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Brief article

Resolving the locus of cAsE aLtErNaTiOn effects in visual word recognition: Evidence from masked priming ☆

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ABSTRACT

Determining the factors that modulate the early access of abstract lexical representations is imperative for the formulation of a comprehensive neural account of visual-word identification. There is a current debate on whether the effects of case alternation (e.g., tRaIn vs. train) have an early or late locus in the word-processing stream. Here we report a lexical decision experiment using a technique that taps the early stages of visual-word recognition (i.e., masked priming). In the design, uppercase targets could be preceded by an identity/unrelated prime that could be in lowercase or alternating case (e.g., table-TABLE vs. crash-TABLE; tAbLe-TABLE vs. cRaSh-TABLE). Results revealed that the lowercase and alternating case primes were equally effective at producing an identity priming effect. This finding demonstrates that case alternation does not hinder the initial access to the abstract lexical representations during visual-word recognition.

1. Introduction

Words presented in aLtErNaTiNg CaSe produce substantially longer reading times (i.e., lexical decision times, semantic categorization times, naming times, eye fixation times) than words presented in lowercase or uppercase (see Juhasz, Liversedge, White, & Rayner, 2006; Mayall, Humphreys, & Olson, 1997). Despite the robustness of this phenomenon, its temporal locus is still an unresolved issue. On the one hand, some authors claim that the locus of this effect is at an early encoding level that carries over the word recognition stream. As discussed by Mayall et al. (1997), within the early encoding theories, the disruption in processing from alternating case words could be due to: (i) lateral masking from the larger uppercase letters (e.g., the lowercase letters in BeAsT may be masked by its uppercase letter neighbors, thus slowing recognition); (ii) a disruption of trans-letter features (i.e., features that are larger than letters but smaller than words; e.g., BeAsT would disrupt the processing of the digraph "ea"); or (iii) an inappropriate grouping of same-case letters (e.g., the uppercase letters in BeAsT could activate BAT). On the other hand, other authors posit that the case alternation effect arises relatively late in word processing, when the word's abstract lexical representation is mapped back onto the sensory input (i.e., post-access checking; see Besner, 1983).

Determining the factors that modulate the access of abstract lexical representations is central for the formulation of computational and neural models of visual-word identification–note that the leading computational models

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of visual-word recognition employ an unrealistic all-uppercase font at the letter level (see Davis, 2010). To tell apart the early vs. late loci of the case alternation effect, Reingold, Yang, and Rayner (2010) conducted a sentence reading experiment in which the participants' eye movements were monitored. Sentences were presented in lowercase or in alternating case, and a target word either of low- or high-frequency was embedded in each sentence. Reingold et al. (2010) found that both case alternation and word-frequency affected the first fixation durations similarly. But the critical finding was that in trials with multiple fixations, the duration of the first fixation was modulated by word-frequency but not by case alternation. Under the assumption that the duration of the first fixation in multiple first-pass fixations is an index of early lexical processing, Reingold et al. concluded that the "case alternation manipulation largely impacts later attentional, lexical and post-lexical processing" (p. 1680).

Lien, Allen, and Crawford (2012) reached the opposite conclusions when exploring the time course of word-frequency (low, high) and case alternation (lowercase, alternating case) using event-related potentials (ERPs) in a lexical decision experiment. Their rationale was that a single-presentation task in which ERPs are measured would be a better method to isolate the locus of case alternation than presenting words in a sentence. Lien et al. (2012) found that case alternation effects occurred earlier in time (N170) than word-frequency effects (P3 component) and concluded: "the ERP data suggest an early locus of case mixing (structural encoding, as indexed by the N170 modulation) and a later locus of word frequency (stimulus categorization, as indexed by the P3 modulation)" (p. 684). In retrospect, the finding that visual word-form related variables yield the earliest effects is not surprising because the analysis of the visual input must start before any other information can be retrieved. However, contrary to Lien et al.'s interpretation, an early ERP effect of case alternation does not necessarily imply a reading cost that will affect the rest of the word processing stream. For instance, Chauncey, Holcomb, and Grainger (2008) obtained an early N/P150 effect of font in a masked priming experiment when they manipulated changes in size and font between prime and target (e.g., table-table; table-*table*), whereas null effects were observed in the N250 and subsequent ERP components. A similar pattern was also obtained by Vergara-Martínez, Gomez, Jiménez, and Perea (2015), who found an N/P150 effect when comparing the matched- and mismatched identity priming conditions in a masked priming lexical decision experiment (e.g., house-####-HOUSE vs. HOUSE-####-HOUSE); importantly for the present debate, this difference vanished later in processing for word stimuli (as revealed by the N250 and N400 components), and response times were similar in the matched and mismatched identity priming conditions (see also Jacobs, Grainger, & Ferrand, 1995, for a parallel behavioral finding).

An excellent technique to unveil the early processes underlying visual word recognition and that is relatively unaffected by processes occurring after lexical access is the masked priming technique (Forster & Davis, 1984; see also Grainger, 2008). In this technique, a briefly presented prime stimulus (around 30–50 ms) is preceded by a pattern of #'s and followed by the target stimulus, so that participants are unaware not only of the prime's identity, but also often of its existence. Therefore, masked priming can be used as "an indicator of completely automatic processes occurring deep within the lexical processor" (Forster, 1998, p. 229) and indeed there are qualitative differences between masked vs. unmasked priming (see Dehaene et al., 2001, for fMRI evidence; see Gomez, Perea, & Ratcliff, 2013, for a diffusion model account of these differences).

Based on the widely held assumption that masked priming taps into the very earliest stages of lexical access, the current masked priming lexical decision experiment was aimed at uncovering the temporal locus of the case alternation effect. The rationale is the following: If case alternation does affect the time required for the initial access to abstract lexical representations, the processing of the alternating case primes would be slower than that of lowercase primes, thus reducing the amount of identity priming (e.g., tAbLe-TABLE vs. cRaSh-TABLE < table-TABLE vs. crash-TABLE) and also yielding an effect of prime case (e.g., tAbLe-TABLE > table-TABLE; cRaSh-TABLE > crash-TABLE). Alternatively, if case alternation does not affect the time required for the initial access to abstract lexical representations but rather a post-access checking stage due to conscious processing (i.e., beyond the early processes that underlie masked priming), then alternating case primes should be as effective as lowercase primes (e.g., tAbLe-TABLE = table-TABLE < cRaSh-TABLE = crash-TABLE).

In a review of the masked priming literature, Forster (1998) cited an unpublished conference paper from his lab that showed that "mixed-case primes are just as effective as pure-case primes in a masked priming experiment (Forster & Guess, 1996)" (p. 221). However, no further information was provided. In addition, Arguin, Bub, and Bowers (1998) conducted a masked priming word naming experiment using a 100-ms prime followed by a 16.6 ms mask before the target presentation (in this study primes were always in alternating case and targets in uppercase, either repeated or unrelated). Arguin et al. found a sizeable (greater than 50 ms) masked identity priming effect with alternating-case primes (i.e., bAnD-####-BAND < gRaY-####-BAND). However, the lack of a lowercase priming condition and the relatively long prime duration makes it difficult to extract firm conclusions regarding the locus of the case alternation effect—the goal of their experiment was to compare the fast access to abstract representations in neurologically intact individuals and an individual with letter-to-letter alexia.

In the current experiment, identity and unrelated primes were presented either in lowercase or in alternating case for 33.3 ms, whereas the target was always presented in uppercase. A pattern mask was presented for 16.6 ms between the prime and the target to avoid the physical overlap between some of the letters (see Jacobs et al., 1995; Perea, Jiménez, & Gómez, 2014; Vergara-Martínez

et al., 2015, for a similar masked priming setup). Thus, the prime-target stimulus-onset asynchrony was 50 ms. Note that we use the standard priming term "identity primes" to refer to prime-target pairs that share the same letters regardless of case (i.e., "identity" does not mean physically identical). The predictions are straightforward. If the locus of the case alternation effect is early in word processing, there should be a processing cost in the targets preceded by an alternating case prime. Alternatively, if the locus of the case alternation effect is late in word processing, lowercase and alternating case primes should behave similarly.

2. Method

2.1. Participants

Forty undergraduate students from the University of Valencia took part in the experiment in exchange for extra credit. All of them were native speakers of Spanish and had normal/corrected-to-normal vision.

2.2. Materials

We selected 120 Spanish words of five letters from the B-Pal database (Davis & Perea, 2005). The mean frequency was 69 occurrences per million (range: 25–268) and the number of orthographic neighbors was 1.6 (range: 0–4). For the purposes of the lexical decision task, we also created 120 orthographically legal pseudowords of five letters. The mean number of orthographic neighbors was 2.1 (range: 1–4). The list of words and pseudowords is available at http://www.uv.es/mperea/alternating_case_MP.pdf. For each target stimulus, which was always presented in uppercase, we created four priming conditions in a 2 (letter prime: lowercase, alternating case) × 2 (prime-target relationship: identity, unrelated) design: (1) the same as the target but in lowercase (regla-REGLA); (2) the same as the target but in alternating case (rEgLa-REGLA; the uppercase letters were the second and the fourth); (3) an unrelated lowercase prime (half words, half nonwords); and (4) an unrelated alternating-case prime (half words, half nonwords; the uppercase letters were the second and the fourth). (Note that the lexical status of the unrelated primes does not affect the processing of the target stimuli; see Perea et al., 2014.) Four lists were created to counterbalance the materials across conditions in a Latin square manner (10 participants in each list).

2.3. Procedure

The experiment took place in a quiet room with groups of up to six participants. DMDX software (Forster & Forster, 2003) was employed to present the stimuli and record the participants' responses. On each trial, a series of five hash marks were presented for 500 ms on the center of a CRT monitor with a 16.6 ms refresh rate. This was replaced by the prime stimulus for 33.3 ms, which in turn was replaced by five hash marks for 16.6 ms. Immediately after, the uppercase target was presented and remained on the screen until the participant responded (or 2.5 ms had elapsed). All the stimuli were presented with a Courier New 14-pt font at the same spatial location. The participants were instructed to press the "sí" (yes) button if the target stimulus was a word in Spanish, and to press the "no" button if the target stimulus was not a word. Both speed and precision were stressed in the instructions. No participant claimed to have seen any prime stimuli when asked after the experiment concluded. Twelve practice trials preceded the 240 experimental trials. The session lasted for approximately 10–12 min.

3. Results

Error responses and response times (RTs) lower than 250 ms or greater than 1500 ms (0.5% of the data for words, and 1.6% of the data for pseudowords) were removed from the latency analyses. The mean correct RTs and error percentages from the by-subject analysis are shown in Table 1. For both the latency and error data, a 2 (prime-target relationship: identity, unrelated) × 2 (prime case: lowercase, alternating case) × 4 (List: list 1, list 2, list 3, list 4) ANOVA was conducted for both subject (F1) and item (F2) means. List was included as a factor to extract the error variance due to the counterbalancing lists. As usual in the masked priming literature, we conducted separate analyses for word and pseudoword targets (see Gomez et al., 2013, for discussion).

3.1. Word data

Responses to words were faster when preceded by an identity prime than when preceded by an unrelated prime, $F1(1,36) = 89.43$, MSE = 581.7, $p < .001$, $p(H_1|D) > 0.99$; $F2(1,116) = 75.56$, MSE = 2065.7, $p < .001$, $p(H_1|D) > 0.99$. (The Bayesian p values were computed using the routines described by Masson, 2011.) In addition, there were no signs of a main effect of Prime case (both Fs < 1;

Table 1
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and pseudoword targets in the experiment.

	Identity	Unrelated	Unrelated–identity
Words			
Lowercase prime	580 (3.3)	613 (3.2)	33 (−0.1)
Alternating-case prime	579 (2.8)	618 (3.9)	39 (1.1)
Pseudowords			
Lowercase prime	705 (6.2)	728 (7.6)	23 (1.4)
Alternating-case prime	708 (7.3)	733 (8.7)	25 (1.4)

$p(H_0|D) = 0.84$ and $p(H_0|D) = 0.90$) or an interaction between the two factors (both $Fs < 1$; $p(H_0|D) = 0.84$ and $p(H_0|D) = 0.91$).

The ANOVA on the error data failed to reveal any significant effects, all $ps > .27$.

3.2. Pseudoword data

The ANOVA on the RTs revealed that responses to pseudowords were faster when preceded by an identity prime than when preceded by an unrelated prime, $F1(1,36) = 17.49$, MSE = 1382.7, $p < .001$, $p(H_1|D) > 0.99$; $F2(1,116) = 13.49$, MSE = 3868.5, $p < .001$, $p(H_1|D) = 0.99$. Neither the effect of Prime case nor the interaction between the two factors was significant (Prime case: $F1(1,36) = 1.72$, MSE = 520.2, $p = .20$, $p(H_1|D) = 0.71$; $F2(1,116) = 1.42$, MSE = 2623.4, $p = .24$, $p(H_1|D) = 0.84$; interaction: both $Fs < 1$, $p(H_0|D) = 0.86$ and $p(H_0|D) = 0.91$).

The ANOVA on the error data revealed that participants committed fewer errors to pseudowords when preceded by an identity prime than when preceded by an unrelated prime, $F1(1,36) = 3.85$, MSE = 18.8, $p = .057$; $F2(1,116) = 2.64$, MSE = 91.3, $p = .107$. The other effects were not significant, both $ps > .14$.

4. Discussion

The current experiment was designed to distinguish the early vs. late accounts of the case alternation effect by using a technique (i.e., masked priming) that taps the earliest stages of visual-word processing (Forster, 1998; Forster & Davis, 1984; Grainger, 2008). If words in alternating case slow down the early stages of word processing, alternating-case primes should reduce the amount of identity priming relative to lowercase primes. Results revealed that targets behaved virtually the same when preceded by an alternating case prime and when preceded by a lowercase prime. Therefore, it follows that the case alternation manipulation does not slow down the initial processing of the words (i.e., the locus of the case alternation manipulation must occur at late, post-access processes). Importantly, the same pattern occurred for word and pseudoword targets (see Perea et al., 2014; Vergara-Martínez et al., 2015, for evidence of masked identity priming effects for pseudowords). That is, top-down feedback from the lexical level was not responsible for the lack of case alternation effects in words.

To corroborate these findings, we examined if the null case alternation effect in the mean RTs might be hiding effects that occur at different points in time and in opposite directions. To this end, we calculated the .1, .3, .5, .7 and .9 quantiles for the identity conditions and averaged them across subjects (i.e., we calculated vincentiles), and then obtained the differences between the lowercase and the alternating-case conditions for each of the quantiles. This allows us to examine the effect sizes across the quantiles of RT distributions (i.e., quantile–quantile differences). The RT distributions were virtually indistinguishable as these differences are quite small (words: 5, 0, −1, −1, −5 ms; pseudowords: −8, −1, −3, −1, 9 ms, for the .1, .3, .5, .7 and .9 quantiles, respectively).

The present data are consistent with recent evidence from other paradigms supporting a late locus of the effect of case alternation. As indicated in Section 1, in a sentence reading experiment, Reingold et al. (2010) found that the duration of the first fixation (in multiple fixation trials) was modulated by word-frequency but not by case alternation, and the authors concluded that the effect of word-frequency (i.e., a marker of lexical access) occurs earlier than the effect of case alternation. Furthermore, in a brain imaging (PET) study using a word-naming task, Mayall, Humphreys, Mechelli, Olson, and Price (2001) found that, when compared with lowercase words, alternating-case words did not increase activation in language areas of the left-hemisphere typically associated with word processing; instead, they produced increased activation in an area of the right parietal cortex which has frequently been associated with visual attention.

How do we reconcile all these data with the findings reported by Lien et al. (2012)? Lien et al. found an effect of case alternation in an early ERP component (N170) that disappeared in a later component (P300), thus suggesting an early locus of the case alternation effect. However, because they did not examine other dimensions of the ERPs but the N170 and the P300 amplitudes, it is difficult to make inferences on the full time course of the case alternation effect. Although the N170 has been related to the early perceptual encoding of faces and orthographic processing, its amplitude is also modulated by non-face and non-orthographic stimuli when participants have extensive experience viewing these stimuli (Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002; see Simon, Petit, Bernard, & Rebaï, 2007, for N170 effects when words are repeated 100 times). Thus, these early effects are sensitive to statistical regularities within well-learned visual image categories of which lowercase words are premier examples (Schendan, Ganis, & Kutas, 1998). While this very early component may be sensitive to the visual familiarity of orthographic patterns, it is difficult to make strong inferences on the connection between this early, perceptual ERP effect and lexical access. As indicated in Section 1, an effect in an early visual component (e.g., N/P150) may not necessarily cascade into later components associated with lexical processing (e.g., N250 or N400; see Chauncey et al., 2008; Vergara-Martínez et al., 2015).

In sum, the present masked priming experiment demonstrated that the case alternation effect does not have its origin early during word processing: visually unfamiliar alternating-case primes behaved similarly to lowercase primes (e.g., tAbLe-TABLE = table-TABLE < cRaSh-TABLE = crash-TABLE). Two theoretically significant conclusions can be advanced. First, identity priming of words are robust to case alternation, which reveals that masked priming effects in lexical decision occur at a level of abstract representations, regardless of visual familiarity. Second, the effect of case alternation has a late temporal locus, probably linked to the interplay between the visual input and the abstract orthographic codes when forming a conscious stable percept.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2015.05.007.

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