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ORIGINAL ARTICLE

Does CaSe-MiXinG disrupt the access to lexico-semantic information?

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Abstract

Mixed-case WoRdS disrupt performance in word recognition tasks and sentence reading. There is, however, a controversial issue around this finding as the hindered performance could be related to impoverished lexico-semantic access or to lack of visual familiarity. The present experiments aim to examine whether there is a genuine mixed-case effect during lexico-semantic access or whether the effect is driven by a visual familiarity bias (i.e., lack of familiarity may induce a bias toward "no" responses in word/nonword decisions). Participants were presented with same-case vs. mixed-case items in a word/nonword discrimination task (lexical decision) and in a task that requires access to semantic information (semantic categorization). In lexical decision, responses were faster and more accurate to same-case words than to mixed-case words, whereas the nonwords showed the opposite pattern. In two semantic categorization experiments, we failed to find any signs of a case-mixing effect for words. Therefore, the case-mixing effect in word recognition is not due to an impoverished access to lexico-semantic information but rather to lack of visual familiarity.

Introduction

A fundamental topic in reading research is the examination of the mechanisms responsible for converting the visual input into stable letter/word representations. With this goal in mind, researchers have devised a number of experimental manipulations aimed at shedding some light on the processes underlying lexical access. One of the most illuminating manipulations entails mixed-case words. Even though mixed-case words are composed of perfectly legible letters, the combination of lowercase and uppercase letters creates a printed stimulus that is visually unfamiliar (e.g., LaTeRaL). Previous research has shown that mixed-case words produce longer response/fixation times than same-case words in word recognition tasks (e.g., lexical decision, see Allen, Wallace, & Weber, 1995; Besner, 1983; Besner & McCann, 1987; Frederiksen, 1978; Kinoshita, 1987; Lavidor, Ellis, & Pansky, 2002; Mayall & Humphreys, 1996) and sentence reading (see Reingold & Rayner, 2006; Reingold, Yang, & Rayner, 2010). Here we examined whether the case-mixing cost for words is due to impoverished lexico-semantic access or simply to lack of visual familiarity.

There is already indirect evidence across several paradigms that may be taken to suggest that the bulk of the case-mixing cost does not occur in the initial contact to the lexico-semantic representations. Using Forster and Davis' (1984) masked priming technique, mixed-case repetition primes are as effective as same-case (lowercase) repetition primes at activating uppercase target words (latency data: LaTeRaL–LATERAL = lateral–LATERAL and nUcLeAr–LATERAL = nuclear–LATERAL; Forster, 1998; see also Lee, Honig, & Lee, 2002; Perea, Vergara-Martínez, & Gomez 2015, for similar evidence). If mixed-case words were initially encoded more slowly than same-case words, one would have expected a smaller masked repetition priming effect for mixed-case primes than for same-case primes. Likewise, Blais and Besner (2005) found that the magnitude of the Stroop effect was similar for same-case (lowercase) words (e.g., green; green) and mixed-case words (gReEn; gReEn) (see also Houston, Rossmiller, & Allen, 2016, for converging evidence). That is, mixed-case words were as effective as same-case words at initially accessing semantic information. Further evidence comes from the picture–word interference paradigm used by Miozzo and Caramazza (2003). They found that the distractor frequency effect (i.e., picture naming times are longer when there is

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a superimposed low-frequency word than when there is a superimposed high-frequency word) was virtually the same for same-case (uppercase) words (e.g., HAND) and mixed-case words (hAnD). Again, if mixed-case words were less effective at activating lexico-semantic representations than same-case words, one would have expected a greater distractor frequency effect for same-case words than for mixed-case words. Finally, in a sentence reading task with mixed-case vs. lowercase words, Reingold et al. (2010) found that, for those target words that received several fixations, the first fixation duration was sensitive to word-frequency (i.e., a lexical effect) but not to letter-case. Therefore, the word-frequency effect arises earlier than the case-mixing effect. Taken together, these findings strongly suggest that the cost that occurs when identifying mixed-cased words does not take place at an early prelexical stage, but rather at a later processing stage[1].

In the present experiments, we directly examined the hypothesis that case mixing mainly affects some post-access decision processes in which the visual familiarity of the whole string is evaluated (see Besner, 1983; Reingold & Rayner, 2006, for a similar proposal). The idea is that, as occurs with faces, a printed word can be understood as a special form of a familiar visual pattern (e.g., a noun [tree], a brand name [IKEA], or an acronym [FBI]). Assuming that lexical decision (i.e., a word/nonword discrimination task) is a variety of recognition memory tasks, the familiarity of the visual configuration of the printed stimulus may be used to bias "yes" or "no" responses—this is akin to recognizing the face of a person as familiar without necessarily knowing the name of the person (see Besner & McCann, 1987). Specifically, Besner (1983) proposed that readers might use a crude estimate of the familiarity of the printed word "as a source of evidence to bias decisions in lexical decision" (Besner, 1983, p. 433): familiar visual patterns (e.g., same-case words: lateral) would produce a "yes" bias, whereas unfamiliar visual patterns (e.g., mixed-case words: LaTeRaL) would produce a "no" bias. Similarly, Forster (1998) suggested that the lack of visual familiarity of the mixed-case word LaTeRaL might induce a bias toward a "no" response in lexical decision when compared to same-case words like lateral or LATERAL. This response conflict would delay—or make more difficult—a "yes" response to mixed-case words. Thus, the visual familiarity hypothesis can readily accommodate the longer response times (and more errors) for mixed-case words than for same-case words in lexical decision (e.g., see Allen et al., 1995; Besner & McCann, 1987; Kinoshita, 1987; Mayall & Humphreys, 1996). Furthermore, the visual familiarity hypothesis can also capture the longer lexical decision times to brand names when presented in a visually unfamiliar letter-case format (e.g., ikea) than when presented in the standard, familiar letter-case format (IKEA; see Perea, Jiménez, Talero, & López-Cañada, 2015). We defer a discussion of how visual familiarity is represented for words until the "General discussion".

Importantly, the visual familiarity hypothesis makes two strong, testable predictions on the case-mixing effect in binary word recognition tasks. First, lack of familiarity of mixed-case stimuli would induce a bias for "no" responses in lexical decision to both words and nonwords. Therefore, mixed-case nonwords like nUbArO would be more biased toward a "no" response than same-case nonwords like nubaro or NUBARO, thus predicting faster "no" responses to nUbArO than to NUBARO. That is, the visual familiarity hypothesis predicts a dissociation of case-mixing effects in lexical decision (i.e., inhibitory for words and facilitative for nonwords). Second, the case-mixing effect should be dramatically diminished in those binary word recognition tasks in which visual familiarity plays (if anything) a minor role (see Besner, 1983; Kinoshita, 1987, for a similar argument), such as a semantic categorization task. Clearly, when deciding that a given word is an animal name or not, the source of evidence should be the meaning of the word and not its visual familiarity (e.g., LATERAL vs. LaTeRaL). As a result, one would expect similar word identification times for LATERAL and LaTeRaL in a semantic categorization task.

Nonetheless, there is empirical evidence that appears to be incompatible with these two predictions. First, whilst effect sizes across studies were highly heterogeneous (ranging from 16 ms [Besner & McCann, 1987] to 129 ms [Kinoshita, 1987]), prior lexical decision experiments in English have consistently reported slower responses to mixed-case nonwords than to same-case nonwords. Second, prior research has shown an advantage of same-case uppercase words over mixed-case words in semantic categorization tasks (Mayall & Humphreys, 1996), but again the magnitude of the effect varied enormously, ranging from 9.5 to 91 ms even with the same participants.

The massive variability in the magnitude of mixed-case effects in prior lexical decision and semantic categorization experiments suggests that a number of potentially uncontrolled factors may have hindered the responses to mixed-case stimuli over and above the case-mixing effect. As Kinoshita and Norris (2010) pointed out, a subtle element such as the use of the potentially ambiguous letter I may severely disrupt word/nonword processing in mixed-case words like sUITrY, as this letter could be perceived as the lower case of the letter L or the upper case of the letter i.

[1] What we should also note is that there is ERP evidence that N170 amplitude is sensitive to case mixing (Lien, Allen, & Crawford, 2012), and this may be taken as an early signature of case-mixing. However, as Perea et al. (2015) noted, "it is difficult to make strong inferences on the connection between this early, perceptual ERP effect and lexical access" (p. 42).

Another element to consider here is that the case-mixing manipulation is typically a "case alternation" manipulation. As a result, depending on the characteristics of the stimuli, case alternation may have disrupted the processing of graphemic units, such as digraphs (e.g., compare thing and tHiNg), double letters (e.g., compare watt with wAtT) or context-dependent vowels (e.g., compared hEaD /hed/ with bEaD /biːd/) in deep orthographies like English. In an attempt to minimize this issue, in the present experiments, we employed a language with simple grapheme-to-sound rules and without context-dependent vowels (Spanish). Furthermore, the letters that composed the mixed-case words were presented in a consistent case for all mixed-case stimuli, either in lowercase or uppercase (e.g., the letters B and L were always presented in uppercase, whereas the letters n and a were always presented in lowercase), as in the words TRiBunaL or LaTeRaL. This manipulation, while creating visually unfamiliar mixed-case words, avoids presenting the double letters (e.g., LL) in different letter-case (e.g., PaeLLa and not PaElLa) or presenting the same letter (e.g., a) in different letter-case within the same word (e.g., aLTaR and not aLtAr).

Furthermore, we controlled for another factor that may potentially disrupt the processing of mixed-case words: letter size (e.g., compare aLTaR with ALTAR). The idea is that uppercase letters—being physically larger—may mask the lowercase letters or induce some letter grouping (e.g., the uppercase letters in sPrInG may activate the word PIG; see Humphreys, Mayall, & Cooper, 2003). To avoid this potential confound, both mixed-case and same-case words had a similar whole-word envelope: mixed-case words were composed of uppercase and lowercase letters with approximately the same height (equal-size mixed-case words like LaTeRaL) and same-case words were composed of uppercase letters (e.g., LATERAL). Finally, to examine whether letter size plays a role in the processing of mixed-case words, we compared equal-size mixed-case words with standard mixed-case words (e.g.,LaTeRaL vs. LaTeRaL)—note that the empirical evidence on this issue is scarce and inconsistent. Smith (1969) and Smith, Lott, and Cronnell (1969) found similar performance in a reading aloud task and in a search task for standard mixed-case words and equal-size mixed-case words, whereas Mayall, Humphreys, and Olson (1997) found slower naming times for standard than for equal-size mixed-case words.

In sum, the current experiments directly examined whether there is a genuine deleterious effect from mixed-case stimuli during lexico-semantic processing or whether the reading cost of mixed-case words is mainly due to lack of visual familiarity. To that end, we compared same-case words vs. mixed-case words in two binary word recognition tasks. In Experiment 1, we employed a task that is sensitive to visual familiarity (lexical decision; "is the item a word?"), whereas in Experiments 2 and 3 we employed a task that requires unique access to semantic information rather than an assessment of visual familiarity (semantic categorization; "is the word an animal name?"). To obtain stable response time data in each of the experimental conditions, we employed a large set of stimuli: 480 trials in the lexical decision experiment and 336 trials in the semantic categorization experiments.

If the case-mixing effect during word recognition is due to a post-access mechanism that takes visual familiarity as a source of evidence in lexical decision (i.e., lack of visual familiarity induces "no" responses), we expect faster and more accurate "yes" lexical decision responses for same-case words (e.g., LATERAL) than for mixed-case words (LaTeRaL) and, conversely, we expect slower and less accurate "no" responses for same-case nonwords (e.g., TEBADA) than for mixed-case nonwords (TeBaDa). We also examined whether letter size played a role in the case-mixing effect by comparing equal-size mixed-case words and standard mixed-case words (i.e., LaTeRaL vs. LaTeRaL). To anticipate the results, we found a case-mixing effect in line with the visual familiarity hypothesis (i.e., a cost for words; a benefit for nonwords). In Experiments 2 and 3, we employed a task that requires unique access to lexico-semantic information: a semantic categorization task ("is the word an animal name?"). If the case-mixing effects in Experiment 1 were purely due to a visual familiarity bias that occurs in lexical decision, we should obtain similar response times for equal-size mixed-case words and same-case words in semantic categorization (e.g., LaTeRaL would produce similar word identification times as LATERAL). Alternatively, if there is genuine cost for mixed-case words at retrieving lexico-semantic information, response times should be faster for same-case than for equal-size mixed-case words (e.g., LATERAL faster than LaTeRaL).

Experiment 1 (lexical decision)

Method

Participants

In each of the experiments, we recruited 24 psychology students at the University of Valencia. All of them were native speakers of Spanish and signed a consent form before starting the experiment. None of them reported having any reading difficulties. The experiments were approved by Experimental Research Ethics Committee of the Universitat de València.

Materials

We selected 240 words from the EsPal subtitle-based Spanish database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). The mean number of letters was 6.4 (range 5–8), the mean familiarity scores (out of seven) was 5.8 (range 3.4–7.0), and the mean Zipf word-frequency was 4.17 (range 2.24–5.91) (see Brysbaert, Mandera, & Keuleers, 2017, for the advantages of the Zipf scale to estimate word-frequency). We also created 240 orthographically legal pseudowords matched in length and subsyllabic segments with the words using Wuggy (Keuleers & Brysbaert, 2010). Each item could be presented in same-case uppercase format (LATERAL), equal-size mixed-case format (LaTeRaL), and standard mixed-case format (LaTeRaL). For the mixed-case items, the vowels and the consonants m, n, and ñ were presented in lowercase, whereas the other letters were presented in uppercase (e.g., LaTeRaL). As most syllables in Spanish are CV or CVC, this typically creates an alternation of letter-case within the words. We employed Verdana 14-pt font for the letters in same-case, standard mixed-case format, and the uppercase letters in the equal-size same-case format. For the lowercase letters in the equal-size mixed-case format we employed Verdana 18-pt except for the letter i in which we employed Verdana 16-pt so that the diacritic mark would not be visually salient. We created three lists in order to counterbalance the stimuli across lists (e.g., one-third of the participants would be presented with LATERAL, another third would be presented with LaTeRaL, and the rest of participants would be presented with LaTeRaL). Thus, each participant received 80 same-case words, 80 equal-size different-case words, and 80 standard mixed-case words. The list of stimuli across the different formats in Experiments 1–3 is available at http://www.uv.es/mperea/Items_PFM.pdf.

Procedure

The experimental session took place individually in a quiet room using a computer equipped with DMDX (Forster & Forster, 2003). On each trial, a fixation point (+) was presented on the center of the screen for 500 ms, and then it was replaced by the stimulus item. The item was on the screen until the participant responded or 2000 ms had elapsed—if no response was made after this period, it was considered as an incorrect response. Participants were instructed to decide whether the letter string at the center of the computer screen was a real word or not by pressing the buttons labeled as "sí" (yes) or "no". This decision had to be made as fast as possible while trying to keep accuracy high. Sixteen practice trials preceded the 480 experimental trials. The entire session lasted for approximately 20–24 min.

Table 1 Mean response times (in ms) and error rates (in parentheses) for words and nonwords in Experiment 1 (lexical decision task)

	Same-case	Equal-size mixed-case	Standard mixed-case
Words	600 (3.6)	630 (5.4)	634 (7.1)
Nonwords	707 (7.2)	694 (4.8)	686 (5.0)

Results and discussion

Incorrect responses and very fast correct response times (shorter than 250 ms; 3 observations) were removed from the latency data. The mean correct lexical decision times and the error rates in each condition are shown in Table 1.

To analyze the data, we employed linear mixed effects models with the fixed factor Type of Stimulus (same-case, equal-size mixed-case, standard mixed-case) for words and nonwords separately using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) in R (R Development Core Team, 2018). For each model, the factor Type of Stimulus was coded to test the two contrasts of interest: the effect of mixed-case (same-case vs. equal-size mixed-case) and the effect of letter size (equal-size mixed-case vs. standard mixed-case conditions). For the word data, we also included Zipf word-frequency as a covariate in the model—this was centered, as recommended by Baayen (2008). We chose the most complex linear mixed effect model—in terms of random effect structure—that converged for each dependent variable (latency data; accuracy data). These models are presented in the supplemental materials. For the latency data, we transformed the response times (−1000/RT) to maintain the normality assumption of these models. The p values were obtained with the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2017). For the accuracy data, we employed generalized mixed effects models, where accuracy was coded as binary values. Finally, the pattern of significant effects in this and subsequent experiments was also corroborated with by-subject and by-item analyses of variance with untransformed RT data.

Word data The analyses of the latency data showed that participants responded to faster to same-case words than to equal-size mixed-case words (600 vs. 630 ms, respectively), $t = 5.642$, $b = 0.076$, $SE = 0.014$, $p < .001$, whereas the 4-ms advantage of the equal-size mixed-case words over the standard mixed-case words was not significant (630 vs. 634 ms, respectively), $t = 1.285$, $b = 0.016$, $SE = 0.013$, $p = .211$. Finally, the effect of Zipf word-frequency was significant (i.e., faster response times to higher frequency words), $t = -9.395$, $b = 0.077$, $SE = 0.008$, $p < .001$.

The analyses of the accuracy rates showed that participants were more accurate to same-case words than to equal-size mixed-case words, $z = 2.903$, $b = 0.479$, $SE = 0.165$,

$p = .004$, and participants were more accurate to equal-size mixed-case words than to standard mixed-case words, $z = -2.14$, $b = -0.300$, SE $= 0.141$, $p = .03$. Finally, the effect of Zipf word-frequency was also significant (i.e., higher accuracy for higher frequency words), $z = 6.863$, $b = 0.873$, SE $= 0.127$, $p < .001$.

Nonword data The analyses of the latency data showed that equal-size mixed-case nonwords were responded to faster than same-case nonwords (694 vs. 707 ms, respectively), $t = 3.495$, $b = 0.003$, SE $= 0.009$, $p < .001$. The 8-ms advantage of the standard mixed-case nonwords over the equal-case mixed-case nonwords (686 vs. 694 ms, respectively) was not significant, $t = -1.582$, $b = 0.001$, SE $= 0.009$, $p = .116$.

The analyses of the accuracy rates showed that participants were more accurate to equal-size mixed-case nonwords than to same-case nonwords ($z = -3.427$, $b = -0248$, SE $= 0.072$, $p < .001$), whereas there were no signs of a difference between the accuracy rates to equal-size mixed-case nonwords and standard mixed-case nonwords ($z < 1$, $p > .95$).

The present experiment showed an advantage in the latency and accuracy data of same-case words (LATERAL) over mixed-case words (LaTeRaL) (30 ms and 1.8%), thus replicating the case-mixing effect for words in lexical decision (e.g., Allen et al., 1995; Besner, 1983; Besner & McCann, 1987; Kinoshita, 1987).

Critically, mixed-case nonwords (TeBaDa) were responded to more quickly and more accurately than same-case nonwords (TEBADA) (13 ms and 2.4%). The dissociation of mixed-case effects for words and nonwords in lexical decision is consistent with the hypothesis that the lack of visual familiarity of mixed-case stimuli induces a "no" response—this bias should hinder word stimuli and help nonword stimuli. Finally, equal-size mixed-case words showed similar latencies and only slightly higher accuracy than standard mixed-case words, thus suggesting that letter size only plays (if anything) a minimal role in the case-mixing effect (e.g., LaTeRaL behaves similarly to LaTeRaL).

The question now is whether the mixed-case effect for words vanishes in a classification word recognition task that requires unique word identification rather than an assessment of visual familiarity: semantic categorization. Participants in Experiments 2 and 3 were asked to decide whether the presented word was an animal name or not. We included the set of words from Experiment 1 as non-exemplars and selected a new set of words that were animal names. (We excluded a small subset of words [15 words] that were animal names or words semantically related to animal names such as granja [farm].) In Experiment 2, we employed a go/no-go procedure ("press a key if the word is not an animal") so that participants would primarily focus on the target stimuli (i.e., the non-animal names), whereas in Experiment 3, we employed a standard two-choice procedure.

Experiment 2 (go/no-go semantic categorization)

Method

Participants

The sample was composed of 24 students from the same population as in Experiment 1.

Materials

For the non-animal names, we selected 225 out of the 240 words from Experiment 1—the 15 excluded words corresponded to animal names or referred to concepts related to animal names (example). We also selected a set of 111 words that corresponded to animal names. The mean number of letters was the same as that for the non-animal names (mean = 6.4; range 5–8) and the mean Zipf word-frequency was 3.38 (range 1.63–4.92) in the EsPal database (Duchon et al., 2013). As in Experiment 1: each item could be presented in same-case uppercase format, equal-size mixed-case format, or standard mixed-case format, and we created three lists to counterbalance the materials. Thus, each participant received 112 same-case words (75 animal names; 37 non-animal names), 112 equal-size mixed-case words (75 animal names; 37 non-animal names), and 112 standard same-case words (75 animal names; 37 non-animal names).

Procedure

It was parallel to Experiment 1 except that participants were instructed to press a button when the word did not correspond to an animal name. This decision had to be made as soon as possible while trying to keep accuracy high. The stimulus was on the screen until the participant responded or up to a maximum of 1500 ms. A set of 12 practice trials preceded the 336 experimental trials. The whole session lasted for approximately 16–18 min.

Results and discussion

The screening process was the same as in Experiment 1—we removed one correct response time shorter than 250 ms—and the statistical analyses were parallel to those performed in Experiment 1. The mean correct response times and the error rates in each condition are displayed in Table 2.

Non-animal data The analyses of the latency data showed similar response times for same-case words and

Table 2 Mean response times (in ms) and error rates (in parentheses) for words and nonwords in Experiment 2 (go/no-go semantic categorization task)

	Same-case	Equal-size mixed-case	Standard mixed-case
Non-animals	640 (1.1)	644 (1.4)	646 (1.2)
Animals	– (12.4)	– (10.1)	– (12.4)

Table 3 Mean response times (in ms) and error rates (in parentheses) for words and nonwords in Experiment 3 (two-choice semantic categorization task)

	Same-case	Equal-size mixed-case	Standard mixed-case
Non-Animals	588 (2.9)	586 (2.9)	582 (3.4)
Animals	595 (8.7)	599 (9.8)	608 (11.3)

equal-size mixed-case words (640 vs. 644 ms, respectively; $t = -1.146$, $b = 0.018$, SE $= 0.016$, $p = .263$). The difference between equal-size mixed-case words and standard mixed-case words did not approach significance (644 vs. 646 ms, respectively; $t < 1$, $p > .90$). Finally, we found a strong Zipf word-frequency effect, $t = -6.872$, $b = -0.077$, SE $= 0.011$, $p < .001$.

The analyses of the accuracy data did not show any significant effects of mixed-case or letter size either, both zs < 1. The effect of word-frequency approached significance, $z = -1.89$, $b = 0.388$, SE $= 0.205$, $p = .058$.

Animal data Neither of the two comparisons was significant, both zs < 1.61, ps > 0.108.

In the present semantic categorization experiment, neither the response time data nor the accuracy data showed any signs of a case-mixing effect: there was only a minimal advantage of the same-case words over the equal-size mixed-case words: 4-ms in the latency data and 0.3% in the accuracy data. The lack of a cost for mixed-case words favors the visual familiarity hypothesis of the case-mixing effect, as this effect should be restricted to those tasks in which there is an assessment of the visual familiarity of the stimulus (e.g., lexical decision).

One might argue, however, that participants could have been responding on the basis of a fixed deadline to non-animal names. However, as shown above, the effect of word-frequency was quite robust in the latency analyses, thus ruling out an explanation of our data as a function of a fixed deadline for "no" responses. Furthermore, this effect replicates and extends earlier research that has reported sizeable word-frequency effects in two-choice semantic categorization tasks for both exemplars and non-exemplars (e.g., see Quinn & Kinoshita, 2008).

As one might argue that the "go" decisions on the non-exemplars could have affected the processes of interest, Experiment 3 was designed to replicate Experiment 2 while measuring latencies for both exemplars and non-exemplars. Thus, the materials were the same as in Experiment 2 except that participants had to make a two-choice semantic categorization task instead of a go/no-go semantic categorization task.

Experiment 3 (two-choice semantic categorization)

Method

Participants

The sample was composed of 24 students from the same population as in Experiments 1 and 2. None of them had taken part in the previous experiments.

Materials

They were the same as in Experiment 2.

Procedure

It was the same as in Experiment 1 except that participants were instructed to make a two-choice decision instead of a go/no-decision. That is, participants were instructed to press the key labeled as "sí" (yes) for animals or "no" for non-animals.

Results and discussion

The statistical analyses were parallel to those performed in Experiments 1 and 2—we removed one correct response time that was shorter than 250 ms. The mean correct response times and the error rates in each condition are displayed in Table 3.

Non-animal data Similarly to Experiment 2, the analyses of the latency data showed similar response times to same-case words and equal-size mixed-case words (588 vs. 586 ms, respectively), $t = -1.048$, $b = -0.012$, SE $= 0.010$, $p = .30$. In addition, there was a small 4-ms advantage of the standard mixed-case words over the equal-size mixed-case words (582 vs. 586 ms, respectively), $t = -2.089$, $b = -0.023$, SE $= 0.011$, $p = .04$—this difference did not approach significance when using untransformed data, $t = 1.296$, $p = .196$. Finally, we found a sizeable word-frequency effect, $t = -4.773$, $b = -0.050$, SE $= 0.010$, $p < .001$.

The analysis of the accuracy data did not show any significant effects of mixed-case or letter size, both ps > 0.50, whereas the effect of Zipf word-frequency was significant (i.e., higher accuracy to higher frequency words), $z = 3.12$, $b = 0.605$, $SE = 0.194$, $p = .002$.

Animal data The analyses of the latency data also showed similar response times to same-case and equal-size mixed-case words (595 vs. 599 ms, respectively), $t < 1$, $p > .78$. In addition, we found a 9-ms disadvantage of the standard mixed-case words over the equal-size mixed-case words (608 vs. 599 ms, respectively), $t = 2.33$, $b = 0.032$, $SE = 0.014$, $p = .025$—again, this difference was not significant when using the untransformed RTs, $t = 1.593$, $p = .120$.

The analysis of the accuracy data did not show any significant effects, both $p\text{s} > 0.50$.

Thus, the present two-choice semantic categorization experiment showed that response times to same-case words and mixed-case words were remarkably similar, thus replicating the findings from the go/no-go semantic categorization task employed in Experiment 2. Furthermore, as in Experiment 2, we found a robust effect of word-frequency for non-exemplars.

Finally, as in the previous experiments, we did not find any clear signs of an effect of letter size for mixed-case words: there was a 4-ms advantage of the standard mixed-case words over the equal-size mixed-case words for the non-exemplars. However, leaving aside the small size of the difference (4 ms; $p = .04$), this was accompanied by a trade-off in the accuracy data and, furthermore, the exemplars showed a small effect in the opposite direction (9 ms; $p = .025$). Thus, one should be cautious not to over-interpret these very small differences—note that these differences were not significant when using untransformed RTs.

General discussion

We designed three experiments to directly test whether the hindered performance when reading mixed-case words was related to impoverished lexico-semantic access or to a visual familiarity bias. To that end, we conducted an experiment with a task that is known to be sensitive to visual familiarity (a word/nonword discrimination task: lexical decision) and two experiments with a task that involves access to unique lexico-semantic information and in which the assessment of visual familiarity is irrelevant (semantic categorization). To isolate the "visual familiarity" component of the mixed-case effect, digraphs were always presented in the same case (e.g., PaeLLa) and the experiment was conducted in a shallow orthography with no context-depending vowels (Spanish). In Experiment 1, lexical decision responses were faster and more accurate for same-case words than for mixed-case words, whereas the nonwords showed the opposite pattern. Critically, there were no signs of a difference between same-case words (LATERAL) and mixed-case words (LaTeRaL) when the word recognition task required access to lexico-semantic information (semantic categorization; Experiments 2 and 3). Finally, we found no clear signs of a modulating role of letter size in case-mixing effects: standard mixed-case words were processed similarly to equal-size mixed-case words in all three experiments. Importantly, this latter finding rules out an explanation of case-mixing effects as due to lateral masking from the (larger) uppercase letters.

Taken together, these findings favor the visual familiarity hypothesis of case-mixing effects: lack of visual familiarity of the stimulus item in mixed-case induces a "no" bias in lexical decision. As the required response to mixed-case words like LaTeRaL or LaTeRaL is "yes", this "no" bias creates a response conflict. This leads to longer "yes" lexical decision responses (and more errors) for mixed-case words than for same-case words (i.e., a mixed-case effect cost). Importantly, the bias for "no" responses in visually unfamiliar stimuli has a benefit for nonwords, as the mixed-case nonword TeBaDa is less visually familiar than the same-case nonword TEBADA. Indeed, "no" lexical decision responses were faster (and more accurate) for mixed-case nonwords than for same-case nonwords (i.e., a mixed-case effect benefit). This latter finding suggests that other factors were responsible for the mixed-case cost to nonwords in previous experiments in English. As we indicated in the Introduction, the vast variability in the size of the observed case-mixing effects (ranging from 16 ms to 129 ms across studies) suggests that some characteristics of the stimuli (e.g., mixed-case stimuli breaking some graphemic units [compare jAtT, fEaD, vIgHt with JATT, FEAD, and VIGHT]) were behind this reading cost. Additional research is necessary to examine how digraphs or context-sensitive vowels are affected by case mixing during word and nonword processing in a deep orthography.

Critically, the present experiments showed no signs of a case-mixing effect when the word recognition task required access of lexico-semantic information (namely, semantic categorization) (i.e., similar response times for LATERAL and LaTeRaL), as revealed by Experiments 2 and 3. This finding poses strong problems for the accounts that propose that mixing case disrupts letter recognition, thereby delaying lexical access. Furthermore, this finding also rules out another possibility, namely that the post-access orthographic check is slower with mixed-case words. Such a checking mechanism would be involved in lexical decision and semantic categorization[2]. Instead, this null effect of case-mixing in semantic categorization is the predicted outcome from the visual familiarity account of case-mixing effects.

Thus, the current experiments extend previous research with the masked priming technique that suggested that the

[2] We thank Ken Forster for suggesting this explanation.

access to lexico-semantic information was not disrupted by case mixing (Forster, 1998; Lee et al., 2002; Perea et al., 2015): mixed-case repetition primes are as effective as same-case primes (e.g., LaTeRaL–LATERAL = lateral–LATERAL) (see Blais & Besner, 2005; Miozzo & Caramazza, 2003, for parallel evidence with Stroop and distractor interference paradigms, respectively). Unlike these experiments, which provided indirect evidence of this phenomenon (e.g., how a mixed-case prime affected target performance), here we provided direct evidence by measuring the responses to the mixed-case words.

How visual familiarity is represented for words? Recent research has shown that the left ventral occipito-temporal cortex is sensitive to visual familiarity in lexical decision. Wimmer, Ludersdorfer, Richlan, and Kronbichler (2016) found that the activation in this brain area is greater to words presented in an unfamiliar letter-case format than when presented in a familiar letter-case format in lexical decision (e.g., ball vs. Ball—German nouns are presented with an initial capital letter) (see Twomey et al., 2013, for converging fMRI evidence in Japanese). Wimmer et al. (2016) concluded that neural representations for printed words in the left ventral occipito-temporal cortex may include not only abstract representations, as commonly thought, but they may also contain information about visual attributes of the format in which the printed word is most typically seen. For instance, the lexical entry for the brand name "IKEA", the acronym "FBI", or the common noun "molecule" would contain information on its more frequent visual configuration (see Peressotti, Cubelli, & Job, 2003). Thus, the degree of visual familiarity of the printed stimulus can be used as a cue to improve performance in lexical decision, thus producing shorter lexical decision times when presented in the usual letter-case configuration (e.g., IKEA < ikea; FBI < fbi; molecule < MOLECULE; see Perea, Marcet, & Vergara-Martínez, 2018, for discussion). In contrast, letter-configuration information would be irrelevant in tasks that require unique word identification (e.g., semantic categorization)—for instance, the advantage in response times of IKEA over ikea vanishes in naming tasks (Perea et al., 2015).

An important remaining question is whether the proposed visual familiarity account is specific to lexical decision or whether it can also be at work during sentence reading. A number of leading models of eye movement control in reading assume that the stage responsible to move the saccades toward the following word is based on a tentative familiarity check judgment of the fixated word rather than on unique lexical access (L1 vs. L2 stages; see Reichle, Pollatsek, Fisher, & Rayner, 1998). This familiarity check judgment may use different sources of evidence (see Reichle, Tokowicz, Liu, & Perfetti, 2011) and it has been recently suggested that visual familiarity can modulate this decision (see Perea, Rosa, & Marcet, 2017), thus producing an overall mixed-case cost.

In summary, the present experiments have shown a dissociation of case-mixing effects in lexical decision (a cost for words and a benefit for nonwords) whereas there were no signs of a case-mixing effect in semantic categorization. This pattern generalizes previous findings from other experimental paradigms (masked priming, Stroop effect, distractor frequency effect) and it suggests that case-mixing does not delay the access to lexico-semantic information during word processing, but it rather affects a visual familiarity assessment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The procedures involving human participants in this study were approved by the Experimental Research Ethics Committee of the Universitat de València and they were in accordance with the Declaration of Helsinki. All individuals provided written informed consent before starting the experimental session.

References

Allen, P. A., Wallace, B., & Weber, T. A. (1995). Influence of case type, word frequency, and exposure duration on visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 914–934. https://doi.org/10.1037/0096-1523.21.4.914.

Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge: Cambridge University Press.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48. https://doi.org/10.18637/jss.v067.i01.

Besner, D. (1983). Basic decoding components in reading: Two dissociable feature extraction processes. *Canadian Journal of Psychology, 37*, 429–438. https://doi.org/10.1037/h0080739.

Besner, D., & McCann, R. S. (1987). Word frequency and pattern distortion in visual word identification and production: An examination of four classes of models. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 201–219). Hove: Erlbaum.

Blais, C., & Besner, D. (2005). When the visual format of the color carrier word does and does not modulate the Stroop effect. *Memory & Cognition, 33*, 1337–1344. https://doi.org/10.3758/bf03193366.

Brysbaert, M., Mandera, P., & Keuleers, E. (2017). The word frequency effect in word processing: An updated review. *Current Directions in Psychological Science, 27*, 45–50. https://doi.org/10.1177/0963721417727521.

Duchon, A., Perea, M., Sebastián-Gallés, N., Martí, A., & Carreiras, M. (2013). EsPal: One-stop shopping for Spanish word

properties. *Behavior Research Methods, 45*, 1246–1258. https://doi.org/10.3758/s13428-013-0326-1.
Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203–233. https://doi.org/10.1023/A:1023202116609.
Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698. https://doi.org/10.1037/0278-7393.10.4.680.
Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35*, 116–124. https://doi.org/10.3758/s13428-014-0493-8.
Frederiksen, J. R. (1978). Assessment of lexical decoding and lexical skills and their relation to reading proficiency. In A. M. Lesgold, J. W. Pellegrino, S. D. Fokkema & R. Glaser (Eds.), *Cognitive psychology and instruction* (pp. 153–169). New York: Plenum Press.
Houston, J. R., Rossmiller, A. C., & Allen, P. A. (2016). *Case mixing does not modulate the Stroop effect*. Poster presented at the 2016 Midwestern Psychological Association Annual Conference, Chicago, IL.
Humphreys, G. W., Mayall, K., & Cooper, A. C. G. (2003). The PIG in sPrInG: Evidence on letter grouping from the reading of buried words. *Psychonomic Bulletin & Review, 10*, 939–946. https://doi.org/10.3758/bf03196555.
Keuleers, E., & Brysbaert, M. (2010). Wuggy: A multilingual pseudoword generator. *Behavior Research Methods, 42*, 627–633. https://doi.org/10.3758/brm.42.3.627.
Kinoshita, S. (1987). Case alternation effect: Two types of word recognition? *Quarterly Journal of Experimental Psychology, 39A*, 701–720. https://doi.org/10.1080/14640748708401810.
Kinoshita, S., & Norris, D. (2010). Does the familiarity bias hypothesis explain why there is no masked priming for "NO" decisions? *Memory & Cognition, 39*, 319–334. https://doi.org/10.3758/s13421-010-0021-8.
Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software, 82*, 1–26. https://doi.org/10.18637/jss.v082.i13.
Lavidor, M., Ellis, A. W., & Pansky, A. (2002). Case alternation and length effects in lateralized word recognition: Studies of English and Hebrew. *Brain and Cognition, 50*, 257–271. https://doi.org/10.1016/s0278-2626(02)00508-0.
Lee, C. H., Honig, R., & Lee, Y. (2002). Phonological recoding of mixed-case words in the priming task. *Reading Psychology, 23*, 199–216. https://doi.org/10.1080/02702710290061328.
Lien, M. C., Allen, P. A., & Crawford, C. (2012). Electrophysiological evidence of different loci for case-mixing and word frequency effects in visual word recognition. *Psychonomic Bulletin & Review, 19*, 677–684. https://doi.org/10.3758/s13423-012-0251-9.
Mayall, K., & Humphreys, G. W. (1996). Case mixing and the task-sensitive disruption of lexical processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 278–294. https://doi.org/10.1037/0278-7393.22.2.278.
Mayall, K., Humphreys, G. W., & Olson, A. (1997). Disruption to word or letter processing? The origins of case-mixing effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 1275–1286. https://doi.org/10.1037/0278-7393.23.5.1275.
Miozzo, M., & Caramazza, A. (2003). When more is less: A counterintuitive effect of distractor frequency in the picture-word interference paradigm. *Journal of Experimental Psychology: General, 132*, 228–252. https://doi.org/10.1037/0096-3445.132.2.228.
Perea, M., Jiménez, M., Talero, F., & López-Cañada, S. (2015). Letter-case information and the identification of brand names. *British Journal of Psychology, 106*, 162–173. https://doi.org/10.1111/bjop.12071.
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. *Experimental Psychology, 65*, 98–104. https://doi.org/10.1027/1618-3169/a000391.
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., Vergara-Martínez, M., & Gomez, P. (2015). Resolving the locus of cAsE aLtErNaTiOn effects in visual word recognition: Evidence from masked priming. *Cognition, 142*, 39–43. https://doi.org/10.1016/j.cognition.2015.05.007.
Peressotti, F., Cubelli, R., & Job, R. (2003). On recognizing proper names: The orthographic cue hypothesis. *Cognitive Psychology, 47*, 87–116. https://doi.org/10.1016/S0010-0285(03)00004-5.
Quinn, W. M., & Kinoshita, S. (2008). Congruence effect in semantic categorization with masked primes with narrow and broad categories. *Journal of Memory and Language, 58*, 286–306. https://doi.org/10.1016/j.jml.2007.03.004.
R Development Core Team. (2018). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing.
Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*, 125–157. https://doi.org/10.1037/0033-295x.105.1.125.
Reichle, E. D., Tokowicz, N., Liu, Y., & Perfetti, C. A. (2011). Testing an assumption of the E-Z Reader model of eye-movement control during reading: Using event-related potentials to examine the familiarity check. *Psychophysiology, 48*, 993–1003. https://doi.org/10.1111/j.1469-8986.2011.01169.x.
Reingold, E. M., & Rayner, K. (2006). Examining the word identification stages hypothesized by the E-Z Reader model. *Psychological Science, 17*, 742–746. https://doi.org/10.1111/j.1467-9280.2006.01775.x.
Reingold, E. M., Yang, J., & Rayner, K. (2010). The time course of word frequency and case alternation effects on fixation times in reading: Evidence for lexical control of eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 1677–1683. https://doi.org/10.1037/a0019959.
Smith, F. (1969). Familiarity of configuration vs. discriminability of features in the visual identification of words. *Psychonomic Science, 14*, 261–263. https://doi.org/10.3758/bf03329112.
Smith, R., Lott, D., & Cronnell, B. (1969). The effect of type size and case alternation on word identification. *American Journal of Psychology, 82*, 248–253. https://doi.org/10.2307/1421250.
Twomey, T., Kawabata Duncan, K. J., Hogan, J. S., Morita, K., Umeda, K., Sakai, K., et al. (2013). Dissociating visual form from lexical frequency using Japanese. *Brain and Language, 125*, 184–193. https://doi.org/10.1016/j.bandl.2012.02.003.
Wimmer, H., Ludersdorfer, P., Richlan, F., & Kronbichler, M. (2016). Visual experience shapes orthographic representations in the visual word form area. *Psychological Science, 27*, 1240–1248. https://doi.org/10.1177/0956797616657319.