To examine the locus and nature of the lowercase advantage in visual word recognition, we conducted an event-related potential (ERP) lexical decision experiment. ERPs were recorded to words and pseudowords presented in lowercase or uppercase. Words also varied in lexical frequency, thus allowing us to assess the time-course of perceptual (letter-case) and lexical-semantic (word-frequency) processing. Together with a lowercase advantage in word recognition times, results showed that letter-case influenced early perceptual components (N/P150), whereas word frequency influenced lexical-semantic components (N400). These findings are consistent with those models of written word recognition that assume that letter-case information from the visual input is quickly mapped onto the case-invariant letter and word units that drive lexical access.

1. Introduction

In a few hundreds of milliseconds, skilled readers are able to identify a word's visual features, match these features with the representations stored in long-term memory, and select the appropriate lexical unit. Although considerable progress has been made in the past decades, there are still many unanswered questions to fully apprehend the journey from ink to letter features to meaning. Here we examined a somewhat neglected topic in visual-word recognition: the effects of letter-case during word recognition. To that end, we compared the identification of words presented in lowercase vs. uppercase (e.g., table vs. TABLE).

Letter-case has often been considered as an irrelevant parameter during the process of lexical access and, hence, researchers in cognitive psychology and cognitive neuroscience have interchangeably employed lowercase and uppercase words in their experiments. Indeed, leading neural models of letter word recognition (e.g., Dehaene et al., 2005; Grainger et al., 2008) assume that letter-case only plays a role in the earliest stages of letter/word processing, before the mapping of the visual input onto the abstract letter representations that underlie lexical access. Specifically, Dehaene et al.'s (2005) Local Combination Detector (LCD) model proposes a hierarchy of increasingly larger and more abstract neural computations which operate over the stimulus, from increasingly more complex visual features to abstract letters, letter sequences and words along the left ventral pathway (see also Cohen et al., 2000; Cohen et al., 2002). Of note, before reaching the invariant-abstract level of representation, visual information for words like "art" or "ART" would activate different shape fragment detectors (e.g., for shape-letter detectors, a ≠ A). Critically, higher in the hierarchy, other neural populations compute and translate these letter shapes into abstract units free from size, font, and orientation information (i.e., the bank of abstract letter detectors: a = A). These abstract units are then used by lexical processing mechanisms for visual word recognition (see Dehaene et al., 2005).

Thus, these neural models would predict that the visual input

☆ Author's notes: The research reported in this article has been partially funded by Grant PSI2017-86210-P (Manuel Perea) from the Spanish Ministry of Science, Innovation and Universities. The raw data for all the analyses are provided in the anonymized OSF website: https://osf.io/jnvgc/?view_only=2cb6512aed844f898ae48eca2edfd01b.

* Corresponding author. Dpto. de Psicología Evolutiva y de la Educación, Universitat de València, Av. Blasco Ibáñez, 21 46010, Valencia, Spain.
E-mail address: Marta.Vergara@uv.es (M. Vergara-Martínez).

https://doi.org/10.1016/j.neuropsychologia.2020.107556
Received 4 April 2020; Received in revised form 8 July 2020; Accepted 9 July 2020
Available online 17 July 2020
0028-3932/© 2020 Elsevier Ltd. All rights reserved.

provided by house, house, house, *house*, or HOUSE would similarly activate the same abstract word representations during lexical access. Indeed, behavioral and neuroimaging evidence supporting this view has been consistently obtained in masked priming experiments: the size of the masked repetition priming effect to uppercase target words is similar when the prime is presented in lowercase (e.g., table-TABLE) and when the prime is presented in uppercase (TABLE-TABLE) (e.g., see Jacobs et al., 1995, for behavioral evidence; see Vergara-Martínez et al., 2015, for electrophysiological evidence; see Dehaene et al., 2001, 2004, for neuroimaging evidence). Clearly, if letter-case congruency had modulated the initial contact with lexical entries, one would have expected smaller masked repetition priming for table-TABLE than for TABLE-TABLE.

This notwithstanding, a number of behavioral experiments across various paradigms have consistently shown that words presented in lowercase produce faster word recognition times than words presented in uppercase (e.g., lexical decision: Paap et al., 1984; Perea and Rosa, 2002; Mayall and Humphreys, 1996; semantic categorization: Mayall and Humphreys, 1996; naming: Mayall and Humphreys, 1996; reading text: Tinker, 1955; Perea et al., 2017). Is this a mere consequence of visual familiarity (i.e., words are more frequently seen in lowercase than in uppercase)? While this may be the most parsimonious interpretation, one should also consider whether word representations are stored in memory along with letter-case information, a result that would pose some problems for the LCD model. Indeed, in the framework of Peressotti et al. (2003) orthographic cue (OC) hypothesis, a given lexical unit would be retrieved not only on the basis of the identity and position of the constituent letters, but also on the basis of letter-case information. In a series of experiments, Peressotti et al. (2003) found that the capitalization of the initial letter of Italian proper names facilitated lexical access, and proposed 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). Clearly, this pattern is particularly evident regarding first letter capitalization, as it follows strict grammatical rules: it is used not only at the beginning of a sentence, but also as a marker or proper names. In sum, first letter case information: a) may be part of the abstract orthographic representation that is used to contact the lexicon; and b) word units in the orthographic input lexicon may contain information about letter-case. Recently, Wimmer et al. (2016) found evidence favoring the OC hypothesis in a lexical decision experiment in German: Ball [a noun] was responded faster than ball, whereas blau [an adjective] was responded faster than Blau—note that, in German, common nouns are also written with their initial letters in uppercase. Wimmer et al. (2016) also reported converging neuroimaging evidence: they found more activation in the visual-word form area (the brain area responsible for abstract word form processing; see Cohen et al., 2000, 2002) for the words with the unfamiliar format (e.g., ball, Blau) than those with the familiar format (Ball, blau). Furthermore, Sulpizio and Job (2018) also provided empirical support to the OC hypothesis in a lexical decision experiment in which they compared the electrophysiological correlates of proper and common nouns that were printed in either their typical or atypical format (e.g., proper name: Simpson, simpson; common noun: mattress, Mattress). Larger ERP amplitudes for stimuli in their typical/more frequent format were obtained around 200 ms post stimuli (i.e., a stage of processing when sublexical information is mapped onto word form representations), hence supporting the proposal that the orthographic representation of words is specified in terms of case typicality.

Taken together, the above-cited results seem to challenge the prevalent assumption that visual word recognition merely rests on purely abstract neural representations for letters and words. Instead, these findings suggest that, at least under some circumstances (e.g., proper names; common nouns in German) orthographic representations in Latin-based scripts might contain information about the canonic format in which words are seen. Consistent with this interpretation, word recognition times to brand names are faster when presented in their archetypical case than when presented in a less familiar case (IKEA faster than ikea; see Gontijo and Zhang, 2007; Perea et al., 2015). Furthermore, this pattern also applies to common nouns that appear in street signs of billboards such as STOP or acronyms like FBI, which may benefit from their usual letter configuration (e.g., see Besner et al., 1984; Perea et al., 2018).

However, despite the specific instances of brand names, street locations and acronyms, one might argue that the memory traces of common word representations (in languages other than German) are marked in lowercase, as they are mainly built on the interaction with many more accounts of the lowercase than the uppercase version of the words. Therefore, the next questions are: 1) Is letter-case information part of the stored lexical representations of common words? and 2) Could the OC hypothesis be extended to whole word letter-case? On the one hand, as outlined by Peressotti et al. (2003), first letter capitalization follows grammatical rules which, in turn, facilitate the discrimination between lexical categories (common nouns vs. proper names: Dr. House). As this is essential for writing in a correct manner, information about the first letter case could form part of the orthographic representation of words. On the other hand, uppercase format (*all caps)* is only used to convey extra-grammatical information. Capitalization of all letters is not only infrequent during normal writing/reading, but it follows specific purposes which are context-guided (e.g., uppercase words in headlines or advertisements), and is not governed by grammatical principles. While an all uppercase format is used for specific purposes such as to indicate the title/heading of a text (e.g., newspaper headlines), to emphasize a word or a sentence, or to indicate that a given word is an acronym, lowercase format is used in all the other general contexts. All in all, whereas the case of the initial letter appears to be a fundamental feature of printed words, letter-case of the whole word may not necessarily enjoy the same privileges during the visual identification of common words.

The main aim of the current experiment is to address the extent to which letter-case information plays a functional role during the visual word recognition of common words. To do so, we examined the time-course of letter-case in printed word processing in an ERP lexical decision experiment with words printed in lowercase vs. uppercase. To directly tackle this issue, we employed a single presentation paradigm (lexical decision task: "is the stimulus a word?"). We chose this paradigm over masked priming because the latter taps the effects of a prime stimulus on a target word, but it is not informative on the time-course of processing of the word itself (see Vergara-Martínez et al., 2013, for discussion).

Notably, behavioral measures such as word recognition times do not permit to thoroughly track whether the locus of the lowercase advantage is at an early prelexical level or at later orthographic-lexical levels. Instead, the Event Related Potentials (ERPs) technique allows for an exquisite time-course tracking of lexical access, a feature that renders it particularly suited to pinpoint the locus of the lowercase advantage during visual word recognition. There is some consensus that different ERPs can be linked with different levels of processing during visual word recognition (for a depiction of processing stages, see Grainger and Holcomb, 2009). Here, we focused on the N/P150, N250, and N400 components. The extraction of perceptual features can be linked to the N/P150, a component starting at around 80 ms and peaking at around 150 ms post-stimuli. Previous studies using various types of alphabetic stimuli (e.g., single letters: Petit et al., 2006; words: Holcomb and Grainger, 2006; Vergara-Martínez et al., 2015) showed that this component is sensitive to the physical variations of visual features (e.g., size, color, case) but not to lexical factors (e.g., lexicality, word frequency). Thus, the N/P150 component would reflect early perceptual/pre-lexical processes involved in the mapping of visual features onto location-specific letter representations. The N250 component peaks around 250–300 ms after stimulus onset and has been interpreted as an interface between sublexical processing and whole-word (lexical) representations. At this time window, the N250 is sensitive to the orthographic elements but not to other visual features such as font or color (Chauncey et al., 2008; Dufau and Grainger, 2008; see also Pickering and Schweinberger, 2003; Dickson and Federmeier, 2014). Finally, lexical-semantic processing has been associated to the N400 component, a negative deflection occurring between 300 and 600 ms after word offset (Kutas and Federmeier, 2000). As an example, either low-frequency words or semantically anomalous words produce larger N400 amplitudes than high-frequency words or semantically related words (see Kutas and Federmeier, 2011, for a review).

In sum, the present ERP lexical decision experiment aimed to pinpoint the locus of the lowercase advantage during visual word recognition (e.g., table vs. TABLE). We also included word-frequency as a factor in the design, the reason being that it is an excellent marker for the activation of lexical properties during visual word recognition [1] (see Kutas and Federmeier, 2011). This allows us to examine the time course not only of the effect of letter-case, but also its interplay with the effect of word frequency. What we should also note is that our experiment also has methodological implications. As indicated earlier, researchers employ interchangeably lowercase and uppercase words in their experiments, presumably on the basis that letter-case does not modulate other effects (e.g. lexical, semantic). If there is an effect of letter-case on lexical access beyond the pre-lexical level (e.g., word-frequency effects in the N400 being greater for low-than for high-frequency words), the choice of lowercase vs. uppercase should be justified in future research.

The predictions are clear. As indicated earlier, the Local Combination Detector model of word identification (Dehaene et al., 2005) assumes that sensitivity to letter-case (as occurs with other "physical" parameters such as color, font, or size) would be rapidly diffused when the visual input is mapped onto case-invariant units—the key elements underlying lexical access. Thus, an early effect of letter-case in a pre-lexical stage that vanished later during word processing would support the LCD model. Alternatively, if the effect of letter-case percolates along later stages during the activation of lexical units, this would favor the view that the lowercase/uppercase letter distinction forms an intrinsic part of word representations. Thus, both scenarios predict early ERPs (N/P150) to be sensitive to letter-case. Critically, if letter-case information were mapped onto abstract orthographic representations, we would expect the N250—and probably, the N400—to be sensitive to letter-case. Finally, as the initial contact to the lexicon has presumably taken place before 300 ms, one would expect the word-frequency effect to reach its maximum in the N400 component.

2. Method

Participants. Twenty-four undergraduate students of the University of Valencia (18 women) participated in the experiment in exchange for a small gift. All of them were native Spanish speakers, with no history of neurological or psychiatric impairment, and with normal (or corrected-to-normal) vision. Ages ranged from 18 to 35 years (mean = 22.5, SD = 3.4). All participants were right-handed, as assessed with a Spanish abridged version of the Edinburgh Handedness Inventory (Oldfield, 1971). Participants gave informed consent prior to the experiment. The data from four participants were discarded because of noisy EEG data. Thus, the final sample was composed of 20 participants. This research was approved by the Research Ethics Committee of the.

University of València and was in accordance with the declaration of Helsinki. All participants provided written informed consent before starting the experiment.

Materials. A set of 160 Spanish words of five and six letters were selected from the EsPal database (subtitle-based lexicon; Duchon et al., 2013). Half of the words were of high-frequency (M = 98.1 per million) and the other half were of low-frequency (M = 2.6 per million). The two sets of words were matched across a number of psycholinguistic variables: Number of Orthographic Neighbors, OLD20, Concreteness, and Imageability (see Table 1).

A set of 160 pseudowords was created with Wuggy (Keuleers and Brysbaert, 2010). The list of words/pseudowords is presented in the Appendix. Half of the stimuli were presented in lowercase and the other half in uppercase. Two counterbalanced lists were created in a Latin square manner, so that each target stimulus was rotated across the different conditions (i.e., if a given stimulus were presented in lowercase in List 1, it would be presented in uppercase in list 2). Different participants were randomly assigned to each list. Each list included 160 words (40 of high-frequency in uppercase; 40 of high-frequency in lowercase; 40 of low-frequency in uppercase; 40 of low-frequency in lowercase) and 160 pseudowords (80 in lowercase, 80 in uppercase).

Procedure. Participants were seated comfortably in a dimly lit and sound-attenuated chamber. All stimuli were presented on a high-resolution monitor that was positioned at eye level at a distance of approximately 60 cm from the participant. The stimuli were displayed in white Courier New 24-pt font (a monospaced font) against a dark-gray background, so that each stimulus occupied the same horizontal space regardless of letter-case. Participants performed a lexical decision task: they 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 (SÍ [YES] and NO). The hand used for each type of response was counterbalanced across subjects. Reaction Times (RTs) were measured from stimuli onset until the participants' response. The sequence of events in each trial was as follows: a fixation cross (+) appeared in the center of the screen for 800 ms, this was followed by a 200 ms blank screen which was replaced by a stimulus word or pseudoword that was presented in lowercase or uppercase and remained on the screen for 400 ms. After a 1000 ms blank screen, a picture of a smiley face was presented for 1800 ms. The appearance of the smiley face signaled to the participants that they could move their eyes or blink. Sixteen practice trials preceded the 320 stimuli of the experimental phase, and there were brief 10-sec breaks every 60 trials. Every 120 trials there was a short break, in which the impedance values were checked. To minimize subject-generated artifacts in the EEG signal during the presentation of the words/pseudowords, participants were asked to refrain from blinking and making eye-movements from the onset of the fixation cross to the onset of the smiley face. Each participant saw the words/pseudowords in a different random order. The whole experimental session lasted approximately 45 min.

EEG recording and analyses. The electroencephalogram (EEG) was recorded from 29 Ag/AgCl electrodes mounted in an elastic cap (EASYCAP GmbH, Herrsching, Germany) according to the 10/20 system, which were referenced to the right mastoid and re-referenced off-line to the averaged signal from two electrodes placed on the left and right mastoids. Eye movements and blinks were monitored with

Table 1
Mean values (range in brackets) of a number of controlled psycholinguistic variables for the stimuli in the experiment.

	Word-frequency	#Neighbors	OLD20	Concreteness	Imageability
HF	98.1 (25.1–657.6)	3.2 (0.0–6.0)	1.7 (1.3–2.9)	5.4 (1–5)	5.6 (1–5)
LF	2.6 (0.9–5.0)	5.0 (0.0–18.0)	1.6 (1.0–2.4)	5.6 (1–5)	5.6 (1–5)
PW	–	0.7 (0.0–7.0)	–	–	–

[1] Note that an alternative way of addressing the activation of lexical properties involves the Lexicality comparison (words vs pseudowords). However, in the lexical decision task, words and pseudowords differ not only on lexical status, but also on the response required for each type of stimuli (yes/no). Therefore, to avoid any confounding, we preferred to focus on the word-frequency comparison as it only involves word stimuli.

electrodes placed on the right lower and upper orbital ridge and on the left and right external canthi. The EEG recording was amplified and bandpass filtered between 0.01 and 100 Hz with a sample rate of 250 Hz by a BrainAmp (Brain Products, GmbH, Gilching, Germany) amplifier. Impedances were kept below 5 KΩ. An off-line bandpass filter between 0.01 and 20 Hz was applied to the EEG signal. All single-trial waveforms were screened offline for amplifier blocking, drift, muscle artifact, eye movements, and blinks. This was done for a 700-ms epoch (600-ms post-stimulus with a 100-ms pre-stimulus baseline). Trials containing artifacts or/and incorrect responses were not included in the average ERPs. This led to an average rejection rate of 11% of all trials (7.6% due to artifact rejection; 3.4% due to incorrect responses). The ANOVA on the number of included trials per condition showed a significant difference between the high (36 items in average, SD = 0.76) and low (35 items in average; SD = 0.65) frequency word conditions, $F(1,19) = 7.3$, $p = .014$, and a significant difference between the lowercase (36 items in average; SD = 0.61) and the uppercase (35 items in average; SD = 0.73) word conditions, $F(1,19) = 11.7$, $p = .003$. However, note that a minimum of 30 trials were included for each condition in the average ERP data from each participant. ERPs were averaged separately for each of the experimental conditions, each of the subjects, and each of the electrode sites.

The statistical analyses were performed on the mean voltage values of each critical condition in three time-epochs: 100–170 ms, 250–325 ms and 350–500 ms, and on the full montage of 27 scalp electrodes. We selected these time epochs to identify the temporal course of reliable differences between experimental conditions, on the basis of previous studies (Carreiras et al., 2007; Holcomb and Grainger, 2006; Grainger and Holcomb, 2009; Vergara-Martínez et al., 2015). To address the topographical distribution of the ERP results, the full set of 27 electrodes was included in the analyses by dividing the electrode montage into seven separate parasagittal columns along the anterior-posterior axis of the head (see Fig. 1; Massol et al., 2011; Vergara-Martínez et al., 2017). The lateral column analyses (referred to as col.1, col.2, col.3, extending outwards) included the factor anterior-posterior (AP) over dorsal electrode sites (three, four, or five levels) and the factor hemisphere (HEM) over rostral electrode sites. The midline column analysis only included the AP factor with three levels.

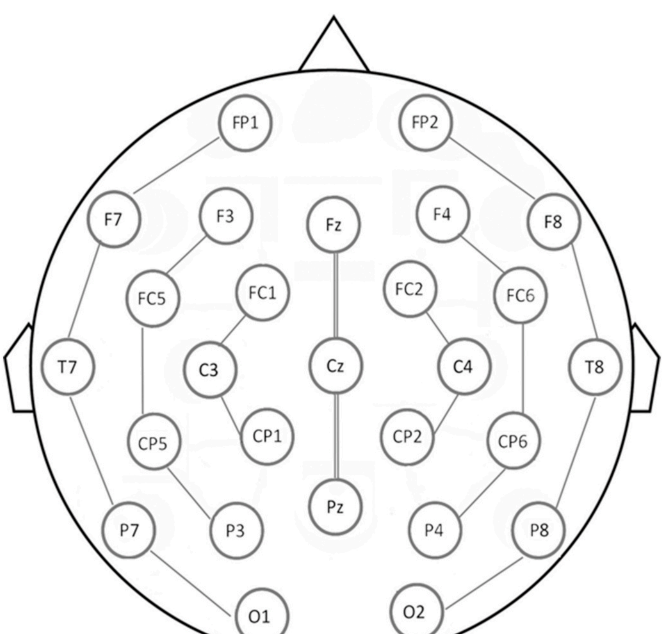


Fig. 1. Schematic representation of the electrode montage. Electrodes are grouped into 4 columns (midline and extending outwards 1, 2 and 3 columns) for statistical analysis.

In each of the three time-windows (100–170 ms, 250–325 ms and 350–500 ms), two distinct analyses of variance were run. In all cases, the Greenhouse–Geisser correction was applied in the case of lack of sphericity in the data. Firstly, separate sets of repeated measures ANOVAs were run on the data with factors Word Frequency and Letter-case. These ANOVAs were applied only to word stimuli and included the factors Word-Frequency, Letter-case, AP, and HEM (on three pairs of columns; Word-Frequency, Letter-case and AP on the midline column). Effects for the AP and HEM factors were reported when they interacted with the experimental manipulations. Interactions between factors were followed up with simple effect tests. Secondly, complementary sets of ANOVAs were performed on word and pseudoword data. In this design, Word-frequency was substituted by Lexicality (words/pseudowords; words' voltages were calculated as the mean values of high- and low-frequency words). Note that the presence and time-course of letter-case effects on non-existing stimuli (pseudowords) compared to the letter-case effects on real words, allows for a more accurate assessment of whether the effects of letter-case are due to some stored memory representations of words.

3. Results

3.1. Behavioral results

Error responses and lexical decision times less than 250 ms or greater than 1500 ms were excluded from latency analyses. The low-frequency word "efigie" was excluded from the analyses because the vast majority of participants did not know that word when asked after the experiment—accordingly, error rates to that word were 95%. The mean response times (RTs) and accuracy rates per condition are displayed in Table 2. For the word stimuli we computed the *F* ratios by participants (*F1*) and items (*F2*) on the latency and accuracy data with word-frequency and letter-case as factors. For the pseudowords the analyses were analogous except that the only factor was letter-case.

Word data. The ANOVA on the latency data showed, on average, faster word identification times for lowercase than for uppercase words (653 vs. 666 ms; $F1(1,19) = 7.89$, $p = .011$; $F2(1,157) = 4.39$, $p = .038$), and faster word identification times for high-frequency than for low-frequency words (627 vs. 692 ms, respectively; $F1(1,19) = 60.11$, $p < .001$; $F2(1,157) = 86.98$, $p < .001$). The interaction between Word-frequency and Letter-case did not approach significance (both $Fs < 1$).

The ANOVA on the accuracy data revealed that, on average, lowercase words were identified more accurately than uppercase words (0.976 vs. 0.967, respectively; $F1(1,19) = 4.70$, $p = .043$; $F2(1,157) = 3.55$, $p = .061$), and that high-frequency words were identified more accurately than low-frequency words (0.992 vs. 0.951, respectively; $F1(1,19) = 18.62$, $p < .001$; $F2(1,157) = 22.54$, $p < .001$). The interaction between the two factors approached significance ($F1(1,19) = 3.09$, $p = .095$; $F2(1,157) = 2.26$, $p = .135$)—this was due to the almost perfect performance for high-frequency words (see Table 2).

Pseudoword data. There were no signs of a letter-case effect in the latency or the accuracy data (all $Fs < 1$).

Although informative, mean RTs represent the sum of the sensory, cognitive and motor processes involved in the lexical decision task, so they do not address the specific locus of the lowercase advantage. Notably, the analyses of the RT distributions allow us to distinguish whether the locus of the effect taps onto encoding and/or evidence accumulation processes in lexical decision (see Gomez and Perea, 2014,

Table 2
Mean lexical decision times (in ms) and accuracy rates for the stimuli in the experiment.

	HF	LF	PW
Lowercase	621 (0.993)	686 (0.956)	754 (0.960)
Uppercase	633 (0.991)	699 (0.939)	756 (0.958)

for discussion). Specifically, changes in encoding processes between two conditions would be reflected as a shift of the RT distributions, whereas changes in evidence accumulation would be reflected as differences in the shape of the RT distributions (i.e., greater asymmetry in the slowest condition). We computed the .1, .3, 0.5, 0.7, and 0.9 quantiles for each participant and then averaged the values for each quantile over the participants. As shown in Fig. 2, we found a large word-frequency effect that increased in the higher quantiles (31, 55, 69, 92, and 110 ms at the 0.1, 0.3, 0.5, 0.7, and 0.9 quantiles, respectively), thus replicating earlier research (i.e., word-frequency influences evidence accumulation; Gomez and Perea, 2014; Ratcliff et al., 2004). Critically, the effect of letter-case was remarkably similar across quantiles (12, 13, 16, 12, and 10 ms at the 0.1, 0.3, 0.5, 0.7, and 0.9 quantiles, respectively), thus suggesting that the lowercase advantage occurs in early encoding stages rather than during lexical-semantic stages.

3.2. ERP results

Figs. 3 and 4 show the ERP waves for the Letter-case vs. Frequency comparisons (Fig. 3), and for the Letter-case vs. Lexicality comparisons (Fig. 4) in nine representative electrodes. The ERPs of all conditions showed an initial negative potential peaking around 100 ms. This was followed by a larger positivity ranging between 170 and 250 ms. Following these early potentials, a larger and slow negativity peaking around 400 ms can be seen at both anterior and posterior areas. Following the N400 component, the waves remain positive until the end of the epoch.

As shown in Figs. 3 and 4, starting around 100 ms, lowercase stimuli elicited larger negative amplitudes than uppercase stimuli. This letter-case difference remained in the following time-window (N250) with larger negativities for the lowercase than the uppercase condition, an effect that vanished at around 300 ms (see Fig. 5). The word-frequency effect and the lexicality effect were apparent at around 250 ms and reached their maximum at around 400 ms post-stimulus (see Figs. 3 and 4, respectively), with low-frequency words eliciting larger negativities than high-frequency words, and pseudowords eliciting larger negativities than words. The results of the statistical analyses are summarized in Tables 3 and 4.

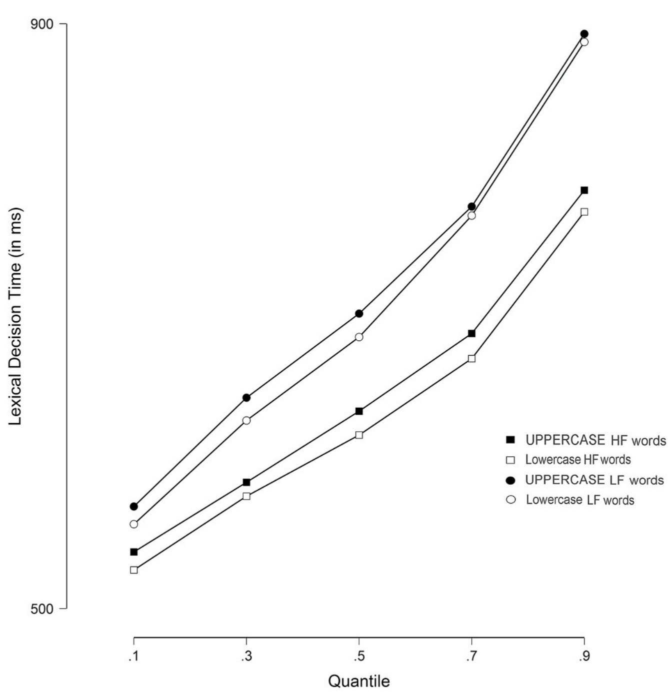


Fig. 2. Group RT distributions in the letter-case and word-frequency manipulations in word stimuli. Each point represents the average RT quantiles (.1, .3, 0.5, 0.7, and 0.9) in each condition. These values were obtained by computing the quantiles for each participant and subsequently averaging the obtained values for each quantile over the participants (see Vincent, 1912).

3.3. 100–170 ms epoch

Words (Letter-case x Word-Frequency design): The analysis on the different electrode-columns showed a main effect of Letter-case. In column 3 (peripheral electrodes), the Letter-case was modulated by AP distribution: frontal-temporal electrodes showed a Letter-case effect, while posterior-occipital electrodes did not. Neither the main effect of Word-Frequency, nor the interaction between Letter-case, Word-Frequency and/or any other topographical factor, was significant.

Words vs. Pseudowords (Letter-case x Lexicality design): As shown in Table 4, the results of this analysis mimicked those obtained above. We found a main effect of Letter-case. Neither the effect of Lexicality, nor the interaction between Letter-case, Lexicality and/or any other topographical factor, was significant.

3.4. 250–325 ms epoch

Words (Letter-case x Word-Frequency design): We found a main effect of Letter-case which was significant on midline and columns 1–2. A main effect of Word-frequency was also obtained across all electrode columns. None of the interactions between Letter-case, Word-Frequency and/or any other topographical factor was significant.

Words and Pseudowords (Letter-case x Lexicality design): Again, the results were parallel to those presented above—the only difference was that the interaction between Letter-case and AP distribution was significant: frontal-temporal electrodes showed a Letter-case effect, while posterior-occipital electrodes did not. A main effect of Lexicality was also obtained across all electrode columns. The interactions between Letter-case, Lexicality and/or any other topographical factor, were not significant.

3.5. 350–500 ms epoch

Words (Letter-case x Word-Frequency design): At this time-window, the analyses across electrode columns revealed no signs of an effect of Letter-case (all $Fs < 1$). This was accompanied by a main effect of Word-Frequency. None of the interactions between Word-Frequency, Letter-case and/or any other topographical factor, was significant.

Words and Pseudowords (Letter-case x Lexicality design): We found no signs of an effect of Letter-case (all $Fs < 1$), and this was accompanied by an effect of Lexicality across all columns. The interactions between Lexicality, Letter-case and/or any other topographical factor were not significant.

4. Discussion

The present experiment examined the locus of the lowercase advantage during the visual-word recognition of common words (table vs. TABLE) by tracking its electrophysiological signature. As in prior research, word identification times were faster for lowercase words than for uppercase words (see Mayall and Humphreys, 1996; Paap et al.,

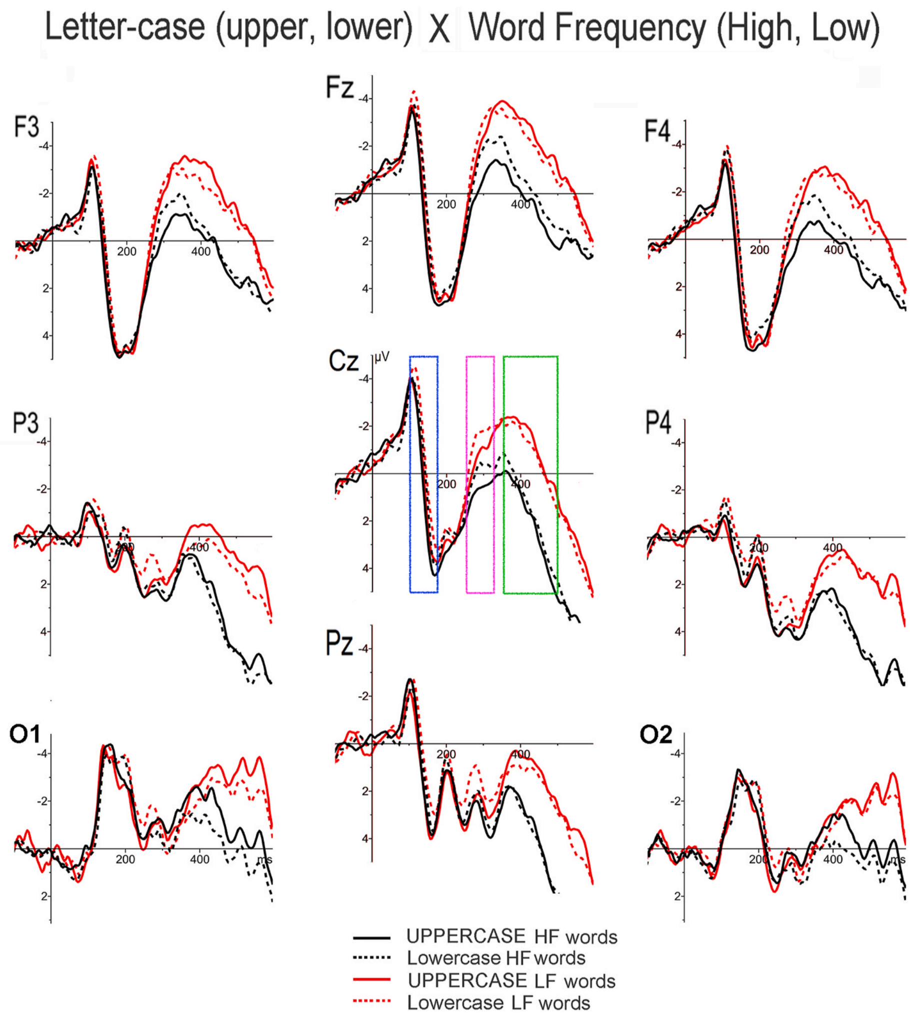


Fig. 3. Grand average event-related potentials to high- and low-frequency words in the two letter-case conditions (see legend), in nine representative electrodes from the different electrode columns. The bar charts represent the time epochs of interest.

1984, for early evidence). More importantly, the ERP results showed that both words and pseudowords elicited larger N/P150 [2] and N250 amplitudes when presented in lowercase than when presented in uppercase. This finding reveals an effect of letter-case originating in early visual-perceptual stages of processing which are independent of lexical status. Critically, this difference disappeared in the N400 time window. Thus, by this time epoch, retrieving lexical-semantic word properties from long-term memory runs independently of the letter-case. We also found a word-frequency effect in the latency data and in the ERP data—the effect started at the N250 component and reached its maximum at the N400. Finally, the effects of letter-case and word-frequency did not interact either in the behavioral or the ERP measures, thus suggesting that they tap different underlying processes (Sternberg, 2013).

In the following lines, we first discuss and interpret the effects of letter-case in the N/P150 and N250 components. Second, we discuss the implementation of perceptual typicality of lowercase in models of visual word recognition. Finally, we analyze the implications of these results for the LCD model (Dehaene et al., 2005) and for the framework of OC hypothesis (Peressotti et al., 2003).

Firstly, the observed effects of letter-case for both words and pseudowords at an early stage of stimulus processing, as measured by the N/P150 component, suggest that the effect of letter-case occurs at initial prelexical stages during visual word recognition. Converging evidence for this interpretation comes from the analyses of the RT distributions—these analyses showed that while the word-frequency effect increased in the higher quantiles, the effect of letter-case was remarkably similar across quantiles. These findings suggest that the letter-case manipulation taps onto early encoding stages of visual word recognition (see Gomez and Perea, 2014). With regard to the meaning of the early ERP letter-case effect, why did stimuli in lowercase elicit larger amplitudes starting in the 100–170 ms compared to the uppercase version? This phenomenon can be interpreted as a function of expertise with the stimuli. We, as readers, are much more familiarized with stimuli printed in lowercase than in uppercase. Indeed, previous research have consistently reported larger amplitudes on early negativities (N170) as a function of expertise in orthographic processing (Brem et al., 2006; Maurer et al.,2005, 2006; Araújo et al., 2015; Wong et al., 2005). For example, Wong et al. (2005) compared the ERPs of letter identification in two writing systems—using different alphabets—in two groups of participants with different expertise levels (monolingual and bilinguals). Monolingual subjects (English or French monolinguals) showed larger

[2] Compared to previous masked priming studies reporting a mirror effect on the N/P150 across frontal and occipital electrodes (Chauncey et al., 2008; Vergara-Martínez et al., 2015), the effects of letter-case were absent in the occipital electrodes in the present single presentation experiment. The specific temporal characteristics of stimulus presentation within each technique (masked priming vs. single presentation) may induce subtle differences in the time course of ERP components related to visual/perceptual processing (see Norris et al., 2018). Letter-case effects were indeed obtained in the 170–220 time-window over occipital electrodes only (see Figs. 3 and 4).

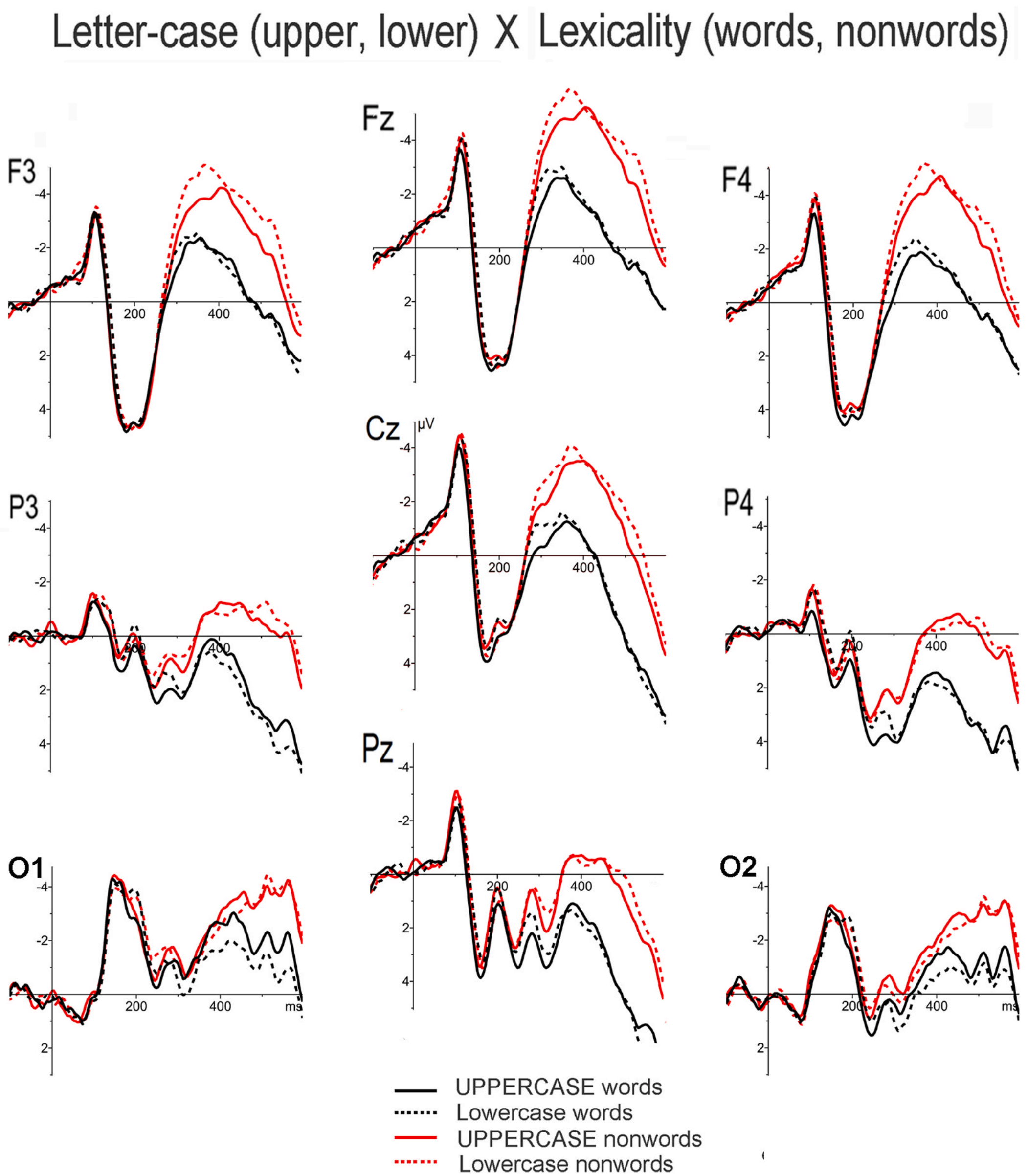


Fig. 4. Grand average event-related potentials to words and pseudowords in the two letter-case conditions (see legend), in nine representative electrodes from the different electrode columns.

N170 amplitudes for letter strings in their native language compared to letter strings of a foreign script (Chinese or Arabic). In contrast, the bilingual participants did not show these differences. Besides, recent research has found that this ERP effect is not only sensitive to expertise but also to visual familiarity (Xue et al., 2019). Similar to the present pattern of results, where lowercase format induced larger ERP amplitudes, Xue et al. (2019) reported larger N170 amplitudes for regular Chinese characters than for cursive Chinese characters—a less familiar format.

Secondly, the early differences regarding letter-case on the N/P150 extended further into the N250 time window, a finding that could be interpreted in terms of the lowercase stimuli being more efficiently computed at an orthographic level (Grainger and Holcomb, 2009). Alternatively, the N250 effect could merely reflect a spillover of earlier perceptual processing onto a prolonged time-interval (note that the effect of letter-case was remarkably similar not only for low- and high-frequency words, but also for pseudowords). To examine whether the effects of letter-case obtained across the two time epochs (100–170 ms and 250–325 ms) were functionally independent, we performed a topographic analysis in which we contrasted the effect of letter-case in the 100–170 ms epoch with the effect of letter-case in the 250–325 ms epoch (see Vergara-Martínez et al., 2015; Handy, 2005). Separate ANOVAs for each electrode column including letter-case, word frequency, epoch and the topographical factors hemisphere and anterior-posterior distribution, were ran on the raw ERP mean values and on the normalized values using a z-score procedure. Both analyses revealed similar results: we found main effects of letter-case and no signs of any interaction between letter-case and epoch, or between letter-case, epoch and any other topographical factor .[3] In light of this evidence, it is not possible to dissociate the effects obtained in the 250–325 as

[3] Statistical values for the raw (R) ERP mean values and on the normalized (N) values across columns. Letter-case [midline: R: $F(1,19) = 12.38$; $p < .01$; N: $F(1,19) = 9.13$; $p < .01$; col.1: R: $F(1,19) = 10.00$; $p < .01$; N: $F(1,19) = 10.69$; $p < .01$; col.2: R: $F(1,19) = 14.55$; $p < .01$; N: $F(1,19) = 11.51$; $p < .01$; col.3: R: $F(1,19) = 4.1$; $p < .05$; R: $F(1,19) = 2.6$; $p = .12$]. Letter-case*Epoch [midline, col.1, col.2: $Fs < 1$; col.3: R: $F(1,19) = 1.2$; $p = .18$; N: $F(1,19) = 2$; $p = .17$].

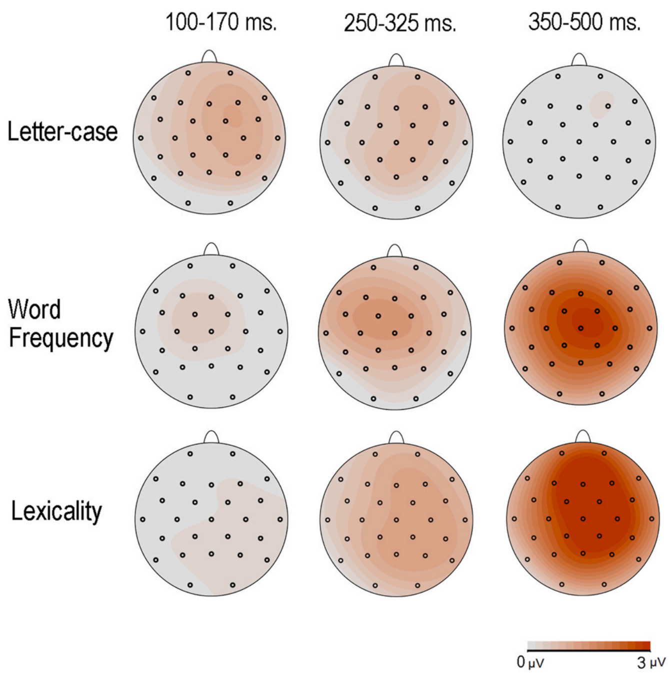


Fig. 5. Topographic distributions of letter-case, word frequency and lexicality effects across the three time-epochs of interest. The effects represent the difference in voltage amplitudes between the event-related potential responses to the upper-minus lowercase conditions across word stimuli (letter-case); the high-minus low-frequency conditions (word-frequency); and the words minus pseudowords conditions (lexicality).

Table 3
Summary of the F, p, and η2p values for the comparisons of letter-case and word frequency over the critical regions at the three time-epochs: 100–170 ms, 250–325 ms, and 350–500 ms). df of comparisons = 1,19. *p < .05. **p < .01. ***p < .001.

	regions	WORD ANALYSIS			
		letter-case		word frequency	
		F	η2p	F	η2p
100–170	midline	11.13**	0.369	…	…
	col.1	12.9**	0.405	…	…
	col.2	13.83**	0.421	…	…
	col.3	6.29*	0.249	…	…
	x AP	5.55*	0.225		
	FP1/FP2 = 6.96*; P7/P8=<1				
	F7/F8 = 9.03**; O1/O2=<1				
	T7/T8 = 10.27**				
		letter-case		**word frequency**	
250–325	midline	6.17*	0.245	13.14**	0.409
	col.1	6.29*	0.249	19.33**	0.504
	col.2	6.6*	0.405	13.07**	0.405
	col.3	1.2		6.06*	0.242
		letter-case		**word frequency**	
350–500	midline	…	…	60.38***	0.761
	col.1	…	…	64.75***	0.763
	col.2	…	…	49.26***	0.722
	col.3	…	…	40.04***	0.678

pertaining to separate underlying mechanisms already present in the 100–170 ms time window. These analyses thus favor the idea that the ERP effects of letter-case emerge very early and remain independent of lexical-semantic attributes. This is again in line with the proposal that letter-case in common words only affects the early stages of visual word recognition.

In short, we have shown that the locus of lowercase advantage in visual word recognition originates at very early stages of visual word processing and it does not percolate into later orthographic/lexical stages, a result that can be readily interpreted in terms of readers being more familiar with lowercase than with uppercase format.

Table 4
Summary of the F, p, and η2p values for the comparisons of letter-case and lexicality over the critical regions at the three time-epochs: 100–170 ms, 250–325 ms, and 350–500 ms). df of comparisons = 1,19. *p < .05. **p < .01. ***p < .001.

	WORD AND PSEUDOWORD ANALYSIS				
	regions	letter-case		lexicality	
		F	η2p	F	η2p
100–170	midline	13.64**	0.418	…	…
	col.1	15.39**	0.448	…	…
	col.2	16.67**	0.467	…	…
	col.3	8.67**	0.314	…	…
	x AP	6.20*	0.246		
	FP1/FP2 = 8.93**; P7/P8=<1				
	F7/F8 = 13.15**; O1/O2 = 1.5				
	T7/T8 = 12.47**				
		letter-case		**lexicality**	
250–325	midline	9.64**	0.33	32.29***	0.622
	col.1	8.84**	0.318	35.64***	0.652
	col.2	8.02*	0.297	38.80***	0.671
	col.3	2.47	0.115	40.34***	0.68
	x AP	4.5*	0.192		
	FP1/FP2 = 4.79*; P7/P8=<1				
	F7/F8 = 7.01*; O1/O2 = 1.5				
	T7/T8 = 4.07*				
		letter-case		**lexicality**	
350–500	midline	…	…	69.36***	0.785
	col.1	…	…	60.06***	0.76
	col.2	…	…	66.43***	0.778
	col.3	…	…	71.76***	0.791

Tables 3 and 4 Summary of the F, p, and η2p values for the comparisons of letter-case and word frequency (Table 3) and letter-case and lexicality (Table 4) over the critical regions at the three time-epochs:100–170 ms, 250–325 ms, and 350–500 ms). df of comparisons = 1,19. *p < .05. **p < .01. ***p < .001.

How could the lowercase advantage be implemented in the perceptual and graphemic units that are learnt and used in visual word recognition? The family of interactive activation models of visual word recognition postulates a hierarchical management of separate levels of representations for features, letters and word processing (see McClelland and Rumelhart, 1981). In these models, word-frequency is implemented at the level of word units: word-frequency effects are explained in terms of higher resting level of activation of word representations as a result of the repeated encounters with words. Nonetheless, the visual word recognition system seems permeable to "frequency" effects not only at the word level of representation, but also at lower levels of representation (letter level or even feature level; see Grainger et al., 2008, for a review). Indeed, New and Grainger (2011) conducted a series of letter identification experiments in which participants had to discriminate letters from pseudoletters. They found that the token frequency of letters (measured as the number of words that contain, for instance, the letter "a", weighted by each word frequency value) was a strong predictor of letter discrimination latencies. This implies that the frequency of exposure to printed words may affect not only the resting level of activation of word representations, as previously thought, but also the resting level of activation of letter representations. But more importantly for the question here (i.e., how is letter-case typicality implemented at a prelexical, letter-level of processing), the New and Grainger (2011) experiments also revealed that the strength of token letter frequency as a predictor of letter discrimination was a function of letters being presented in lower or uppercase, and whether the letter was presented in isolation or embedded in character strings (e.g. XXCXX). More specifically, the strongest predictor value of letter frequency in lowercase letter discrimination was reached when lowercase letters were embedded in strings (independently of position). In contrast, the strongest predictor value of letter frequency in uppercase letter discrimination was reached when uppercase letters were presented in isolation or in first position when embedded in strings. In sum, perceptual processing is not only sensitive to letter frequency but also to letter-case typicality (i.e., lowercase format). Thus, both exposure to printed words and letter-case are key factors in the early stages of orthographic/letter encoding. Future implementations of models of word recognition in Latin-based languages should accommodate these case-specific letter processing mechanisms.

What are the implications of these findings for the LCD model? As stated in the Introduction section, the LCD model posits a very limited and early role of letter-case during word recognition. Our experiment provided ERP evidence in support of this view, as we found robust and independent effects of letter-case (early stages of processing) and word frequency (later stages of processing) in both the behavioral and the electrophysiological data. In addition, the findings of identical effects of letter-case in both words and pseudowords, along with null effects of letter-case in the N400, do suggest that letter-case information for common words vanishes at early stages of visual word recognition (Dehaene et al., 2005; see also Grainger and van Heuven, 2003).

In light of the present findings, letter-case information does not seem to be part of the abstract orthographic representations of common words. This poses some limits to the idea of orthographic cues such as letter-case as playing a functional role during lexical retrieval. Indeed, the OC account (Peressotti et al., 2003) was originally proposed for the first letter-case of proper names in Italian, which embraces a scenario where letter-case does play a significant role: all names are written in lowercase except proper names, where first letter must be written in uppercase. We must learn this distinction during reading and writing acquisition. This information may facilitate lexical access by pre-activating units that share that common feature (proper names, if first letter is capitalized). Therefore, the representation of an orthographic feature such as case at a lexical level is functional regarding the specific context of the words' first letter. A similar scenario occurs in German, where the initial letter of all nouns must be capitalized. Indeed, Wimmer et al. (2016) found empirical and neuroimaging evidence fully consistent with the OC account. However, leaving aside these scenarios in which letter-case plays a linguistic function (e.g., proper names; nouns in German), capitalization of all letters is barely used and it is context-guided (e.g., headlines, billboards). Thus, the most parsimonious account for the effects of whole word letter-case is in terms of perceptual familiarity (New and Grainger, 2011; Perea et al., 2018).

In summary, we designed an experiment to track the locus of the lowercase advantage (e.g., table faster than TABLE) in visual word recognition. We found converging evidence favoring the idea of an early locus of the effect of letter-case: 1) it does not interact with the effect of word-frequency (i.e., a signature of lexical processing) behaviorally or electrophysiologically; 2) its magnitude is very similar for words and pseudowords in early time windows (N/P150); and 3) it vanishes in a lexical-semantic component (N400). At the theoretical level, these findings favor those neural models of visual word recognition that assume fast access to case-invariant representations (e.g., Dehaene et al.'s, 2005, LCD model). At the methodological level, these findings reveal that the practice of using interchangeably all lowercase or all uppercase stimuli in word recognition experiments is unlikely to make a difference regarding lexical-semantic processing. Further research is necessary to refine theoretical models of word recognition by examining the role of the visual familiarity of letters and words.

CRediT authorship contribution statement

Marta Vergara-Martínez: Conceptualization, Formal analysis, Writing - original draft. **Manuel Perea:** Conceptualization, Formal analysis, Writing - original draft. **Barbara Leone-Fernandez:** Conceptualization, Investigation, Formal analysis.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2020.107556.

References

Araújo, S., Faísca, L., Bramão, I., Reis, A., Petersson, K.M., 2015. Lexical and sublexical orthographic processing: an ERP study with skilled and dyslexic adult readers. Brain Lang. 141, 16–27. https://doi.org/10.1016/j.bandl.2014.11.007.

Besner, D., Davelaar, E., Alcott, D., Parry, P., 1984. Wholistic reading of alphabetic print: evidence from FBM and FBI. In: Henderson, L. (Ed.), Orthographies and Reading. Lawrence Erlbaum Associates, Inc, Hillsdale, NJ, ISBN 0863770096, pp. 121–135.

Brem, S., Bucher, K., Halder, P., Summers, P., Dietrich, T., Martin, E., Brandeis, D., 2006. Evidence for developmental changes in the visual word processing network beyond adolescence. Neuroimage 29, 822–837. https://doi.org/10.1016/j.neuroimage.2005.09.023.

Carreiras, M., Vergara, M., Perea, M., 2007. ERP correlates of transposed-letter similarity effects: are consonants processed differently from vowels? Neurosci. Lett. 419, 219–224. https://doi.org/10.1016/j.neulet.2007.04.053.

Chauncey, K., Holcomb, P., Grainger, J., 2008. Effects of stimulus font and size on masked repetition priming: an event-related potentials (ERP) investigation. Lang. Cognit. Process. 23, 183–200. https://doi.org/10.1080/01690960701579839.

Cohen, L., Dehaene, S., Naccache, L., Lehéricy, S., Dehaene-Lambertz, G., Hénaff, M.A., Michel, F., 2000. The visual word form area: spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. Brain 123, 291–307. https://doi.org/10.1093/brain/123.2.291.

Cohen, L., Lehéricy, S., Chochon, F., Lemer, C., Rivaud, S., Dehaene, S., 2002. Language-specific tuning of visual cortex? Functional properties of the visual word form area. Brain 125, 1054–1069. https://doi.org/10.1093/brain/awf094.

Dehaene, S., Cohen, L., Sigman, M., Vinckier, F., 2005. The neural code for written words: a proposal. Trends Cognit. Sci. 9, 335–341. https://doi.org/10.1016/j.tics.2005.05.004.

Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J.-B., Le Bihan, D., Cohen, L., 2004. Letter binding and invariant recognition of masked words: behavioral and neuroimaging evidence. Psychol. Sci. 15, 307–313. https://doi.org/10.1111/j.0956-7976.2004.00674.x.

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J.-F., Poline, J.-B., Rivière, D., 2001. Cerebral mechanisms of word masking and unconscious repetition priming. Nat. Neurosci. 4, 752–758. https://doi.org/10.1038/89551.

Dickson, D.S., Federmeier, K.D., 2014. Hemispheric differences in orthographic and semantic processing as revealed by event-related potentials. Neuropsychologia 64, 230–239. https://doi.org/10.1016/j.neuropsychologia.2014.09.037.

Duchon, A., Perea, M., Sebastián-Gallés, N., Martí, A., Carreiras, M., 2013. EsPal: one-stop shopping for Spanish word properties. Behav. Res. Methods 45, 1246–1258. https://doi.org/10.3758/s13428-013-0326-1.

Dufau, S., Grainger, J., Holcomb, P.J., 2008. An ERP investigation of location invariance in masked. Repetition Priming. Cognit. Affect Behav. Neurosci. 8, 222–228. https://doi.org/10.3758/cabn.8.2.222.

Gomez, P., Perea, M., 2014. Decomposing encoding and decisional components in visual-word recognition: a diffusion model analysis. Q. J. Exp. Psychol. 67, 2455–2466. https://doi.org/10.1080/17470218.2014.937447.

Gontijo, P.F.G., Zhang, S., 2007. The mental representation of brand names: Are brand names aclass by themselves? In: Lowrey, T.M. (Ed.), Psycholinguistic phenomena in marketing communications. Erlbaum, Hillsdale, NJ, pp. 23–37.

Grainger, J., Holcomb, P.J., 2009. Watching the word go by: on the time-course of component processes in visual word recognition. Language and Linguistic Compass 3, 128–156. https://doi.org/10.1111/j.1749-818X.2008.00121.x.

Grainger, J., van Heuven, W.J.B., 2003. Modeling letter position coding in printed word perception. In: Bonin, P. (Ed.), Mental Lexicon: Some Words to Talk about Words. Nova Science Publishers, Hauppauge, NY, pp. 1–23.

Grainger, J., Rey, A., Dufau, S., 2008. Letter perception: from pixels to pandemonium. Trends Cognit. Sci. 12, 381–387. https://doi.org/10.1016/j.tics.2008.06.006.

Handy, T.C., 2005. Event Related Potentials: A Methods Handbook. MIT Press, Cambridge, MA. Bradford Books, 978–0262083331.

Holcomb, P.J., Grainger, J., 2006. On the time course of visual word recognition: an event-related potential investigation using masked repetition priming. J. Cognit. Neurosci. 18, 1631–1643. https://doi.org/10.1162/jocn.2006.18.10.1631.

Jacobs, A.M., Grainger, J., Ferrand, L., 1995. The incremental priming technique: a method for determining within-condition priming effects. Percept. Psychophys. 57, 1101–1110. https://doi.org/10.3758/BF03208367.

Keuleers, E., Brysbaert, M., 2010. Wuggy: a multilingual pseudoword generator. Behav. Res. Methods 42, 627–633. https://doi.org/10.3758/BRM.42.3.627.

Kutas, M., Federmeier, K.D., 2000. Electrophysiology reveals semantic memory use in language comprehension. Trends Cognit. Sci. 4, 463–470. https://doi.org/10.1016/s1364-6613(00)01560-6.

Kutas, M., Federmeier, K.D., 2011. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). Annu. Rev. Psychol. 62, 621–647. https://doi.org/10.1146/annurev.psych.093008.131123.

Massol, S., Midgley, K.J., Holcomb, P.J., Grainger, J., 2011. When less is more: feedback, priming, and the pseudoword superiority effect. Brain Res. 1386, 153–164. https://doi.org/10.1016/j.brainres.2011.02.050.

Maurer, U., Brem, S., Bucher, K., Brandeis, D., 2005. Emerging neurophysiological specialization for letter strings. J. Cognit. Neurosci. 17, 1532–1552. https://doi.org/10.1162/089892905774597218.

Maurer, U., Brem, S., Kranz, F., Bucher, K., Benz, R., Halder, P., et al., 2006. Coarse neural tuning for print peaks when children learn to read. Neuroimage 33, 749–758. https://doi.org/10.1016/j.neuroimage.2006.06.025.

Mayall, K., Humphreys, G.W., 1996. Case mixing and the task-sensitive disruption of lexical processing. J. Exp. Psychol. Learn. Mem. Cognit. 22, 278–294. https://doi.org/10.1037/0278-7393.22.2.278.

McClelland, J.L., Rumelhart, D.E., 1981. An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. Psychol. Rev. 88, 375–407. https://doi.org/10.1037/0033-295X.88.5.375.

New, B., Grainger, J., 2011. On letter frequency effects. Acta Psychol. 138, 322–328. https://doi.org/10.1016/j.actpsy.2011.07.001.

Norris, D., Kinoshita, S., Hall, J., Henson, R., 2018. Is reading automatic? Are the ERP correlates of masked priming really lexical? Language, Cognition and Neuroscience 33, 1152–1167. https://doi.org/10.1080/23273798.2018.1493516.

Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9, 97–113. https://doi.org/10.1016/0028-3932(71)90067-4.

Paap, K.R., Newsome, S.L., Noel, R.W., 1984. Word shape's in poor shape for the race to the lexicon. J. Exp. Psychol. Hum. Percept. Perform. 10, 413–428. https://doi.org/10.1037/0096-1523.10.3.413.

Perea, M., Jiménez, M., Talero, F., López-Cañada, S., 2015. Letter[HYPHEN]case information and the identification of brand names. British Journal of Psychology 106, 162–173. https://doi.org/10.1111/bjop.12071.

Perea, M., Rosa, E., Marcet, A., 2017. Where is the locus of the lowercase advantage during sentence reading? Acta Psychologica 177, 30–35. https://doi.org/10.1016/j.actpsy.2017.04.007.

Perea, M., Marcet, A., Vergara-Martínez, M., 2018. Are you taking the fastest route to the RESTAURANT? The role of the usual letter-case configuration of words in lexical decision. Exp. Psychol. 65, 98–104. https://doi.org/10.1027/1618-3169/a000391.

Perea, M., Rosa, E., 2002. Does "whole word shape" play a role in visual word recognition? Percept. Psychophys. 64, 785–794. https://doi.org/10.3758/BF03194745.

Peressotti, F., Cubelli, R., Job, R., 2003. On recognizing proper names: the orthographic cue hypothesis. Cognit. Psychol. 47, 87–116. https://doi.org/10.1016/S0010-0285(03)00004-5.

Petit, J.P., Midgley, K.J., Holcomb, P.J., Grainger, J., 2006. On the time-course of letter perception: a masked priming ERP investigation. PsychonomicBullettin& Review 13, 674–681. https://doi.org/10.3758/BF03193980.

Pickering, E.C., Schweinberger, S.R., 2003. N200, N250r, and N400 event-related brain potentials reveal three loci of repetition priming for familiar names. J. Exp. Psychol. Learn. Mem. Cognit. 29, 1298–1311. https://doi.org/10.1037/0278-7393.29.6.1298.

Ratcliff, R., Gomez, P., McKoon, G., 2004. A diffusion model account of the lexical decision task. Psychol. Rev. 111,159–182. https://doi.org/10.1037/0033-295X.111.1.159.

Sternberg, S., 2013. The meaning of additive reaction-time effects: some misconceptions. Front. Psychol. 4, 744. https://doi.org/10.3389/fpsyg.2013.00744.

Sulpizio, S., Job, R., 2018. Early and multiple-loci divergency of proper and common names: an event-related potential investigation. Neuropsychologia 119, 107–117. https://doi.org/10.1016/j.neuropsychologia.2018.07.034.

Tinker, M.A., 1955. Prolonged reading tasks in visual research. J. Appl. Psychol. 39, 444–446. https://doi.org/10.1037/h0041553.

Vergara-Martínez, M., Comesaña, M., Perea, M., 2017. The ERP signature of the contextual diversity effect in visual word recognition. Cognit. Affect Behav. Neurosci. 17, 461–474. https://doi.org/10.3758/s13415-016-0491-7.

Vergara-Martínez, M., Gomez, P., Jiménez, M., Perea, M., 2015. Lexical enhancement during prime-target integration: ERP evidence from matched-case identity priming. Cognit. Affect Behav. Neurosci. 15, 492–504. https://doi.org/10.3758/s13415-014-0330-7.

Vergara-Martínez, M., Perea, M., Gomez, P., Swaab, T.Y., 2013. ERP correlates of letter identity and letter position are modulated by lexical frequency. Brain Lang. 125, 11–27. https://doi.org/10.1016/j.bandl.2012.12.009.

Vincent, S.B., 1912. The function of vibrissae in the behavior of the white rat. Behavioral Monographs 1 (Whole No. 5).

Wimmer, H., Ludersdorfer, P., Richlan, F., Kronbichler, M., 2016. Visual experience shapes orthographic representations in the visual word form area. Psychol. Sci. 27, 1240–1248. https://doi.org/10.1177/0956797616657319.

Wong, A.C., Gauthier, I., Woroch, B., Debuse, C., Curran, T., 2005. An early electrophysiological response associated with expertise in letter perception. Cognit. Affect Behav. Neurosci. 5, 306–318. https://doi.org/10.3758/CABN.5.3.306.

Xue, L., Maurer, U., Weng, X., Zhao, J., 2019. Familiarity with visual forms contributes to a left-lateralized and increased N170 response for Chinese characters. Neuropsychologia 134, 107194. https://doi.org/10.1016/j.neuropsychologia.2019.107194.