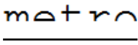
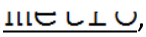
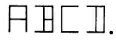
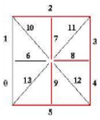
Perea, M., Comesaña, M., Soares, A. P., & Moret-Tatay, C. (2012). On the role of the upper part of words in lexical access: Evidence with masked priming. *Quarterly Journal of Experimental Psychology*, 65(5), 911-925. DOI:10.1080/17470218.2011.636151.

Abstract

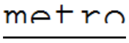
More than 100 years ago, Huey (1908) indicated that the upper part of words was more relevant for perception than the lower part. Here we examined whether mutilated words, in their upper/lower portions (e.g., , , , ), can automatically access their word units in the mental lexicon. To that end, we conducted four masked repetition priming experiments with the lexical decision task. Results showed that mutilated primes produced a sizeable masked repetition priming effect. Furthermore, the magnitude of the masked repetition priming effect was greater when the upper part of the primes was preserved than when the lower portion was preserved –this was the case not only when the mutilated words were presented in lowercase but also when the mutilated words were presented in uppercase. Taken together, these findings suggest that the front-end of computational models of visual-word recognition should be modified to provide a more realistic account at the level of letter features.

Key words: masked priming, orthographic encoding, lexical decision

Most current computational models of visual-word recognition employ, at the level of letter features, the font created by Rumelhart and Siple (1974) (e.g., interactive activation model, McClelland & Rumelhart, 1981; dual-route cascaded model, Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001; spatial coding model, Davis, 2010; multiple read-out model, Grainger & Jacobs, 1996), despite the fact that "more plausible accounts of the features that readers use to identify letters are now available" (Davis, 2010, p. 725).

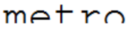
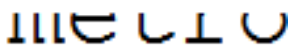
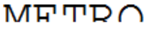
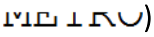
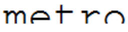
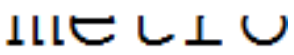
As McClelland and Rumelhart (1981) acknowledged, the Rumelhart and Siple font was chosen "for simplicity". This is an uppercase font, with simplified characters (i.e., the letters … defined by a 14-line matrix) in which each letter is composed of straight line segments. For instance, the letter B would be represented as 00111101110000 in the 

matrix. These line segments work independently of each other so that potentially relevant features (vertices, curved segments, etc.) do not play a role. Furthermore, all segments are equally valid in activating letter representations (see Lanthier, Risko, Stolz, & Besner, 2009). In fairness to the above-cited models, we should indicate that their goal was not to examine the dynamics of the feature/letter-to-word processing but rather to examine the dynamics of visual-word recognition at the word level. Nonetheless, an excessive oversimplification at the front-end of the models of visual-word recognition may lead to incorrect predictions. For instance, the orthographic coding scheme of the interactive activation model (and its successors) is unable to cope with letter transposition effects (i.e., <u>jugde</u> activates judge; see Perea & Lupker, 2004). In the present paper, we examine whether or not all parts of a word's constituent letters are equally important in the process of visual-word recognition.

More than one hundred years ago, Huey (1908) indicated that words are "better differentiated" in the upper portion than in the lower portion. In particular, Huey indicated that "the upper half of a word is more important for perception than the lower half" (p. 65). To illustrate this point, Huey included three passages (see Figure 11 in Huey, 1908): one intact passage, a passage in which only the upper part of the words was presented and another passage (much less legible) in which only the lower part of the words was presented. Nonetheless, under those conditions, differences in readability could have been influenced by top-down processes. A stronger argument in favor of the special role of the upper portion of words during visual-word recognition –and the potential necessity to modify the front-end of existing models– would be obtained if mutilated words like  activate to a large extent their corresponding lexical units during the early stages of word-processing, in absence of top-down conscious strategies.

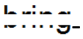
To tap into the earliest moments of visual-word recognition, a highly valuable procedure is the masked priming technique (Forster & Davis, 1984; see Grainger, 2008, for a recent review). In the standard setup, a pattern mask (a series of #'s) is presented for 500 ms and is immediately followed by a briefly presented prime stimulus in lowercase (around 30-50 ms) which, in turn, is replaced by a target stimulus (in UPPERCASE) until the participant's response (e.g., "is the uppercase stimulus a word or not?" as in the typical lexical decision experiment). Participants are not usually aware of the prime stimulus, and the obtained effects are thought to be early and automatic.

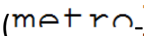
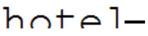
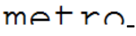
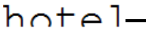
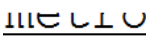
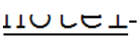
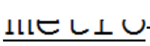
Importantly, prior research has revealed that the effects of masked repetition priming is of similar magnitude when the prime and the target look visually similar (e.g., soon-SOON vs. post-SOON) and when the prime and the target look visually dissimilar (edge-EDGE vs. able-EDGE) (Bowers, Viglioco & Haan, 1998 Norris & Kinoshita, 2008; see also Kinoshita & Kaplan, 2008, for similar evidence concerning masked repetition priming effects with visually similar/dissimilar letters). These findings imply that there is a very fast access to abstract letter identities in the early stages of processing. Furthermore, masked priming effects are still sizeable when the prime is not presented intact: masked priming effects have been reported when some of the primes' letters are replaced by letter-like digits (i.e., 4=A, 3=E; e.g., M4T3R14L-MATERIAL faster than M8T6R92L-MATERIAL; Perea, Duñabeitia, & Carreiras, 2008), when some letters of the prime are replaced by mirror non-reversible letters (e.g., CAƧINO-CASINO faster than CA%INO-CASINO; Perea, Moret-Tatay, & Panadero, 2011), and when the primes are presented in handwritten form (e.g., melón-MELÓN faster than cable-MELÓN; Gil-Lopez, Perea, Moret-Tatay, & Carreiras, 2011). Taken together, the above-cited findings strongly suggest that: i) there is a very fast access to an abstract (shape invariant) level of representation, and ii) the cognitive system tolerates a high degree of "noise" in the initial formation of the orthographic code.

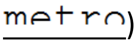
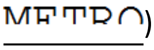
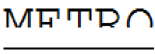
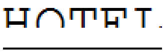
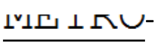
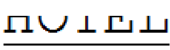
Here we examine whether mutilated words (e.g., , , , ) can rapidly and automatically allow access to their corresponding word units in a masked priming paradigm. We chose the masked priming paradigm rather than a single-presentation paradigm because the presence of faster responses to  than to  does not imply that the locus of the effect is at an early processing stage (i.e., the effects obtained in a single-presentation paradigm could occur at a late, verification stage). It is also worth noting that the presence of a masked priming effect with mutilated words would be a demonstration of the Gestalt principle of closure with word stimuli, in a scenario in which top-down conscious processing is minimized. The principle of closure indicates that if enough of the shape of a given (incomplete) object is provided (e.g., the mutilated word metro), we may perceive the whole object by filling in the missing information (see Snodgrass & Kinjo, 1998, for research on perceptual closure with visible objects).

The three main questions under scrutiny in the present study are: i) whether mutilated primes can produce a sizeable masked repetition priming effect (i.e., metro-METRO vs. hotel-METRO), ii) whether masked repetition priming with mutilated primes is greater when the upper portion is preserved (whether metro-METRO vs. hotel-METRO) than when the lower portion is preserved (e.g., metro-METRO vs. hotel -METRO), and iii) whether masked repetition priming with mutilated words is restricted to lowercase words or whether it also appear with uppercase words (e.g., METRO-metro vs. HOTEL-metro, METRO-metro vs. HOTEL-metro). The answers to these questions have important implications on future implementations of the feature/letter level in computational models of visual-word recognition and reading.

To our knowledge, the empirical evidence concerning the role of the upper portions of letters/words during the process of visual word/letter identification is very scarce. At the letter level, Fiset et al. (2008) examined the diagnostic features for the identification of isolated, lowercase letters using the so-called Bubbles technique. The

Bubbles technique is a classification image technique in which participants are presented with samples of degraded stimuli, letters in this case, which are randomly sampled in both space and spatial frequency bands. Fiset et al. reported that only 41% of the significant voxels were located in the upper half of lowercase letters. Thus, this finding suggests that there does not seem to be an advantage for the upper half of letters at the letter level. Nonetheless, letters presented in isolation and letters embedded in words are not processed in the same way. Indeed, when the letters are embedded in words, Blais et al. (2009) reported, also using the Bubbles technique, that the upper part of the lowercase words contained more significant voxels than the lower portion –consistent with Huey's observation of the special status of the upper part of the words. In the present study, we examined the role of the upper part of lowercase words <u>and</u> uppercase words at the earliest stages of visual-word recognition in a paradigm that directly taps into the early moments of processing (i.e., masked priming). It is worth noting here that Beech and Mayall (2005) conducted a masked priming experiment with mutilated lowercase primes. However, they did not directly examine the role of the upper/lower portion of the mutilated words but rather the differences between the priming effects obtained from outer and inner primes (e.g., -BRING and -BRING, respectively). At a 50-ms SOA, Beech and Mayall found similar naming times to word targets preceded by the outer and inner primes (510 and 513 ms, respectively) and to targets preceded by a blank stimulus (513 ms). (They found an advantage for the outer primes at longer SOAs, when the primes were visible.) Leaving aside that the Beech and Mayall was not explicitly designed to explore the role of the upper portion of the words, they did not employ intact or unrelated primes as controls –which makes it difficult to extract strong conclusions from their experiment. Finally, we should note here that Petit and Grainger (2002) employed a masked priming paradigm with degraded prime letters and found faster response times for -B than the control -B. However, no attempt was made to systematically explore the parallel effect with word stimuli.

In sum, we conducted four masked repetition priming experiments with the lexical decision task (i.e., the most common task in the literature on visual-word recognition; see Dufau et al., in press). In Experiment 1, we examined whether there is a masked repetition priming effect for mutilated lowercase primes in which only the upper portion of the lowercase prime was preserved (-METRO vs. –METRO; i.e., as an illustration, the red area from  was deleted). For comparison purposes, we included an intact priming condition (i.e., metro-METRO vs. hotel-METRO). We also manipulated word-frequency to examine whether the effects of mutilated primes could be affected by word-frequency—note that frequent words might benefit more from the upper outline contour than low-frequency words (see Beech & Mayall, 2005). The goal of Experiment 2 was to directly test whether the magnitude of masked repetition priming with mutilated lowercase primes is greater when the upper portion of the lowercase word is preserved (e.g., -METRO vs. –METRO) than when the lower portion of the word is preserved (e.g., -METRO vs. -HOTEL) –note here that Experiment 2 was analogous to Experiment 1 except that the "intact" primes were replaced with mutilated primes in which only the lower portion of the word was preserved, as in -METRO (as an illustration, the red area from metro was deleted).

To examine whether the observed masked priming effects in Experiments 1-2 could be specific to the particularities of lowercase prime words (i.e., because of the role of outline word shape) or whether they would reflect a more general phenomenon, we designed Experiments 3-4. Bear in mind that that the upper portion of lowercase words may “contain more salient visual features” than the lower portion of words (Beech & Mayall, 2005, p. 311), so that it is critical to examine not only the processing of mutilated lowercase words (e.g., ), but also the processing of mutilated uppercase words (e.g., ). Experiments 3-4 were parallel to Experiments 1-2 except that the primes were presented in uppercase. To avoid visual continuity, the targets were presented in lowercase (e.g., -metro vs. -metro; -metro vs. -metro). It may be important to note here that previous research has shown that the magnitude of masked repetition priming effects are remarkably similar for uppercase targets preceded by lowercase primes (e.g., metro-METRO vs. hotel-METRO) and for lowercase targets preceded by uppercase primes (e.g., METRO-metro vs. HOTEL-metro) (e.g., see Qiao et al., 2009).

Experiment 1

Method

Participants. Sixteen students from the University of Minho participated voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of European Portuguese.

Materials. We selected a set of 240 target words from the P-Pal European Portuguese lexical database (Soares et al., 2011). Half of the words were of high-frequency (mean: 119 occurrences per million words, SD=113; mean length: 6.0, range 5-7; mean number of substitution-letter neighbors: 1.7) and the other half were of low-frequency (mean: 11.6 occurrences per million words, SD=4.8; mean length: 6.3, range 5-7; mean number of substitution-letter neighbors: 1.3). The targets were presented in uppercase and were preceded by primes in lowercase that were: i) the same as the target (identity condition), e.g., metro-METRO or metro-METRO; or ii) completely unrelated to the target (unrelated condition), e.g., hotel-METRO or hotel-METRO. For the purposes of the lexical decision task, 240 nonword targets were created (mean length: 6.3 letters; range: 5-7) by changing two letters from European Portuguese words –none of these words was a word target. Nonword targets were preceded by identity nonword primes or by unrelated nonword primes (e.g., clauta-CLAUTA vs. niltro-CLAUTA) –as in the case of the words, the nonword primes were presented either intact or mutilated. Words/nonwords with diacritic marks (e.g., é, ã, etc) were not included in the experiment. Prime and target stimuli were presented in Courier New 18-pt. Four lists of stimuli were created to counterbalance the materials across Prime type and Relatedness, so that each target appeared only once in each list, but in a different priming condition (e.g., METRO would be preceded by metro, or metro, hotel, or hotel in the different lists; as an illustration, the red area in metro was deleted). The list of (intact and mutilated) stimuli is available at http://www.uv.es/mperea/saw.xlsx. Participants were randomly assigned to each list.

Procedure. Participants were tested in groups of up to four in a quiet room. Presentation of the stimuli and recording of RTs were controlled by computers using DMDX (Forster & Forster, 2003). On each trial, a forward mask consisting of a string of hash marks (#'s) was presented for 500 ms in the centre of the CRT monitor. Then, the lowercase prime was presented for 50 ms and was followed immediately by the presentation of the target stimulus in uppercase. RTs were measured from target onset to the participant's response. The letter strings were presented centered in black, on a white background. Participants were instructed to push a button labeled "sim" [yes] if the letter string formed an existing Portuguese word and a button labeled "não" [no] if the letter string was a nonword. They were not informed of the presence of lowercase items –when asked after the experiment, participants did not report having seen any prime stimuli. Each participant received a different order of trials. The whole experimental session lasted for about 15 minutes.

Results and Discussion

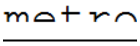
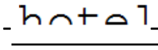
Incorrect responses (3.8% of the data for word targets) and RTs less than 250 ms or greater than 1500 ms (1.5% of the data for word targets) were excluded from the latency analyses. The mean RTs and error percentages from the participant analysis are presented in Table 1. ANOVAs based on the participant (F1) and item (F2) mean correct RTs were conducted based on a 2 (Prime-Target Relatedness: identity, unrelated) x 2 (Prime type: intact, mutilated) x 2 (Word frequency: low, high) x 4 (List: list 1, list 2, list 3, list 4) design. List was included as a factor in the ANOVAs to remove the error variance due to the counterbalancing lists (Pollatsek & Well, 1995).

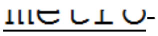
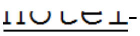
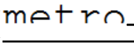
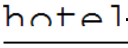
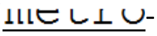
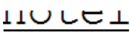
Word data. The ANOVA on the latency data showed that, on average, target words preceded by an identity prime were responded to 36 ms faster than the targets words preceded by an unrelated prime, F1(1,12)=29.68, MSE=1404.9, p<.001; F2(1,232)=96.53, MSE=4393.2, p<.001, and that high-frequency words were responded to 39 ms faster than low-frequency words, F1(1,12)=135.32, MSE=357.5, p<.001; F2(1,232)=41.17, MSE=11519.1, p<.001. The effect of relatedness was greater for low- than for high-frequency words (44 vs. 28 ms), as deduced from the word-frequency by relatedness interaction in the analysis by items, F1(1,12)=4.33, MSE=473.3, p=.06; F2(1,232)=5.73, MSE=4393.2, p<.02. None of the other effects/interactions approached significance (all ps>.50).

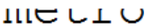
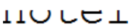
The ANOVA on the error data showed that, on average, participants made more errors on low-frequency words than on high-frequency words, F1(1,12)=20.57, MSE=16.75, p<.002; F2(1,232)=12.26, MSE=210.8, p<.002. None of the other factors/interactions was significant.

Nonword data. The ANOVAs on the latency/error data failed to show any significant effects (all ps>.25).

The present experiment revealed a sizeable masked repetition priming effect with mutilated primes: the magnitude of the priming effect was around 34 ms –the magnitude of this effect was very similar to that with intact primes (39 ms). As in previous research, the magnitude of masked repetition priming was slightly greater for low- than for high-frequency words (see Kinoshita, 2006, for review).

Importantly, we conducted a replication of this experiment with a new sample of 16 participants. All the conditions were the same except that the mutilated primes suffered a greater mutilation (e.g., -METRO vs. --METRO; as an illustration, note that the red area of metro was deleted). Even under those circumstances, results revealed a sizeable masked repetition priming effect. The priming effect was of same magnitude for the word targets preceded by an intact prime and for word targets preceded by a degraded prime (43 ms). In other words, masked priming effects can be readily obtained with mutilated primes when the upper part of the word is preserved. Thus, this finding supports the view that the cognitive system is able to process mutilated words with very little cost—at least when the upper portion of the word is preserved.

The question now is whether masked repetition priming can be observed when only the lower portion of the lowercase word is preserved (i.e., whether -METRO is faster than -HOTEL). The aim of Experiment 2 is to directly examine whether the magnitude of masked repetition priming with mutilated lowercase primes is greater when the upper portion of the lowercase word is preserved (-METRO vs. –METRO; i.e., the mutilated primes from Experiment 1) than when the lower portion of the word is preserved (-METRO vs. -HOTEL). Thus, Experiment 2 was identical to Experiment

1 except that the intact primes were replaced by primes in which only the lower portion of the word was preserved (e.g., , , etc).

Experiment 2

Method

Participants. Sixteen students from the University of Minho participated voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of European Portuguese. None of them had taken part in Experiment 1.

Materials. The materials were the same as in Experiment 1, except that the intact priming condition was replaced with a condition in which only the lower part of the stimuli was preserved. The list of stimuli is available at http://www.uv.es/mperea/saw.xlsx.

Procedure. This was the same as in Experiment 1.

Results and discussion

Incorrect responses (3.9% of the data for word targets) and RTs less than 250 ms or greater than 1500 ms (1.1% of the data for word targets) were excluded from the RT analyses. The mean RTs and error percentages from the participant analysis are presented in Table 2. The design was the same as in Experiment 1, except that the intact prime condition was now a priming condition in which only the lower part of the stimuli were preserved.

Word data. The ANOVA on the RT data showed that, on average, target words preceded by an identity prime were responded to 33 ms faster than the targets words preceded by an unrelated prime, F1(1,12)=54.09, MSE=663.3, p<.001; F2(1,232)=66.58, MSE=4680.5, p<.001, and that high-frequency words were responded to 42 ms faster than low-frequency words, F1(1,12)=100.72, MSE=550.5, p<.001; F2(1,232)=45.88, MSE=11745.5, p<.001. The relatedness x type of prime interaction was significant, F1(1,12)=4.79, MSE=621.9, p<.05; F2(1,232)=5.14, MSE=4543.9, p<.025: this interaction reflected that the effect of relatedness was greater for the primes which conserved the upper portion (43 ms; F1(1,12)=59.72, MSE=498.5, p<.001; F2(1,232)=53.20, MSE=4751.4, p<.001) than for the primes which conserved the lower portion (24 ms; F1(1,12)=11.55, MSE=786.7, p<.006; F2(1,232)=18.37, MSE=4473.1, p<.001). None of the other effects/interactions approached significance (all ps>.14).

The ANOVA on the error data showed that, on average, participants made more errors on low-frequency words than on high-frequency words, F1(1,12)=12.61, MSE=20.08, p<.005; F2(1,232)=9.56, MSE=198.5, p<.003. In addition, the interaction between relatedness and type of prime approached significance in the analysis by participants, F1(1,12)=3.74, MSE=13.37, p=.077; F2(1,232)=4.56, MSE=82.21, p<.04, which reflected that there was a repetition priming effect (in the analyses by items) when the primes conserved the upper portion (2.3%; F1(1,12)=4.71, MSE=17.82, p=.051; F2(1,232)=8.06, MSE=78.13, p<.006), but not when the primes conserved the lower portion (both Fs<1). The other effects/interactions were not significant.

Nonword data. The ANOVAs on the latency/error data failed to show any significant effects –nonetheless, the masked repetition priming effect in the latency data approached significance in the analysis by participants, F1(1,12)=3.55, MSE=348.1, p=.085; F2(1,236)=2.65, MSE=130.0, p=.105.

The results of the present experiment replicate and extend the findings from Experiment 1. Masked repetition priming can be readily obtained when the prime words are mutilated: this is the case when the upper part is preserved (a 43-ms priming effect) and also (to a lesser degree) when the lower part is preserved (a 24-ms priming effect).

As indicated in the Introduction, the present finding provide empirical support to Huey's (1908) claim concerning the fact that words are "better differentiated" in the upper portion than in the lower portion. This raises another important question: whether or not this phenomenon is specific to lowercase words. Keep in mind that, unlike UPPERCASE words, lowercase words present some characteristics in terms of overall outline shape with the ascending, descending, and neutral letters (e.g., shape) (see Perea & Rosa, 2002). To answer this question, it is critical to examine whether mutilated uppercase words (e.g., METRO) can also produce a masked repetition priming effect. This is the goal of Experiment 3.

Thus, in Experiment 3, we examined whether mutilated uppercase primes in which only the upper portion of the lowercase prime was preserved can produce masked repetition priming (METRO-metro vs. HOTEL-metro) –as in Experiment 1, we also included an intact priming condition (i.e., METRO-metro vs. HOTEL-metro). As indicated in the Introduction, the size of the masked repetition priming effect is similar when uppercase targets are preceded by lowercase primes and then lowercase targets are preceded by uppercase primes (see Qiao et al., 2009).

Experiment 3

Method

Participants. Sixteen students from the University of Minho took part voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of European Portuguese. None of them had participated in Experiments 1-2.

Materials. The materials were the same as in Experiment 1, except that the primes were presented in uppercase and the targets were presented in lowercase (mutilated primes: METRO-metro vs. HOTEL-metro; intact primes: METRO-metro vs. HOTEL-metro). The list of stimuli is available at http://www.uv.es/mperea/saw.xlsx.

Procedure. This was the same as in Experiments 1-2.

Results and discussion

Incorrect responses (3.0% of the data for word targets) and RTs less than 250 ms or greater than 1500 ms (less than 0.5% of the data for word targets) were excluded from the latency analyses. The mean RTs and error percentages from the participant analysis are presented in Table 3. The design was the same as in Experiment 1.

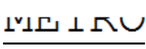
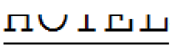
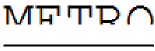
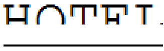
Word data. The ANOVA on the latency data showed that, on average, target words preceded by an identity prime were responded to 38 ms faster than the targets words preceded by an unrelated prime, $F1(1,12)=132.32$, $MSE=343.2$, $p<.001$;

F2(1,232)=151.2, MSE=2687.6, p<.001. In addition, targets words preceded by an intact prime were responded to 11 ms faster than the target words preceded by a mutilated prime, F1(1,12)=6.47, MSE=638.2, p<.03; F2(1,232)=11.65, MSE=2643.0, p<.002, and that high-frequency words were responded to 29 ms faster than low-frequency words, F1(1,12)=38.97, MSE=675.5, p<.001; F2(1,232)=42.82, MSE=7071.9, p<.001. The effect of relatedness was greater for low- than for high-frequency words (45 vs. 31 ms), as deduced from the significant word-frequency by relatedness interaction, F1(1,12)=6.72, MSE=227.9, p<.025; F2(1,232)=5.09, MSE=2687.6, p<.025. Importantly, the relatedness x type of prime interaction was significant, F1(1,12)=8.45, MSE=176.4, p<.015; F2(1,232)=4.73, MSE=2457.8, p<.035: this interaction reflected that the effect of relatedness was greater for the intact primes (44 ms; F1(1,12)=98.35, MSE=154.8, p<.001; F2(1,232)=115.97, MSE=2393.7, p<.001) than for the primes which conserved the upper portion (31 ms; F1(1,12)=86.84, MSE=364.8, p<.001; F2(1,232)=50.97, MSE=2751.5, p<.001). None of the other effects/interactions approached significance (all ps>.50).

The ANOVA on the error data showed that, on average, participants made more errors on targets when preceded by an unrelated word than when preceded by an repeated word, F1(1,12)=6.71, MSE=14.09, p<.025; F2(1,232)=9.93, MSE=71.4, p<.003, and that participants made more errors on low-frequency words than on high-frequency words, F1(1,12)=20.29, MSE=10.27, p<.002; F2(1,232)=12.34, MSE=126.7, p<.002. None of the other effects/interactions was significant (all ps>.25).

Nonword data. The ANOVAs on the latency/error data failed to show any significant effects (all ps>.25).

Similarly to Experiment 1, the present experiment has revealed a sizeable masked repetition priming effect with mutilated uppercase primes –the only (minor) difference is that the masked repetition priming effect was 13 ms greater for intact primes (44 ms) than for mutilated primes (31 ms). The parallel masked repetition priming effects in Experiment 1 were 39 vs. 34 ms, respectively. In addition, as in Experiment 1, the magnitude of masked repetition priming was slightly greater for low- than for high-frequency words.

Once we have demonstrated that masked repetition priming occurs to a large degree for mutilated uppercase prime words when the upper portion of the words is preserved, the issue now is to examine whether masked repetition priming can also be observed when only the lower portion of the uppercase word is preserved (i.e., whether -metro is faster than -metro). More important, we directly tested whether the magnitude of masked repetition priming with mutilated uppercase primes is also greater when the upper portion of the word is preserved (as in -metro vs. -metro). This was the goal of Experiment 4 –note that this experiment is parallel to Experiment 2 except that we employed uppercase primes and lowercase targets.

Experiment 4

Method

Participants. Sixteen students from the University of Minho took part voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of European Portuguese. None of them had participated in Experiments 1-3.

Materials. The materials were the same as in Experiment 2, except that the primes were presented in uppercase and the targets were presented in lowercase. The list of stimuli is available at http://www.uv.es/mperea/saw.xlsx.

Procedure. This was the same as in Experiments 1-3.

Results and Discussion

Incorrect responses (3.0% of the data for word targets) and RTs less than 250 ms or greater than 1500 ms (less than 0.4% of the data for word targets) were excluded from the RT analyses. The mean RTs and error percentages from the participant analysis are presented in Table 4. The design was the same as in Experiment 2.

Word data. The ANOVA on the RT data showed that, on average, target words preceded by an identity prime were responded to 26 ms faster than the targets words preceded by an unrelated prime, F1(1,12)=196.7, MSE=108.5, p<.001; F2(1,232)=40.07, MSE=3986.1, p<.001. In addition, targets words preceded by a prime which conserved its upper part were responded to 9 ms faster than the target words preceded by a prime which conserved its lower part, F1(1,12)=5.37, MSE=477.6, p<.04; F2(1,232)=6.47, MSE=4008.9, p<.015, and high-frequency words were responded to 32 ms faster than low-frequency words, F1(1,12)=143.12, MSE=327.6, p<.001; F2(1,232)=46.91, MSE=12010.8, p<.001. The relatedness x type of prime interaction was significant, F1(1,12)=11.99, MSE=299.6, p<.006; F2(1,232)=6.02, MSE=3150.7, p<.015: this interaction reflected that the effect of relatedness was greater for the primes which conserved the upper portion (36 ms; F1(1,12)=87.51, MSE=217.6, p<.001; F2(1,232)=35.70, MSE=4044.3, p<.001) than for the primes which conserved the lower portion (15 ms; F1(1,12)=19.49, MSE=190.5, p<.002; F2(1,232)=11.10, MSE=3092.5, p<.002). None of the other effects/interactions approached significance (all Fs<1).

The ANOVA on the error data showed that, on average, participants made more errors on targets when preceded by an unrelated word than when preceded by a repeated word, F1(1,12)=4.14, MSE=8.38, p=.065; F2(1,232)=4.18, MSE=63.3, p<.05, and participants made more errors on low-frequency words than on high-frequency words, F1(1,12)=16.78, MSE=15.10, p<.002; F2(1,232)=10.96, MSE=173.2, p<.002. In addition, the interaction between type of prime, relatedness, and frequency approached significance in the analysis by participants, F1(1,12)=4.35, MSE=9.66, p=.059; F2(1,232)=4.06, MSE=77.6, p<.05, which reflected a masked repetition priming effect for the low-frequency words with intact primes, F1(1,12)=6.26, MSE=10.88, p=.03; F2(1,116)=6.61, MSE=77.2, p<.02, but not for the other conditions (all ps>.15). The other effects/interactions were not significant.

Nonword data. The ANOVAs on the latency/error data failed to show any significant effects.

The results of the present experiment are clear-cut. As occurred in Experiment 2 with lowercase prime words, we found a sizeable masked repetition priming when the uppercase prime words are mutilated. This was the case when the upper part is preserved (a 36-ms priming effect) and also (to a smaller degree) when the lower part is preserved (a 15-ms priming effect).

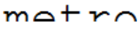
General Discussion

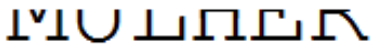
The present series of masked priming experiments provide an empirical demonstration of Huey's (1908) proposal concerning the special status of the upper portion of words in the early stages of visual-word recognition. Importantly, this advantage is not merely due to the specific characteristics of lowercase words (e.g., in terms of "outline word shape") because it also occurs with uppercase words. The main findings can be summarized as follows. First, mutilated primes in which the upper portion of the word is preserved produce a substantial masked repetition priming effect not only in the case of a moderate mutilation (e.g., metro-METRO faster than hotel-METRO; METRO-metro faster than HOTEL-metro), but also in the case of a more substantial mutilation (metro-METRO faster than hotel-METRO). Second, the magnitude of masked repetition priming effects with primes which preserve their upper part (e.g., metro, metro, METRO) is not dramatically smaller to that obtained with intact primes (metro) –a nonsignificant 5-ms difference for lowercase words (Experiment 1) and a significant 13-ms difference for uppercase words (Experiment 3). Third, when only the lower part of the words is preserved (e.g., metro), masked repetition priming is still sizeable (around 24- and 15-ms for lowercase and uppercase words, respectively), but its magnitude is smaller than that when the upper portion of the words is preserved (around 34-43 ms [Experiments 1-2] and around 31-36-ms [Experiments 3-4] for lowercase and uppercase words, respectively).

The present data are consistent with the Blais et al. (2009) findings with the Bubbles technique concerning the special role of the upper portion of lowercase words—this suggests that the Bubbles technique probably taps in some of the same reading mechanism as masked repetition priming. More important, we have shown that the special role of the upper portion of words occurs not only for lowercase words, but also for uppercase words –in which the role of “outline word shape” is much less defined than for lowercase words. The presence of a sizeable masked repetition priming effect even under conditions in which the mutilation is rather large (e.g., metro-METRO) and when the prime only conserves the lower part of lowercase or uppercase words (metro-METRO; METRO-metro) strongly suggests that the cognitive system is able to compensate the missing information in the early stages of word processing without much processing cost –consistent with the Gestalt principle of closure (see Snodgrass & Kinjo, 1998).

What are the implications of the present data for current computational models of visual-word recognition (e.g., interactive-activation model, spatial coding model, multiple read-out model, dual-route cascaded model)? All existing models of visual-word recognition fail to consider in detail the perceptual processes involved in feature extraction. Indeed, simulations of masked priming experiments with existing models of visual-word recognition assume that both prime and targets are presented in uppercase –using the font defined by Rumelhart and Siple (1974). Leaving aside that it is desirable that models employ both a lowercase and uppercase font in their front-end, we should note here that repetition priming effects are equivalent in size for visually similar and for visually dissimilar prime-target pairs (Bowers et al., 1998; Kinoshita & Kaplan, 2008; Norris & Kinoshita, 2008). Thus, letter representations in the cognitive system go beyond visual appearance quite rapidly so that the system readily attains a letter's identity independent of case or font (see Polk et al., 2009, for simulation work on how the brain could generate abstract representations from, say, the letters a and A via contextual correlations). Furthermore, visual word shape does not appear to play a particular role "for the race to the lexicon" (Paap, Newsome, & Noel, 1984; see also Perea & Rosa, 2002).

More importantly, models of visual-word recognition need to adopt a more realistic letter feature level than the Rumelhart and Siple (1974) font in order to explain not only the present data, but also other recent findings, such as the presence of masked priming effects for words which contain mirror letters embedded in words (Perea et al., 2011), words with letter-like digits (Perea et al., 2008), or the processing of handwritten words (e.g., Gil-López et al., 2011). This is not an easy endeavor and, as Balota, Yap, and Cortese (2006) indicated in a recent review on letter/word processing, "there are still many questions that need to be resolved in mapping features onto letters" (p. 289). One approach for a biologically plausible model of letter/word recognition is the (non-implemented) Local Combination Detector (LCD) model of Dehaene, Cohen, Sigman, and Vinckier (2005). This model assumes a hierarchy of processing levels across the ventral route in the brain. As presented in Figure 4 of Dehaene et al. (2005), the visual information would be initially processed in the thalamus (lateral geniculate nucleus) in terms of on/off contrasts. Then, the information would reach the primary visual cortex (V1), in which oriented bars (e.g., horizontal, vertical) would be processed. The following level would be the prestriate cortex (V2) in which the neurons would process letter contours. (In passing, it may be important to note here that, as shown by Changizi, Zhang, Ye, and Shimojo [2006], and consistent with Dehaene and Cohen's [2007] cortical recycling hypothesis, the shapes of letters across a large variety of languages share a clear similarity to the contours found in natural scenes.) The following stage in the LCD model would be around the visual area V4 in the extrastriate visual cortex, in which the "neurons can detect a letter, but only in a given case and shape" (p. 337). Critically, around the bilateral V8 area, Dehaene et al. assumed that there would be a bank of abstract letter detectors as a result of the pooled activation "from populations of shape detectors coding for the different upper and lowercase versions of a letter" (p. 337). In an upper hierarchical level, the model assumes the existence of "open bigrams" (i.e., combination of close-by letters) at the occipito-temporal sulcus (around the so-called "visual word form area"), and even small words and frequent strings (e.g., suffixes).

Can the LCD model –once implemented–capture the presence of masked priming effects with mutilated word primes? As indicated by Dehaene and Cohen (2007), the "letter" neurons in their model "rest on a robust pyramid of lower-level feature detectors with increasingly larger receptive fields and with a considerable redundancy" (p. 456). This implies that the letter receptors can respond to a partial input (i.e., a mutilated word). Indeed, as pointed out by Dehaene and Cohen (2007), inferotemporal neurons in monkeys which are sensitive to complex shapes also discharge when the visual presentation consists of a simpler combination of these visual shapes. Thus, the LCD model can, in principle, capture the presence of masked priming effects with mutilated word primes. The remaining question is why mutilated words in which the upper part is conserved are more effective as primes than the mutilated words in which the lower part in conserved? Our initial hypothesis was that the advantage of the upper portion of the words would be restricted for lowercase words (e.g., ). This way, letter detectors for letters like “h” and “d” could have features that are particularly salient in the context of letters like “n” and “c” –on the basis that these letters have features that extend above the bulk of the word. Note that even early models of letter recognition (e.g., Selfridge’s Pandemonium model; see Selfridge, 1959) had the capacity to adjust the weights of the features were more discriminating among letters –via learning, so that this would be relatively easy to implement in the models. However, we found an advantage of the upper portion of the words not only for lowercase words, but also for UPPERCASE words (e.g., ; i.e., stimuli with a much less defined “outline shape”), which rules out the previous explanation.

What is special about the upper part of the letters (at least in the Latin alphabet)? (footnote 1) One initial, perceptual explanation, attributed to Javal, for the superiority of the upper part (over the lower part) of a word, is that, when reading, the eyes tend to fixate on the upper half of the lines (see Huey, 1908). However, to our knowledge, there is no empirical evidence supporting this claim. One second possibility is that the degree of ambiguity with the mutilated words might differ across conditions. To further examine this issue, we conducted some post hoc analyses on the item averages to examine whether the potential degree of ambiguity in the upper vs. lower portions of the mutilated uppercase words –which is the apparently puzzling finding. For instance, words like DIOCESE are composed of several potentially ambiguous letters when the lower portion of the word is removed, as in  (i.e., the mutilated letters O, C , and E resemble the mutilated letters Q, Ç, and F, respectively); similarly, words like MULHER (the Portuguese for woman) are composed of several potentially ambiguous letters when the upper portion of the word is removed, as in  (i.e., the mutilated letters U, L, and R resemble the mutilated letters O, E, and K, respectively). However, none of these analyses revealed any signs of relationship between the size of the priming effect and the number of (potentially) ambiguous letters in the mutilated primes in any of the conditions. One relevant piece in the puzzle is that the an advantage of the upper part of the words in the Bubbles technique is restricted to word stimuli (Blais et al., 2009); in contrast, isolated letters do not yield an advantage for the upper part of letters with the same technique (see Fiset et al., 2008). This suggests that the advantage of the upper portion of words appears to be the result of the dynamics in the word-recognition system –rather than the dynamics of an isolated letter-recognition system. As Blais et al. (2009) indicated, “letter representations may be slightly different for isolated letters and for letters in words” (p. 6). This may reflect the role of continuous cascades, where perceptual processes do not resolve themselves prior to the initiation of higher-level processes – such as visual-word recognition. Simulations on an implemented version of the LCD model –or in a modified version of current computational models of visual-word recognition– would be necessary to assess whether the advantage of the upper portion of the words falls naturally from the dynamics of the letter feature level, or whether the observed effect is the result of some feedback from the word level. To examine this possibility, one would need to implement a feature detection process (from a set of realistic letter features; see Sanocki, 1991, for some insightful suggestions) that activates lexical units either with feedback to the letter level or without feedback to the letter level (see Jacobs & Grainger, 1992, for a similar approach in the context of neighborhood effects).

In sum, the present series of masked priming experiments have demonstrated that the cognitive system employs a fast and flexible orthographic encoding process that allows the recovery of partial/degraded information, even in the absence of top-down conscious information –via a masked priming paradigm. When only the upper portion of the words is available, this process is achieved with very little reading cost –consistent with Huey's (1908) proposal. Importantly, the advantage of the upper portion of the words occurs not only for lowercase words (which might convey potentially useful "outline word shape" information), but also for uppercase words. Further research (combining behavioral and neurophysiological techniques) is necessary to unveil the intricacies of the earliest stages of letter-to-word processing during visual-word recognition and reading. In the past decade, the growing interest in letter transposition effects led to a new generation of computational models of visual-word recognition aimed at explaining in detail the process of letter position coding. We believe that the present data with degraded words may serve as a challenge for computer modelers to consider in detail the processing mechanisms that mediate the visual input and the word level –and which are underspecified in the current implementations.

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Table 1. Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in Experiment 1

	Type of prime			
	Intact (metro)		Upper part (metro)	
	Low-Freq	High-Freq	Low-Freq	High-Freq
Words				
Identity	628 (3.3)	593 (2.1)	624 (6.0)	597 (2.1)
Unrelated	673 (5.8)	625 (2.5)	667 (6.6)	621 (2.1)
Rep.Priming	45 (2.5)	32 (0.4)	43 (0.6)	24 (0.0)
Nonwords				
Identity	762 (6.7)		756 (7.2)	
Unrelated	763 (6.4)		764 (7.3)	
Rep.Priming	1 (-0.3)		8 (0.1)	

Table 2. Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in the Experiment 2

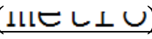
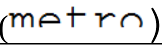
	Type of prime			
	Lower part ()		Upper part ()	
	Low-Freq	High-Freq	Low-Freq	High-Freq
Words				
Identity	621 (5.2)	590 (2.7)	607 (4.2)	568 (1.3)
Unrelated	652 (4.6)	607 (2.9)	656 (7.1)	605 (2.9)
Rep.Priming	31 (-0.6)	17 (0.2)	49 (2.9)	37 (1.6)
Nonwords				
Identity	752 (6.7)		757 (7.6)	
Unrelated	772 (5.8)		755 (6.0)	
Rep.Priming	20 (-0.9)		-2 (-1.6)	

Table 3. Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in Experiment 3

	Type of prime			
	Intact (METRO)		Upper part (METRO)	
	Low-Freq	High-Freq	Low-Freq	High-Freq
Words				
Identity	520 (2.7)	498 (0.8)	538 (3.8)	517 (1.5)
Unrelated	571 (5.2)	536 (2.3)	576 (5.6)	540 (2.5)
Rep.Priming	51 (2.5)	38 (1.5)	38 (1.8)	24 (1.0)
Nonwords				
Identity	641 (4.9)		639 (5.7)	
Unrelated	641 (5.4)		638 (4.6)	
Rep.Priming	0 (0.5)		-1 (-1.1)	

Table 4. Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and nonword targets in Experiment 4

	Type of prime			
	Lower part ()		Upper part ()	
	Low-Freq	High-Freq	Low-Freq	High-Freq
Words				
Identity	587 (2.7)	546 (1.0)	557 (4.9)	548 (1.0)
Unrelated	602 (5.6)	561 (1.7)	621 (4.2)	582 (2.5)
Rep.Priming	15 (2.9)	15 (0.7)	39 (-0.7)	34 (1.5)
Nonwords				
Identity	700 (6.9)		706 (6.4)	
Unrelated	707 (6.6)		715 (6.2)	
Rep.Priming	7 (-0.3)		9 (-0.2)	

Footnotes

1. It may be interesting to note that a recent experiment in Chinese revealed that the removal of beginning strokes in a character is more disruptive to normal reading than the removal of ending strokes (see Yan et al., in press). That is, similar to what occurs in the Latin script with the lower/upper half of the words, not all strokes within a character in Chinese are equally important.

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