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Effects of alternating letter case on processing sequences of written words

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Abstract

In three grammatical decision experiments, we examined the impact of alternating letter case on sentence reading to determine the locus of case-alternation effects. Experiments 1 and 2 compared grammatical decision responses ("Is this a grammatically correct sequence of words or not?") in three different conditions: (1) SAME CASE/same case; (2) alternating CASE between WORDS; and (3) aLterNaTing cAsE wItHin WoRdS. For the grammatically correct sequences, we observed significantly faster responses in the same-case conditions compared with the between-word case manipulation, as well as a significant advantage for the between-word condition compared with within-word alternating case. These results confirm that case-alternation deteriorates sentence reading, but more so at the level of single word processing (within-word alternation) than at the sentence level (between-word alternation). Experiment 3 demonstrated that between-word case-alternation facilitates sentence processing compared with an all-lowercase condition when betweenWORDspacesAREremoved. Therefore, in the absence of between-word spacing, case changes across words facilitate sentence processing, possibly by guiding readers' eyes to optimal locations for word identification.

Keywords

Reading; letter case; grammatical decisions; alternating case

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Introduction

The impact of alternating between lowercase and uppercase letters has mainly been investigated in studies of single word recognition using the popular lexical decision task (e.g., see Besner, 1983; Besner & McCann, 1987; Kinoshita, 1987; Mayall & Humphreys, 1996, for early research). The typical manipulation in these early studies involves comparing lexical decisions to words presented in aLtErNaTiNg case with words presented in a blocked case format (i.e., all-lowercase or ALL-UPPERCASE). All these studies revealed that case alternation made lexical decisions to word stimuli harder compared with a blocked case condition (see Perea et al., 2020, for a review). Two key results obtained in the following research suggest that the locus of this mixed-case disadvantage found in the lexical decision task resides in the lower visual familiarity of mixed-case format biasing participants to consider the word stimuli as nonwords. A key observation in line with this interpretation is that when the case manipulation is made on prime stimuli in a masked priming experiment (with target stimuli presented in blocked case), then there is little or no impact of case alternation (Perea et al., 2015b). Another important result is that when participants had to make a semantic decision on word stimuli (e.g., animal vs. non-animal decision), then no effect of case alternation was found to the same set of word stimuli that showed an effect in lexical decision (Perea et al., 2020; see also Blais & Besner, 2005,

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and Miozzo & Caramazza, 2003, for similar evidence for null effects of case alternation with a Stroop task and a picture–word interference paradigm).

Moreover, research using eye movements in reading suggests that changes in letter case across fixations do not have an early impact on sentence reading (see Rayner et al., 1980, for early evidence). Critically, Reingold et al. (2010) argued that the effect of case alternation occurs at a later post-access stage. In that study, initial fixation durations from multiple fixations on a target word revealed a reliable word-frequency effect, but no effect of case alternation. How can these findings be reconciled with the conflicting results obtained in semantic categorisation (no effect) and sentence reading? One possibility is that the effect seen in gaze durations in the Reingold et al. (2010) study reflects the operation of a familiarity check, as postulated in the EZ-Reader model of eye movements and reading (Reichle et al., 1998), which determines when readers' eyes move away from the currently fixated word (or remain in that word at a different location) prior to full identification of that word. This familiarity check would be influenced by case alternation, in the same way as lexical decisions, with words in alternating case being judged as less familiar. In other words, under the hypothesis that case alternation mainly affects how familiar a written word appears, then case alternation does not affect first fixation durations because these are unaffected by familiarity, but only on decisions made about where to move the eyes following the first fixation.

In the present study, we provide a further test of the impact of case alternation on sentence reading. Our aim was to provide further evidence with respect to specifying the precise locus (or loci) of case-alternation effects when reading sentences. Given the ongoing controversy with respect to the extent that eye-movement recordings reflect linguistic processing during sentence reading (see Rayner & Fischer, 1996; Vitu et al., 1995, for early investigations), we manipulated case alternation in the recently developed speeded grammatical decision task, the sentence-level equivalent of the lexical decision task for word stimuli (Mirault & Grainger, 2020). Grammatical decisions reflect the time it takes to decide whether a sequence of words is grammatically correct or not, and therefore obligatorily involve (a minima) word identification and syntactic processing. Crucially, prior work from our group (Fournet et al., 2022) has shown that the grammatical decision task is sensitive to the contrast between all-lowercase and all-uppercase presentation of word sequences, with faster and more accurate decisions to lowercase stimuli. Most importantly, the overall pattern of results in the Fournet et al. (2022) study pointed to individual word identification processes as the principal locus of the lowercase advantage. Thus, words printed in lowercase letters would appear to be easier to identify (thus facilitating processing at the sentence level) than words printed in uppercase letters. This is in line with the results of eye-movement studies that revealed a sizeable lowercase advantage in gaze durations, but not in first-fixation durations (Perea et al., 2017). We therefore expected to observe an effect of case alternation in the grammatical decision task. Moreover, apart from the task, the novelty of the present study lies in the two types of case manipulation that were operated: the typical within-word manipulation and a novel between-word manipulation. This was done to distinguish between case-alternation effects operating at the word level and those operating at the sentence level.

Based on the results obtained in prior research summarised above, we made the following predictions. Alternating case within words should hinder reading (i.e., slower grammatical decision latencies and more errors) compared with an all-uppercase text condition. We predicted this on the basis of results showing that within-word alternating case impairs lexical decisions to single words and increases gaze durations during sentence reading. Concerning the contrast between alternating case between-words and the all-uppercase condition, we predicted either no significant difference, or even possibly an advantage for the alternating case condition. This case change advantage might arise if letter case is used in the same way as word length information in guiding the association of word identities with locations along a line of text during reading (e.g., OB1-reader: Snell et al., 2018). To test these predictions, we analysed the data of Experiment 1 using two pairwise comparisons: (1) contrasting the all-uppercase condition and the between-word alternating case condition, and (2) contrasting the between-word alternating case condition and the within-word alternating case condition.

Experiment 1

Method

Participants. Forty-two native speakers of English (25 female) participated with their personal computer in a 25-min online experiment. The age of participants ranged from 20 to 60 years ($M = 36.14$ years; $SD = 10.96$). Participants received £3.5 in compensation. The purpose of the experiment was not revealed to participants. Prior to initiation of the experiment, participants were informed that data would be collected anonymously, and they then provided informed consent for participation, as well as information concerning age, native language, and gender. Ethics approval was obtained from the *Comité de Protection des Personnes SUD-EST IV* (No. 17/051).

Design and stimuli. We first selected 300 seven-word grammatical sequences in English and, for each of these sequences, we created a corresponding ungrammatical sequence (see example in Table 1). The average word frequency of the sequences in Zipf values was 6.19 ($SD = 0.29$). The 300 grammatical 7-word sequences were

Table 1. Examples of the different sequences of words tested in Experiment 1.

Grammatical	*All-uppercase*	THE BIG CAT SAT ON THE MAT
	Between-word	THE big CAT sat ON THE mat
	Within-word	ThE bIg cAt sAT ON tHe MaT
Ungrammatical	*All-uppercase*	THE SAT BIG THE ON MAT CAT
	Between-word	THE sat BIG the ON MAT cat
	Within-word	ThE sAt bIg tHE ON mAt CaT

Sequences could be presented entirely in uppercase (*all-uppercase*), with case changes occurring across different words (*between-word*), or with case changes occurring within words (*within-word*). Sequences were either grammatically correct sentences or ungrammatical reorderings of the same words.

active forms extracted from *the British National Corpus*. All words in the sequences were considered as content words if they were annotated as "VERB," "ADJ," "SUBST" (NOUN), or "ADV." For content words, we only retained sequences with content words composed of 3–5 letters. For function words, we excluded sequences that contained function words annotated as "CONJ," "INTERJ" or "UNC" (unknown), and we only retained sequences with function words composed of 2–5 letters. We also excluded sequences with the pronouns "I," "you," "us," "me," and "your," and we excluded sequences containing one or more words with a SUBTLEX-UK frequency less than 3 Zipf, where Zipf is the $\log_{10}$ of the number of occurrences per billion (van Heuven et al., 2014). We also excluded all interrogative or exclamatory sequences. For the creation of one of the conditions (alternating case grouped by word), it was also necessary that the sequence contained either at least 3 content words of 3 letters long, or 1 content word of 4 letters and 1 content word of 5 letters. Thus, all the sequences not respecting this criterion were removed. Finally, by hand, we excluded sequences with proper nouns, with strange expressions, inappropriate content, or those that were considered to be ungrammatical. The 300 ungrammatical sequences were created from the grammatical sequences by changing word order but respecting the length of the words in each position in the grammatical sequence (see Table 1). Thus, the same set of words were presented in a grammatical sequence and an ungrammatical sequence. From these grammatical and ungrammatical sequences, the critical stimuli were created from an all-uppercase baseline condition by changing 9 of the letters into lowercase in two ways. The first type of change was operated between-words by changing 2–3 content words into lowercase format. These content words were from 3 to 5 letters long (i.e., 3 words of 3 letters in length, or 2 words of 4 and 5 letters in length). The second type of change was operated within-words by changing 9 letters distributed across the 7 words into lowercase. The words involved in this change were 3–5 letters long and could be content or function words. Here the letter-case change never involved adjacent letters.

Apparatus. The experiment was created with LabVanced (Finger et al., 2017) and we used the Prolific platform (Palan & Schitter, 2018) to recruit the participants.

Procedure. Installed in front of their screen, participants were asked to click on the screen to launch the experiment. After that, they were shown the complete set of instructions for the experiment on a single page. Once they had read and understood the instructions, the participant could start the practice trials by pressing the space key. The practice session was composed of 12 trials that were representative of the six conditions tested in the main experiment but were not included in the main experiment. Once the practice session was complete, participants were prompted to press the space key when they were ready to begin the main experiment. Here, participants had to perform a grammatical decision task. That is, they were instructed to determine as rapidly and as accurately as possible whether the sequence of words formed a grammatically correct sentence or not. Each trial started with a fixation cross for 500 ms indicating the centre of the upcoming sequence of words. Then a blank screen was presented for 200 ms followed by the screen with the sequence of words displayed until participant's response. Participants were instructed to press the right arrow key on their computer keyboard if they thought that the word sequence was grammatically correct, or to press the left arrow if not. After their response, they received feedback in the form of a green circle (correct response) or a red cross (incorrect response) shown for 500 ms. After this feedback, a blank screen was presented for 200 ms before the next trial. A pause was proposed after every 100 trials. The procedure is illustrated in Figure 1.

Analysis. We used linear mixed effects models (LME) to analyse response times (RTs) and generalised (logistic) linear mixed effects models (GLME) to analyse error rate, with participants and items as crossed random effects (Baayen et al., 2008; Barr et al., 2013). The models were fitted with the lmer (for LME) and glmer (for GLME) functions from the lme4 package (Bates et al., 2015) in the R statistical computing environment (R Core Team, 2022). We report regression coefficients (b), standard errors (*SE*), and *t*-values (for LME) or *z*-values (for GLME) for our two planned comparisons (all-uppercase vs. between-word alternating case; between-word alternating case vs. within-word alternating case). We also included average word frequency (in Zipf values) and number of characters per target sequence as continuous variables in the analyses. Fixed effects were deemed reliable if $|t|$ or $|z| > 1.96$

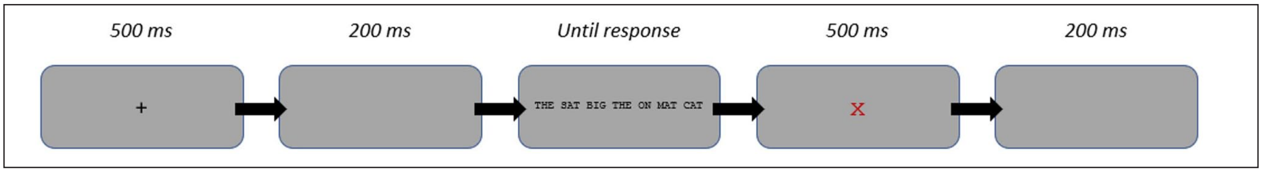

Figure 1. Procedure of one experimental trial with an example of an ungrammatical sequence presented in all-uppercase.

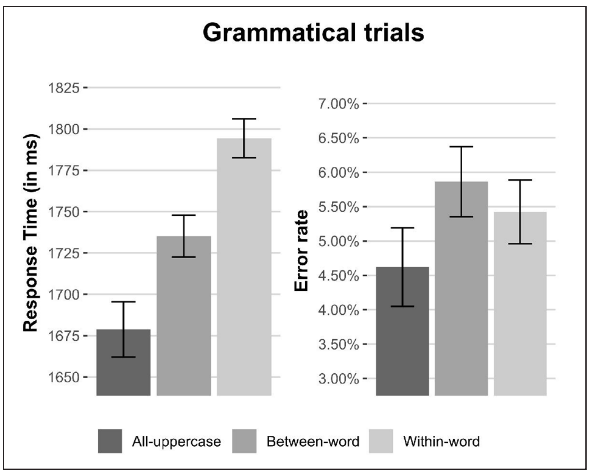

Figure 2. Mean RT (in ms) and error rate (in %) for grammatical trials in the three conditions tested in Experiment 1: all-uppercase letters, between-word alternating case, and within-word alternating case.

Error bars represent within-participant 95% confidence intervals (Cousineau, 2005).

(Baayen et al., 2008). RTs were log transformed prior to analysis to normalise the distribution. We used the maximal random structure model that converged (Barr et al., 2013), and this included by-participant and by-item random intercepts.

Results

All participants performed with accuracy above 75%. Prior to analysis, 20 items were removed due to their average accuracy being lower than 75%. Then, we deleted 3.31% of trials with very short RTs (<300 ms) or very long (>4,000 ms) RTs. The remaining dataset was composed of 11,371 observations, a number that substantially exceeds the recommendation of Brysbaert and Stevens (2018) for having sufficient power. Results are shown in Figures 2 (grammatical trials) and 3 (ungrammatical trials).

RTs. We first excluded trials with incorrect responses (5.95%) and values lying beyond 2.5 *SD*s from the grand mean (2.41%). The remaining dataset was composed of 10,436 observations. The grammatical and ungrammatical trials were analysed separately.

Grammatical trials. For grammatical trials, the dataset was composed of 5,313 observations. We found a significant difference between the all-uppercase and between-word conditions ($b=-0.02$, $SE=0.00$, $t=4.70$) with slower RTs in the between-word alternating case condition. There was also a significant difference between the between-word and the within-word alternating case conditions ($b=0.01$, $SE=0.00$, $t=4.12$), with faster RTs in the between-word condition. Average word frequency and number of characters per sequence were added to the model and both produced significant effects: frequency ($b=–0.05$, $SE=0.01$, $t=5.04$); number of characters ($b=0.01$, $SE=0.00$, $t=5.23$.

Ungrammatical trials. For ungrammatical trials, the dataset was composed of 5,123 observations. For these trials, we also found a significant difference between the all-uppercase and the between-word conditions ($b=0.01$, $SE=0.00$, $t=3.54$), but this time with slower RTs in the all-uppercase condition. In line with the results for the grammatical trials, there was a significant difference between the two alternating case conditions ($b=0.02$, $SE=0.00$, $t=4.44$), with participants taking more time to respond when case was alternated within words. The effect of number of characters in the sequence was significant ($b=0.00$, $SE=0.00$, $t=3.04$).

Error rates. The dataset for error rates was composed of 11,371 observations. We ran separate GLMMs for the grammatical and ungrammatical trials.

Grammatical trials. For grammatical trials, the dataset was composed of 5,722 observations. There was a marginally significant difference between the all-uppercase and between-word conditions ($b=0.31$, $SE=0.16$, $z=1.97$), with more errors occurring in the between-word condition. No significant difference was found between the two alternating case conditions ($b=0.12$, $SE=0.15$, $z=0.82$). Finally, the effect of number of characters was significant ($b=–0.18$, $SE=0.05$, $z=3.76$).

Ungrammatical trials. For ungrammatical trials, the dataset was composed of 5,649 observations. The difference between the all-uppercase and the between-word conditions was not significant ($b=-0.15$, $SE=0.14$, $z=1.04$). Neither was the difference between the two alternating case conditions ($b=0.02$, $SE=0.15$, $z=0.15$).

Discussion

Experiment 1 compared performance in a grammatical decision task ("is the word sequence grammatically correct

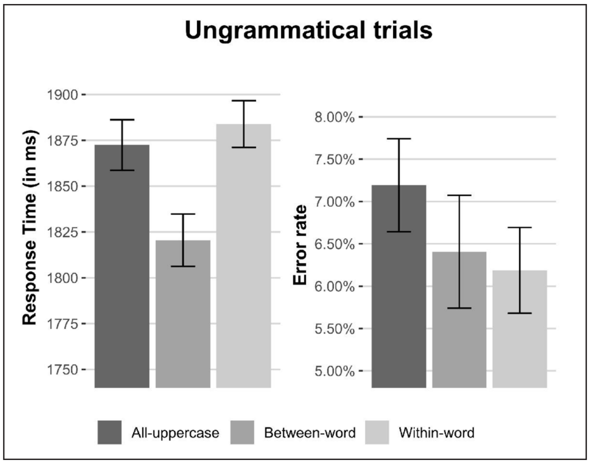

Figure 3. Mean RT (in ms) and error rate (in %) for ungrammatical trials in the three conditions tested in Experiment 1: all-uppercase letters, between-word alternating case, and within-word alternating case.
Error bars represent within-participant 95% confidence intervals (Cousineau, 2005).

or not?") while varying the letter case in which the words were presented. Responses to correct sentences (grammatical trials) were facilitated (shorter RTs and fewer errors) when all words were presented in uppercase compared with the two conditions involving a change in case. Moreover, grammatical decision RTs were faster in the condition when the case change was operated across words as opposed to the within-word case change condition (see Table 1 and Figure 2). In the ungrammatical trials, we found an advantage in RTs for the between-word alternating case condition compared with the all-uppercase condition. This specific result was predicted on the basis that changes in visual information across words could help guide eye movements and facilitate the processing of word sequences, and particularly so in the absence of syntactic constraints (Snell et al., 2018). However, in a separate line of research we have also found that all-lowercase text facilitates grammatical decisions compared with all-uppercase text (Fournet et al., 2022). The results of that study point to individual word identification as the locus of the lowercase advantage. Thus, the advantage seen for the between-word alternating case condition in RTs to ungrammatical trials could be due to the greater ease of word identification for the words presented in lowercase. To test this possibility, in Experiment 2 we replaced the all-uppercase condition with an all-lowercase condition.

Experiment 2

Method

Participants. Forty-two native speakers of English (27 female) participated with their personal computer in a 25-min online experiment. The age of participants ranged from 20 to 60 years (M=35.86 years; SD=11.96). Participants received £3.5 in compensation. The purpose of the experiment was not revealed to participants. Prior to initiation of the experiment, participants were informed that data would be collected anonymously, and they then provided informed consent for participation, as well as information concerning age, native language, and gender.

Design and stimuli. We used the same design and same set of stimuli as in Experiment 1, except that the all-uppercase condition was replaced with an all-lowercase condition.

Apparatus, procedure, and analyses. The same as for Experiment 1.

Results

All participants performed with accuracy above 75%. Prior to analysis, 23 items were removed due to their average accuracy being lower than 75%. Then, we deleted 5.29% of trials with very short RTs (<300 ms) or very long (>4,000 ms) RTs. The remaining dataset was composed of 11,019 observations, a number that substantially exceeds the recommendation of Brysbaert and Stevens (2018) for having sufficient power. Results are shown in Figures 4 (grammatical trials) and 5 (ungrammatical trials).

RTs. We first excluded trials with incorrect responses (7.51%) and values lying beyond 2.5 SDs from the grand mean (1.87%). The remaining dataset was composed of 10,001 observations. The grammatical and ungrammatical trials were analysed separately.

Grammatical trials. For grammatical trials, the dataset was composed of 5,180 observations. As in the previous experiment for grammatical trials, we found a significant difference between the all-lowercase and between-word conditions (b=−0.02, SE=0.00, t=5.32) with faster RTs in the all-lowercase condition. We also found a significant difference between the between-word and within-word alternating case conditions (b=0.03, SE=0.00, t=7.88), with slower RTs in the within-word condition. Average word frequency and number of characters per sequence were added to the model and both produced significant effects: frequency (b=−0.05, SE=0.01, t=4.84); number of characters (b=0.01, SE=0.00, t=6.12).

Ungrammatical trials. For ungrammatical trials, the dataset was composed of 4,821 observations. For these trials, the difference between the all-lowercase and the between-word conditions was not significant (b=−0.00, SE=0.00, z=0.59). Neither was the difference between the two alternating case conditions (b=−0.00, SE=0.00, z=0.42). The effect of number of characters in the sequence was significant (b=0.00, SE=0.00, t=2.63) and there was a marginally significant effect of average word frequency (b=−0.02, SE=0.01, t=1.75).

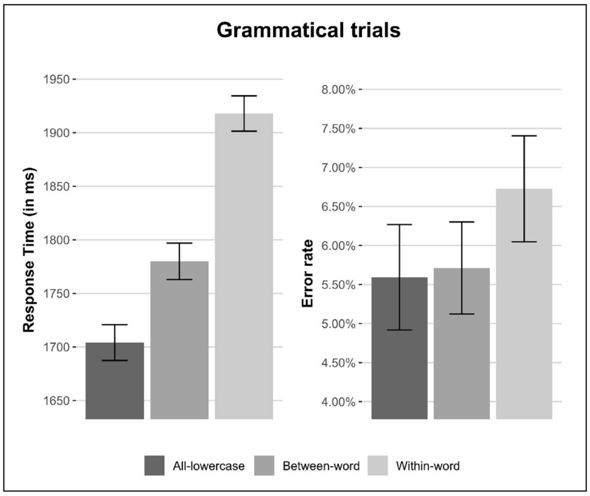

Figure 4. Mean RT (in ms) and error rate (in %) for grammatical trials in the three conditions tested in Experiment 2: all-lowercase letters, between-word alternating case, and within-word alternating case.
Error bars represent within-participant 95% confidence intervals (Cousineau, 2005).

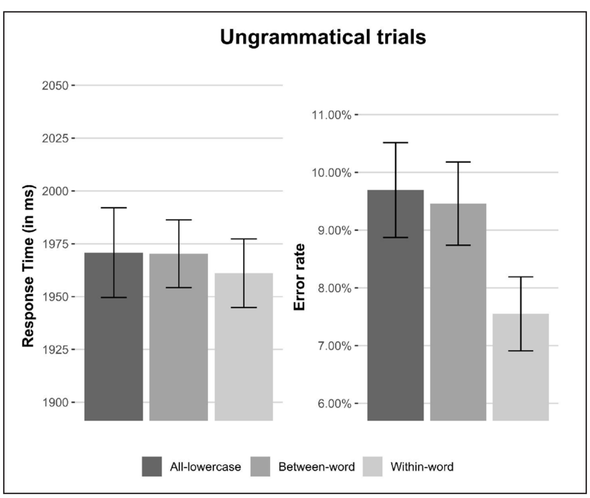

Figure 5. Mean RT (in ms) and error rate (in %) for ungrammatical trials in the three conditions tested in Experiment 2: all-lowercase letters, between-word alternating case, and within-word alternating case.
Error bars represent within-participant 95% confidence intervals (Cousineau, 2005).

Error rates. The dataset for error rates was composed of 11,019 observations. We ran separate GLMMs for the grammatical and ungrammatical trials.

Grammatical trials. For grammatical trials, the dataset was composed of 5,588 observations. The difference between the all-lowercase and the between-word conditions was not significant ($b=0.04$, $SE=0.15$, $z=0.27$). Neither was the difference between the two alternating case conditions ($b=–0.18$, $SE=0.14$, $z=1.22$). Finally, the effect of average word frequency was significant ($b=1.33$, $SE=0.30$, $z=4.42$).

Ungrammatical trials. For ungrammatical trials, the dataset was composed of 5,431 observations. The difference between the all-lowercase and between-word conditions was not significant ($b=-0.03$, $SE=0.12$, $z=0.29$). We found a significant difference between the between-word and within-word alternating case conditions ($b=0.28$, $SE=0.12$, $z=2.29$), with more errors in the between-word condition.

Discussion

In Experiment 2, we re-examined the effects of between-word and within-word alternating case during sentence reading, but this time comparing the alternating case conditions against an all-lowercase condition. The results concerning grammatical decision RTs to correct sentences mirror those seen in Experiment 1 where the baseline condition was all-uppercase. That is, alternating case produced slower RTs compared with the all-lowercase condition, and significantly more so when the alternation occurred within words (Figure 4, left panel). There were no significant effects in the error rates on grammatical trials or ungrammatical trials. Therefore, the most robust effects to emerge across both experiments are the patterns seen in RTs on grammatical trials, which do not depend on whether the baseline is all-uppercase or all-lowercase.

Overall, Experiments 1 and 2 failed to provide convincing evidence that alternating case between-words could facilitate sentence reading by providing physical cues for word locations over and above those provided by between-word spaces. Experiment 3 therefore investigates whether changes in case might be used to facilitate sentence reading in the absence of inter-word spacing. This was done by comparing a normally spaced all-lowercase condition with an unspaced all-lowercase condition and an unspaced between-word alternating space condition. Prior research has shown that reading textwithoutbetweenwordspacing is harder than reading normally spaced text (e.g., Mirault et al., 2019a, 2019b; Perea & Acha, 2009; Rayner et al., 1998; Rayner & Pollatsek, 1996; Veldre et al., 2017). These studies have revealed that reading unspaced text is slower by between 40% and 70% than reading normally spaced text (see Rayner et al., 1998 and Rayner & Pollatsek, 1996, for an initial appraisal of this deficit).

Experiment 3

Method

Participants. Forty-two native speakers of English (30 female) participated with their personal computer in a

25-min online experiment. The age of participants ranged from 20 to 60 years (M=37.05 years; SD=11.60). Participants received £3.5 in compensation. The purpose of the experiment was not revealed to participants. Prior to initiation of the experiment, participants were informed that data would be collected anonymously, and they then provided informed consent for participation, as well as information concerning age, native language, and gender.

Design and stimuli. The basic design and stimuli were the same as in Experiment 2 with the following changes. We maintained the all-lowercase condition tested in Experiment 2 and replaced the two other conditions with an all-lowercase without space condition (by removing the between-word spaces from the all-lowercase sequences) and a between-word alternating case without space condition (removing the between-word spaces from the between-word alternating case sequences tested in Experiments 1 and 2).

Apparatus, procedure, and analyses. The same as for Experiments 1 and 2.

Results

All participants performed with accuracy above 75%. Prior to analysis, 30 items were removed due to their average accuracy being lower than 75%. Then, we deleted 7.03% of trials with very short RTs (<400 ms) or very long (>5,000 ms) RTs. The remaining dataset was composed of 10,543 observations, a number that substantially exceeds the recommendation of Brysbaert and Stevens (2018) for having sufficient power. The results are shown in Figures 6 (grammatical trials) and 7 (ungrammatical trials).

RTs. We first excluded trials with incorrect responses (8.05%) and values lying beyond 2.5 *SD*s from the grand mean (2.09%). The remaining dataset was composed of 9,491 observations. The grammatical and ungrammatical trials were analysed separately.

Grammatical trials. For grammatical trials, the dataset was composed of 4,923 observations. There was a significant difference between the all-lowercase with space condition and the all-lowercase without space condition (b=−0.13, SE=0.00, t=26.37) with faster RTs in the all-lowercase with space condition. There was also a significant difference between the all-lowercase without space condition and the between-word alternating case without space condition (b=−0.02, SE=0.00, t=4.39), with faster RTs in the alternating case condition. Average word frequency and number of characters per sequence were added to the model and both produced significant effects: frequency (b=−0.09, SE=0.01, t=7.32); number of characters (b=0.01, SE=0.00, t=4.39).

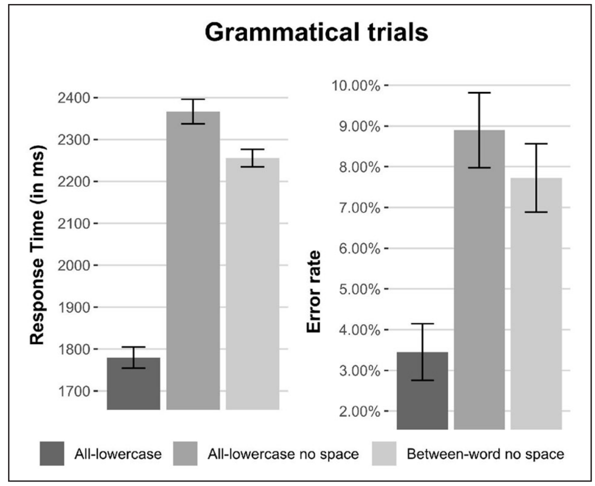

Figure 6. Mean RT (in ms) and error rate (in %) for the grammatical trials in the three conditions tested in Experiment 3: all-lowercase letters with between-word spacing, all-lowercase with no between word spacing, and between-word alternating case with no between-word spacing.
Error bars represent within-participant 95% confidence intervals (Cousineau, 2005).

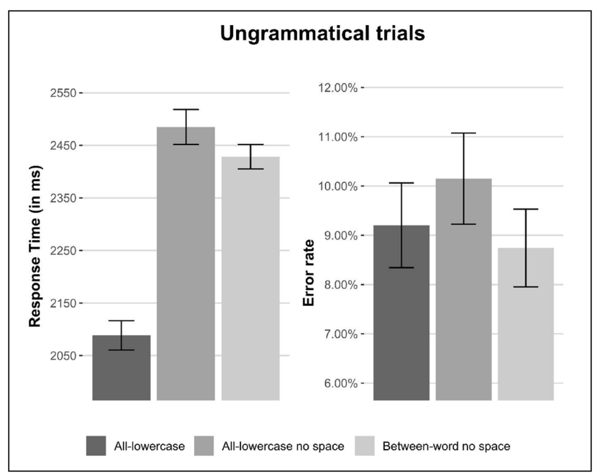

Figure 7. Mean RT (in ms) and error rate (in %) for the ungrammatical trials in the three conditions tested in Experiment 3: all-lowercase letters with between-word spacing, all-lowercase with no between word spacing, and between-word alternating case with no between-word spacing.
Error bars represent within-participant 95% confidence intervals (Cousineau, 2005).

Ungrammatical trials. For ungrammatical trials, the dataset was composed of 4,568 observations. For these trials, the difference between the all-lowercase with space and the all-lowercase without space conditions was significant (b=−0.08, SE=0.01, z=14.28) with slower RTs in the all-lowercase without space condition. The difference between the two without space conditions failed to reach significance (b=−0.01, SE=0.01, z=1.87).

Error rates. The dataset for error rates was composed of 10,543 observations. We ran separate GLMMs for the grammatical and ungrammatical trials.

Grammatical trials. For grammatical trials, the dataset was composed of 5,351 observations. There was a significant difference between the all-lowercase conditions ($b=1.26$, $SE=0.17$, $z=7.45$) with less errors made in the all-lowercase with space condition. The difference between the two without space conditions was not significant ($b=0.22$, $SE=0.14$, $z=1.64$). Finally, the effect of number of characters was significant ($b=–0.13$, $SE=0.04$, $z=2.98$).

Ungrammatical trials. For ungrammatical trials, the dataset was composed of 5,192 observations. The difference between the all-lowercase with space and the all-lowercase without space conditions was not significant ($b=0.15$, $SE=0.12$, $z=1.24$). Neither was the difference between the two without space conditions ($b=0.18$, $SE=0.12$, $z=1.50$). Finally, the effect of average word frequency was significant ($b=-0.74$, $SE=0.29$, $z=2.50$).

Discussion

In Experiment 3, we examined whether a between-word change in case might facilitate sentence processing when the spaces between words are removed. The grammatical decision RTs revealed that this was indeed the case, with faster RTs in the unspaced alternating case condition compared with the unspaced all-lowercase condition on grammatical trials. Experiment 3 also revealed the standard facilitatory effect of between-word spacing relative to unspaced text reported in prior research (e.g., Mirault et al., 2019a, 2019b; Perea & Acha, 2009; Rayner et al., 1998; Rayner & Pollatsek, 1996; Veldre et al., 2017), and here for the first time in the grammatical decision task. We therefore draw two conclusions from these results: (1) that grammatical decisions are an accurate reflection of the time it takes to read sentences and (2) that in the absence of between-word spaces as a cue to word boundaries, changing letter-case between words helps compensate for this lack of information.

General discussion

In three grammatical decision experiments, we studied the impact of changes in letter case on the ease of processing sequences of words. We examined the impact of two types of letter case change: one where the changes occurred within-words and across the entire sequence of words, and one where the case changes only occurred between-words. Experiment 1 examined the impact of these two types of case change against an all-uppercase baseline condition. Experiment 2 examined the impact of these two types of case change against an all-lowercase baseline. The key result to emerge from these experiments is that letter case changes interfered with sentence processing (longer grammatical decision RTs and more errors to grammatical sequences[1] in which there was a change in case), and more so when the changes occurred within-words. In Experiment 3, we then tested the impact of between-word changes in case in conditions where between-word spaces were removed. We replicated the standard finding that removing between-word spaces interferes in sentence reading, and crucially found that between-word changes in case now facilitated performance compared with an all-lowercase unspaced condition.

The main results of the present work can be summarised as follows in terms of three novel findings: (1) changes in letter case interfere with word sequence processing in the grammatical decision task; (2) the interfering effect of changes in letter case is greater when the changes occur within-words than between-words; and (3) between-word changes in letter case facilitate sentence processing in the absence of between-word spaces. The main conclusions to be drawn on the basis of these findings are as follows: (1) during sentence reading, the interfering effect of changes in letter case operates mainly at the level of individual word identification rather than more global sentence-level processing; (2) when between-word spaces are removed, then between-word changes in case facilitate sentence processing by providing alternative bottom-up cues for word boundaries.

The conclusion that effects of alternating case operate principally at the level of individual word identification is in line with the results of prior research studies using eye-movement measures during sentence reading (e.g., Reingold et al., 2010). Effects of case alternation were found mainly in individual word gaze durations in the Reingold et al. study, and the authors interpreted this in terms of how case alternation affects individual word familiarity, and how that affects the decision to move the eyes on to the next word in the sentence (Reichle et al., 1998). Moreover, the fact that alternating case affects lexical decisions to single words, but not semantic decisions with the same set of words (Perea et al., 2020), suggests that it is not word identification per se that is affected by case alternation, but a critical stage of the word identification process that involves an assessment of how familiar the stimulus is. This stage of familiarity assessment could affect both single word identification in the lexical decision task (Grainger & Jacobs, 1996) and eye-movement control (see Reichle, 2015; Reichle et al., 1998), and would operate prior to completion of the word identification process and access to higher-level semantic and syntactic information.

The results of Experiment 3 suggest that other types of low-level visual information can be used during sentence reading when between-word spaces are removed. This points to a more general mechanism for oculomotor control during reading, rather than one that is specifically developed to use between-word spacing. Importantly, our finding fits with prior research showing that in the absence of between-word spacing, an alternating bold condition (Perea & Acha, 2009) and an alternating colour condition (Perea et al., 2015a; Song et al., 2021; Zhou et al., 2020) facilitates sentence reading. Thus, the use of between-word spacing to guide eye movements during reading can be replaced by the use of alternative physical cues for word segmentation. Mirault et al. (2018) also provided evidence that in the absence of between-word spacing, upcoming word identification can guide eye movements by indicating the likely spatial extent of the upcoming word given its length in letters.

Conclusion

When reading sequences of words to make a speeded grammatical decision (is this a correct sentence or not?), changes in letter case disrupt processing compared with same case sequences, and more so when the changes occur within-words as opposed to between-words. We conclude that alternating letter case mainly affects individual word identification rather than higher-level sentence processing. The predicted facilitatory effect of between-word changes in letter case was not found, except when between-word spaces were removed. Only then did the between-word change in case facilitate grammatical decisions, most likely by providing physical cues to optimise eye guidance. Future eye-tracking research could test this explanation.

Author contributions

Colas Fournet: Design, Creation of the experiment, Analysis, Writing. Manuel Perea: Writing. Jonathan Mirault: Design, Analysis. Jonathan Grainger: Design, Writing.

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Ethics approval and consent to participate

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Data accessibility statement

The data and materials from the present experiment are publicly available at the Open Science Framework website: https://osf.io/72snc/

Note

1. We remind readers that the ungrammatical sequences were included for the purpose of the grammatical decision task, and that we had no hypotheses with respect to effects obtained with such sequences. The results concerning the ungrammatical trials are presented and analysed for completeness.

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