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The effects of word identity, case, and SOA on word priming in a subliminal context.

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Abstract

It is widely assumed that subliminal word priming is case insensitive and that a short SOA (< 100 ms) is required to observe any effects. Here we attempted to replicate results from an influential study with the inclusion of a longer SOA to re-examine these assumptions. Participants performed a semantic categorisation task on visible word targets that were preceded either 64 or 192 ms by a subliminal prime. The prime and target were either the same or different word and could appear in the same or different case. We confirmed the presence of subliminal word priming (same word < different word reaction times). The word priming effect did not differ when case was the same or different, which supports case insensitive word priming. However, there was a general facilitation effect driven by case (same case < different case). Finally, there was a significant difference between the two SOA conditions; however, there were no interactions between SOA and any other factor, demonstrating that subliminal priming did not differ between short and long SOAs. The results demonstrate that word priming is case insensitive but that there is nevertheless an overall facilitation when words, regardless if they are repeated or not, are presented again in the same case. This facilitation in case may reflect modularity in the low-level processing of the visual characteristics of words.

Introduction

A long-standing question in cognitive science is the extent to which stimuli are processed when we do not consciously perceive them. More specifically, are subliminal stimuli confined to a low-level sensory analysis or are they also processed at a higher semantic level? Word stimuli have been extensively studied in this regard and have been shown to influence behaviour despite being visually masked (Kouider & Dehaene, 2007). Visual masking refers to a paradigm in which briefly flashed (< 50 ms) stimuli are suppressed from the participant's awareness by presenting other stimuli that act as noise in close spatial and temporal proximity. The influence that subliminally presented stimuli has on subsequent processing can be tested by examining the priming effect in a semantic decision task.

For example, after the presentation of a masked word (the prime), a participant might be instructed to categorise a visible word (the target) as belonging to either one of two semantic categories (e.g. 'natural' for the word 'lion', or 'manmade' for the word 'radio'). If the experiment has a repetition-priming design, then priming is inferred when participants are faster to categorise the target when the prime is the same word compared to when the prime is a different word from the opposite semantic category (Dehaene et al., 2001). Alternatively, if the experiment has a category-priming design, then priming is inferred when the target is categorised faster when the prime and target are different words but belong to the same semantic category compared to when they are not. Category-priming designs are widely used in many decision tasks, including, but not limited to, male / female first name (Draine & Greenwald, 1998; Greenwald, Draine, & Abrams, 1996) and positive / negative valence word (Abrams & Greenwald, 2000; Gaillard et al., 2006; Greenwald et al., 1996; Klauer, Eder, Greenwald, & Abrams, 2007) classification tasks.

Subliminal word priming experiments in the past 20 years seemed to have treated two key findings from two landmark studies as seldomly questioned working assumptions, which have not been verified or validated in a long time yet continue to influence experimental designs. The first is that subliminal word priming is case-insensitive (Dehaene et al., 2001) and the second is that a stimulus-onset-asynchrony (SOA) of less than 100 ms between the prime and the target is required for subliminal word priming effects to occur (Greenwald et al., 1996). The present study sought to re-examine these two widely adopted notions by repeating similar experiments as in the Dehaene et al. (2001) study but with typical as well as longer SOA relative to most word masking studies. In terms of the latter, there have been the occasional study testing and reporting subliminal priming with SOAs longer than 100 ms (Armstrong & Dienes, 2013; Berkovitch & Dehaene, 2019; Kiefer & Spitzer, 2001; Ortells, Kiefer, Castillo, Megías, & Morillas, 2016).

Case-independent word processing

In a word priming study, Dehaene et al. (2001) demonstrated that the mechanisms of subliminal word priming could be case-insensitive. The participants' task involved classifying visible target words as either 'natural' or 'manmade'. Priming was examined by having the prime and target words (a) repeated (i.e., same word) or non-repeated (i.e., different word), and (b) presented in the same or different case. The results demonstrated that reaction times (RT) were faster when the prime and target were repeated compared to when they were not. In addition, this effect was reported to be similar in magnitude even when the case differed between the prime and the target. Namely, participants seemed to have correctly encoded word identity irrespective of how the words appeared according to their case – a phenomenon referred to as case-independent priming. Neuroimaging with functional magnetic resonance imaging (fMRI) further revealed that the subliminal words elicited neural responses in high-level visual areas analogous to those that are engaged in processing the meaning of words. Specifically, responses were observed in an area of the left posterior fusiform gyrus called the visual word form area (VWFA). This result was highly influential and showed that subliminally presented words could reach an advanced stage of processing.

Reading involves the rapid integration of several stages of processing, including the visual processing of the physical appearance of words (i.e. the letter contours and shapes that form impressions on the retina), the pre-lexical orthographic and phonological decoding of letter strings, and the lexical-semantic processing of word identity (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Carreiras, Armstrong, Perea, & Frost, 2014). Within this hierarchy, a broad distinction can be made between 'perceptual-orthographic' (low-level) and 'lexical-semantic' (high-level) processes (Carreiras et al., 2014). Typically, the perceptual-orthographic features of words do not influence lexical-semantic recognition. This might be because the goal of reading is usually to access the semantic content of words and does not depend on letter *font* or CASE except when italicised / capitalised letters signal something special about the word. For example, literate adults can efficiently recognise the words 'rage' and 'RAGE' as having the same meaning despite the letters having different shapes, but if an uppercase 'RAGE' was encountered mid-sentence then it has been emphasised and is read differently. The ability to recognise words meaning despite wide variability in physical appearance is sometimes referred to as the perception of the 'word form unit' (Cohen & Dehaene, 2004; Grainger, Rey, & Dufau, 2008; McCandliss, Cohen, & Dehaene, 2003). The response properties of the VWFA appear to reflect this stage of invariant word processing (Dehaene & Cohen, 2011; Dehaene, Le Clec'H, Poline, Bihan, & Cohen, 2002; McCandliss et al., 2003). Thus, case-independent priming and the corresponding neural activation in the VWFA demonstrate that subliminal words can be processed at the level of the word form unit (Dehaene et al., 2001; McCandliss et al., 2003).

Many researchers seem to assume that the analysis of subliminal words operates exclusively at a high-level and do not consider including the appropriate controls to verify if priming is case independent. For instance, some studies present upper-case primes and lower-case targets (Abrams, 2005; Abrams & Greenwald, 2000; Draine & Greenwald, 1998; Klauer et al., 2007; Ortells et al., 2016; Van den Bussche & Reynvoet, 2007), others present lower-case primes and upper-case targets (Kouider, Dehaene, Jobert, & Le Bihan, 2006), and some present both in the same case (Armstrong & Dienes, 2013; Diaz & McCarthy, 2007; Klauer et al., 2007; Klinger, Burton, & Pitts, 2000). Although all these studies provided suitable controls to verify that the prime was presented outside of awareness, none incorporated a proper control to verify case-independent word priming. Namely, no comparisons could be made between same case and different case.

Equally problematic, studies that did include the conditions necessary to make these comparisons did not provide proper verification that the primes were presented outside of awareness (Jacobs, Grainger, & Ferrand, 1995; Perea Jiménez, & Gómez, 2014; Perea, Vergara-Martínez, & Gomez, 2015). Instead, they asked participants at the conclusion of the study if they thought they saw the primes. This is not a stringent enough measure of prime visibility (Kouider & Dehaene, 2007).

Effective masking is difficult to achieve, and it could be the case that participants could have seen the prime through the mask. Thus, case-insensitive priming at a subliminal level is perhaps not as well established as many in the discipline might believe. In the present investigation, we sought to determine if priming is still case-sensitive under genuinely subliminal conditions. Therefore, the first objective of this study was to investigate the effects of case in a semantic decision task by repeating methods like those in the Dehaene et al. (2001) study while providing verification that the primes were subliminally presented. We urge all masking studies to consider some form of verification as to whether participants were aware of seeing primes – especially if the intent is to present primes outside of conscious awareness. Otherwise, inferences about subliminal processing are limited and may not necessarily involve the same word processing mechanisms as those examined in this study, which we were able to determine was in a subliminal context, or in the original Dehaene et al. (2001) study that has provided a thorough examination of the underlying neural correlates.

Stimulus-onset-asynchrony between the prime and target

The length of SOA in priming experiments is an important consideration given they can not only influence the results but they can do so in a manner that is different across tasks, such as category and repetition-priming experiments (Ferrand, 1996; Stolz, Besner, & Carr, 2005). In the subliminal literature, Greenwald et al. (1996) published a study that has been seminal in guiding later experimental designs in terms of selecting SOAs. Participants classified target words as corresponding to unambiguously male (e.g., Mike) or female (e.g., Sarah) first names, which were preceded by a congruent (e.g., 'David' prime – 'Mike' target) or an incongruent (e.g., 'Sarah' prime – 'Mike' target) prime. The authors varied the SOA from 67 to 400 ms and found that subliminal word priming was short-lived and deteriorated rapidly at SOAs longer than 100 ms. Therefore, they concluded that "the target word must occur within about 100 milliseconds of the prime" (pg. 1699) to observe any subliminal effects. This notion has since been widely adopted in many subliminal priming experiments and is not restricted to category-priming designs specifically. Nevertheless, a few studies have since examined and observed category-priming effects with SOAs longer than 100 ms. For example, studies by Kiefer and Spitzer (2001) and Ortells, Kiefer, Castillo, Megías, and Morillas (2016) demonstrated word priming effects with both short (67 ms) and long (200 ms) SOAs. In addition, Armstrong and Dienes (2013) also observed effects in a noun decision-making task with a minimum SOA of 166 ms. More recently, Berkovitch and Dehaene (2019) found subliminal syntactic word priming with an SOA of 133 ms. Whether or not an SOA greater than 100 ms can likewise result in priming in a truly subliminal repetition-priming experiment has not been tested recently. Therefore, the second objective of the present investigation was to test if effects associated with the subliminal prime can be observed with an SOA greater than 100 ms in a repetition-priming design under a subliminal context.

Study aims

The aims of this study were to clarify two aspects of subliminal word priming. First, we aimed to examine if subliminal repetition-priming is case-sensitive, which has been overlooked since the Dehaene et al. (2001) study. We repeated the paradigm employed by Dehaene et al. (2001) by manipulating the congruency of case between prime and target to test this. If word case is irrelevant to the processing of subliminal primes, then priming effects should be comparable between same-case and different-case trials. Second, we aimed to examine if repetition-priming is undetectable with an SOA longer than 100 ms, which the earlier category-priming experiments by Greenwald et al. (1996) suggest and that much subsequent research has likewise seemed to assume to be true. To test this possibility, we had two SOAs: 64 ms and 192 ms. If the influence of the subliminal prime is short-lived, then we would expect to observe priming effects at the shorter SOA only – as demonstrated originally by the Greenwald et al. (1996) study.

Methods

Overview

Participants completed four tasks. A naming task was followed by a recognition task as in the Dehaene et al. (2001) study. The other two tasks examined the word priming effect at both short (64 ms) and long (192 ms) SOAs. The order of the tasks was counterbalanced, such that participants either completed the naming and recognition tasks first, followed by the long-SOA priming task, and finished with the short-SOA priming task; or, participants completed the short-SOA priming task, followed by the long-SOA priming task, and finished with the naming and recognition tasks.

Participants

Twenty right-handed, native English speakers (M_{age} = 24.10 years, 7 males) participated in the experiment. None of the participants reported any history of neurological or psychiatric disorder and all gave written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and approved by the La Trobe Human Ethics Committee (FHEC14R93).

Apparatus and materials

The four tasks were presented on a 17-inch LCD monitor (1280 x 1024-pixel resolution with a 60 Hz screen refresh rate) with E-Prime 2.0 and 3.0 software (Psychology Software Tools, Sharpsburg, PA, United States). Word stimuli consisted of 240 English nouns between 4 and 5 letters in length. The words were selected according to the SUBTLEX frequency norms, which come from the $SUBTLEX_{US}$ corpus. The corpus is comprised of American subtitles from 8,388 films and television episodes (including a total of 51 million words) (Brysbaert & New, 2009). This corpus was chosen because frequencies based on television and film subtitles are known to be more representative of everyday language than frequencies based on written sources, particularly for short monosyllabic and bisyllabic words of up to 5 letters in length (for a review, see Brysbaert & New, 2009). The 240 words had a mean subtitle log word form frequency ($SUBTLEX_{WF}$) of 2.64 per million words. Half of the words were natural (e.g. lion, mango) and the other half denoted man-made (e.g. radio, coat) words (See Appendix for full list of words). The words were presented in Courier New font, which subtended 1.4° visual angle in width and 0.4° in height. These 240 words were separated into 2 lists of 120 words (termed 'set A' and 'set B') each containing 60 natural and 60 man-made words. The words in set A and B were matched according to frequency in everyday language ($t = 0.092$, $p = .927$), number of syllables ($t = 0.395$, $p = .639$), and number of letters ($t = 1.302$, $p = .194$). For each participant, one list was used for the naming-recognition tasks (e.g. set A) and the other was used (e.g. set B) for the two priming tasks. To avoid practice effects in the priming tasks, the prime and target were presented in a reverse-order so that the prime in one SOA task was presented as the target in the second SOA task. Words forming congruent word pairs were never presented in incongruent pairs, and vice versa. These conditions were also matched for frequency in everyday language, number of syllables, and number of letters. A high-contrast pixel pattern which subtended 2.6° visual angle in width and 1° in height was used to mask the words (see Figure 1).

Naming task

Participants were presented with 40 visible and 40 masked words presented in a random order. The instructions for this task were as follows. When participants perceived a word, they were asked to name it aloud. Alternatively, they were instructed to say 'seen' whenever they thought they saw something (like part of a word, such as a letter or a 'gist'). If they saw nothing other than the pixel patterns, they were asked to remain silent. Once participants understood the task instructions, the experimenter pressed the space bar to begin the trials. As shown in Figure 1a, the sequence of events for the visible condition was: (1) fixation for 3,000 ms; (2) mask for 80 ms; (3) blank for 80 ms; (4) word stimulus for 32 ms; (5) blank for 80 ms; (6) mask for 80 ms; and finally (7) participant response for 2,000 ms. The sequence of events for the subliminal condition was identical, with the exception that the order of masks and blanks was adjusted so that a mask rather than a blank screen immediately flanked the word stimulus (Figure 1b). Verbal responses were recorded with a Shure X2u XLR-to-USB microphone (Shure Incorporated, Chicago, IL, USA).

Recognition task

Participants completed the recognition task immediately after the naming task. Participants were told that they would be presented with a series of words and that their task was to indicate whether the word had been presented in the previous naming task. We displayed the same 40 visible and 40 masked words as the naming task plus an additional 40 new distractor words one at a time in isolation without any masking. Using a model RB-840 Cedrus response pad (Cedrus Corporation, San Pedro, CA, USA), participants pressed “1” whenever they thought the word had been presented earlier (i.e. “old”) and “2” when they did not (i.e. “new”). Each word was displayed until a response was recorded. Accuracy and RT measures were collected for the three different conditions (i.e., previously visible, previously masked, and not presented earlier).

Priming tasks

In each of the priming tasks, the participants were instructed to categorise the target words, which were always visible, as either natural or manmade as quickly and accurately as possible. Responses were recorded using the same Cedrus response pad as the recognition task, with the exception that “1” corresponded to ‘natural’ and “2” to ‘manmade’.

Short SOA. The sequence of events for the short-SOA task was as follows: (1) fixation for 3,000 ms; (2) mask for 272 ms; (3) mask for 32 ms; (4) prime for 32 ms; (5) mask for 32 ms; and (6) target until response (Figure 2a). The SOA was therefore 64 ms between the onset of the prime and the onset of the target. On each trial, the prime and target could be either the same word or different words. On different word trials, the words were from the opposite semantic category (e.g., if the prime was natural, then the target was man-made) and had no letter in common at the same location. Additionally, the prime and target could be presented in the same or different case. This meant that there were four possible presentations:

(1) Non-Repeated Word, Different-Case (e.g. BULL-shoe);

(2) Non-Repeated Word, Same-Case (e.g. BEAR-CAKE);

(3) Repeated-Word, Different-Case (e.g. bush-BUSH);

(4) Repeated-Word, Same-Case (e.g. DIRT-DIRT).

Each type of presentation occurred 20 times. Thus, the total number of trials with an SOA of 64 ms was 80.

Long SOA. The sequence of events for the long-SOA task was like the one used in the naming task: (1) fixation for 3,000 ms; (2) blank for 80 ms; (3) mask for 80 ms; (4) prime for 32 ms; (5) mask for 80 ms; (6) blank for 80 ms; and finally (7) target until response (Figure 2b). The SOA was therefore 192 ms between the onset of the prime and the onset of the target. Like the short-SOA task, there were four possible presentations of 20 trials each that could either differ or not in word identity or case. The total number of trials with an SOA of 192 ms was 80.

Statistical analyses

The data were analysed using Jamovi software (The Jamovi Project; Sydney, New South Wales, Australia) with the gamlj module, Statistical Package for Social Science (SPSS) version 25 (IBM Corporation; Armonk, New York, USA) and GraphPad Prism version 6 (GraphPad Software Inc.; La Jolla, California, USA). Like the study by Dehaene et al. (2001), we examined accuracy to visible and masked words in the naming task in a descriptive manner. For the recognition task, we examined accuracy and RT for categorising the masked and distractor words with paired-samples *t*-tests. For the priming tasks, RT from error trials and outliers were excluded (< 200 ms and > 2,000 ms). Together, these criteria resulted in a loss of 3.8% of the data with 3080 remaining observations. From there, an analysis based on a general linear model was carried out. The model had case congruency (same vs. different), word repetition (repeated vs. unrepeated), and SOA (short vs. long) as fixed factors and participant and item as random factors. These random factors were included in the model to remove all effects driven by participants and items. Participant accuracy was not compared between conditions as mean performance was at ceiling level (96-99%).

Results

Naming and recognition tasks

Participants correctly identified 98.69% of visible words but not a single masked word (0%). For the recognition task, participants correctly categorised 78.21% of the visible words presented earlier in the naming task (range = 47.50% to 97.50%). Conversely, participants recognised only 10.48% of the masked words. This detection rate did not differ from the 10.71% commission errors that were made to the distractors ($t_{(19)} = 0.43$, $p = .672$). RTs to the masked and distractor words also did not differ (1,118.04 ms and 1,113.77 ms, respectively; $t_{(19)} = 0.11$, $p = .915$). The results from these tasks demonstrate that primes could not be detected under masking conditions and that masked words were treated just like words that had never been presented before.

Priming tasks

The analysis revealed a main effect of word repetition such that participant RTs were faster when the prime and target were the same word compared to when they were different words ($F_{(1, 297)} = 4.32$, $p = .039$). This main effect demonstrates that there was a subliminal word-priming effect. There was also a main effect of case congruency, which revealed that the same case prime-target pairs were categorised faster than the different case prime-target pairs ($F_{(1, 297)} = 7.63$, $p = .006$). This main effect demonstrates that word case also influenced RTs. There was a facilitation effect when the same case was repeated. There was no interaction between word repetition and case congruency ($F_{(1, 636)} = 0.37$, $p = .541$). The lack of an interaction confirms that word priming is case insensitive. The main effect of SOA on RTs was also significant ($F_{(1, 636)} = 7.53$, $p = .005$), which showed that RT was slower in the short compared to long SOA condition. None of the other interactions were significant either (all $\geq p = .087$). (see Table 1 for means and standard errors in each of the priming task conditions).

Discussion

We had two aims in the present investigation. First, we aimed to re-examine if word priming is case-insensitive under subliminal conditions, as originally reported by Dehaene et al. (2001). Second, we aimed to test if subliminal priming effects can be observed with an SOA longer than 100 ms. We observed case-independent word priming, as participants were faster to classify targets when they were the same word as the prime even when the case was different. However, there was also a main effect of case, which Dehaene et al (2001) did not report. That is, the same case trials were categorised faster than the different case trials regardless of whether the target was a repeated or non-repeated word. Finally, we found a main effect of SOA, where participants were slower to categorise targets in the short rather than long SOA conditions (short SOA $M = 783 <$ long SOA $M = 808$). Importantly, SOA did not interact with any other factor, demonstrating that subliminal priming did not differ between short and long SOAs. As discussed below, these results are informative to understanding subliminal word priming as well as future experimental designs.

The main effect of case does not undermine notions that subliminal word priming is case-independent. To explain, participants were clearly able to encode word identity *independent of case*. Take the short-SOA condition as an example (see Table 1): word repetition-priming was present on same case (repeated word $M = 774 <$ non-repeated word $M = 818$) and different case (repeated word $M = 805 <$ non-repeated word $M = 836$) trials. This illustrates that participants were primed with word identity even when the words physical appearance differed due to case (e.g., raft-RAFT). If word-identity priming *was* case dependent, then priming effects should only be evident on same case (repeated $<$ non-repeated) and not on different case (repeated $\neq$ non-repeated) trials. Instead, a visual facilitation effect driven by letter case occurred simultaneously with identity priming. To use the short-SOA condition as an example again: there was a case processing advantage on repeated word (same case $M = 774 <$ different case $M = 805$) and non-repeated word (same case $M = 818 <$ different case $M = 836$) trials. If case was irrelevant then there should be no same case advantage and the RT's similar (same case ≠ different case). Dehaene et al. (2001) do not appear to have observed the case effect, or if they did, it was not reported. We speculate that two distinct forms of facilitation were present that explain the two main effects: conceptual and perceptual facilitation.

Conceptual facilitation refers to the facilitation in processing the meaning of stimuli, independent of physical properties, whereas perceptual facilitation refers to the facilitation in processing the physical features of stimuli, independent of meaning (Chouinard, Morrissey, Köhler, & Goodale, 2008; Henson, 2003). The main effects of word repetition and case could reflect conceptual and perceptual facilitation, respectively. The former is in line with many other studies demonstrating that word identity can be processed under subliminal viewing conditions (for a review, see Kouider & Dehaene, 2007). Nothing new can be inferred from this result. What deviates from current thinking is that case, despite being task-irrelevant and not receiving task related attention, can also exert a strong influence on target processing. This highlights that feature-specific visual encoding affects subliminal facilitation and not just high-level perception of word identity.

This interpretation of two separate forms of facilitation fits well with the view that two separate computational systems operate in parallel to encode the visual form of words (Marksolek, Kosslyn, & Squire, 1992; Marsolek, 2004). Marsolek and colleagues' postulate that one system processes *form-specific* information while the other processes *abstract-category* information. Abstract-category word processing is synonymous with notions of the word form unit developed by Dehaene and colleagues (Dehaene & Cohen, 2011). As discussed in the Introduction, this describes how a reader can efficiently generalise across word appearance to recognise identity. Neuroimaging studies show that this stage of processing involves the VWFA (McCandliss et al., 2003). The logic behind form-specific encoding of word forms is simple: information about how a word looks must be encoded by the brain, otherwise how else can we recognise form-specific information like a friend's handwriting or differentiate between various fonts?

Neuroimaging techniques show that the extrastriate area in the posterior right hemisphere is specialised in processing the typographic features of words (Posner & McCandliss, 1993). For instance, an increased neural response in this area is observed when a variety of word-like stimuli are seen (e.g., words, nonsense letter strings, and visual stimuli like letters) (Posner & McCandliss, 1993). Moreover, attending to visual attributes like letter thickness or case amplifies activation in this area (Compton, Grossenbacher, Posner, & Tucker, 1991). Thus, the abstract-category subsystem is thought to operate more effectively in the left hemisphere and is associated with higher-order areas like the VWFA, whereas the form-specific subsystem is thought to operate more effectively in the right hemisphere and is associated with activity in earlier visual areas. This fits with the well-documented architecture of the ventral occipito-temporal cortex (VOTC), in which there is a posterior-to-anterior gradient reflecting the processing of information that is more related to basic features to those that are more complex (Lochy et al., 2018).

However, even though form-specific information is an integral part of word processing, the role that case and other factors like word length have on recognition has not been as widely tested. Research from De Moor and Brysbaert (2000) reported stronger priming effects in a masked priming lexical decision task when primes and targets were the same length compared to when they differed in length. In addition, there were twice as many errors when the prime and target differed in length compared to when they did not. Thus, the proper matching of word length in the present study may have been another factor that contributed to the form specific priming observed. Only three other studies have reported an effect of case like the one observed in our study (Hayman & Jacoby, 1989; Marksolek et al., 1992; Masson, 1986). The generalisability of their results to our study is limited due to discrepancies in task and design. Namely, they involved familiarising participants with prime words in a practice phase that was followed shortly after by a test phase, they used different paradigms (i.e., word-stem completion task, Marsolek, et al., 1992; perceptual identification task, Hayman & Jacoby, 1989; reading task, Masson, 1986), and they did not attempt to mask or limit the visibility of primes. The present study is the first to our knowledge to demonstrate an effect of word case on target processing under truly subliminal conditions.

It is important to verify that primes are processed under truly subliminal conditions when examining subconscious processing. As discussed in the Introduction, other studies have tested and shown that low-level features, like word case, do not influence target processing under some masking conditions. For example, Vergara-Martínez, Gomez, Jimenez, & Perea (2015), like many others (Jacobs, Grainger, & Ferrand, 1995; Perea, Jiménez, & Gómez, 2014; Perea, Vergara-Martínez, & Gómez, 2015), have demonstrated that same case prime-target word pairs are not categorised faster than different case prime-target word pairs when prime visibility is limited. However, these studies lacked the necessary control measures to be confident that the primes were truly subliminal. In the present study, the results of our naming and recognition tasks means that we can be more confident that the primes were adequately masked from participants' awareness. Not a single word could be identified under our masking conditions and the masked words were treated like words that had never been encountered before when presented again as visible targets. Thus, relative to the above masking experiments, we are in a better position to make inferences about subconscious processing.

We think the case effect could be partially explained by a lack of feedback from higher levels of processing that are known to characterise subliminal perception (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme & Roelfsema, 2000). Interactive models of word processing demonstrate that higher-order processing of lexical-semantic word properties modulates low-level processing of perceptual-orthographic word properties in a top-down manner (Carrieras et al., 2014). Neuroimaging data supports this model as considerable feedforward and feedback connections exist between low-level (i.e., early visual areas) and high-level (i.e., VWFA) areas within the VOTC (Kravitz, Saleem, Baker, Ungerleider, & Mishkin, 2013). A possible implication of this feedback, which occurs normally under typical viewing conditions, is to prevent the physical features of words from interfering with the processing of their conceptual meaning.

However, under visual masking, when there is no awareness of stimuli, the initial feedforward processing is preserved but there is no further integration with feedback or recurrent processing (Dehaene et al., 2006; Lamme & Roelfsema, 2000). So, although the feedforward 'sweep' reaches the VWFA (Dehaene et al., 2001), the capacity for high-level processing to feedback and modulate processing in the posterior parts of the VOTC is limited. Thus, we speculate that lexical processing supersedes perceptual processing to a lesser degree when this feedback is not permitted to occur normally, such as under our masking conditions. Consequently, here we observed both abstract-category and form-specific priming. The main effect of case calls attention to the importance of controlling for the visual properties of word stimuli in subliminal priming studies. To be clear, we do not think that the main effect of case negates any high-level interpretations of subliminal word processing, but rather highlights that perceptual properties also influence subliminal perception simultaneously. Future research could also examine the robustness of the case effect by testing if the same effect arises for semantically related prime-target pairs in a category-priming study rather than the repetition-priming design used in present investigation.

The other notable finding in the present study concerns the overall reactions to the two SOAs. On average, participants were slower to categorise target words in the short compared to the long SOA condition (short SOA $M = 783$ $<$ long SOA $M = 808$). The reason for the slower reaction time is unclear. We can only speculate that this may reflect some kind of interference from subliminal processing of the prime in the short SOA condition. Nonetheless, the lack of interaction between SOA and any other factor highlights that there were no differences in priming between the short and long SOAs. This calls into question the notion that SOAs longer than 100 ms are too long for subliminal priming to occur, as suggested originally by the Greenwald et al. (1996) study. Differences in methodology may explain the discrepancy. A key feature in the Greenwald et al. (1996) study was to force participants to respond within a short-time window of 383-517 ms. As acknowledged by the authors, mean response latencies for highly motivated participants is typically between 550 and 650 ms. Consequently, this response window did not permit high levels of accuracy and the priming effect was inferred by the substantial error rates rather than response latencies. This methodological change that was implemented by Greenwald et al. (1996) does not appear to have been widely adopted, as later work typically infers priming from RTs rather than error rates. Thus, we think it is unreasonable to assume that interpretations drawn from the Greenwald et al. (1996) study must also apply to studies using more conventional designs. In fact, similar to the present investigation, several category-priming studies (Armstrong & Dienes, 2013; Berkovitch & Dehaene, 2019; Kiefer & Spitzer, 2001; Ortells et al., 2016) have found priming with SOAs longer than 100 ms from RTs and did not restrict responses to short-time windows. For these reasons, we believe that the residual effects of a subliminal prime can still be detected with an SOA beyond 100 ms.

There are aspects to our experimental design that need to be considered too. The mask duration between the prime and targets in the short and long SOA were not the same. The former (32 ms) was shorter than the latter (80 ms), which is suboptimal for comparing the two. Even so, it is still remarkable that the longer mask in the SOA condition did not reduce priming, further undermining the notion that priming cannot occur at SOAs longer than 100 ms. Another point to consider is the number of participants per condition for the purposes of statistical analysis. To enhance the design in future studies it would be ideal to have 40 participants and 40 observations per condition (Brysbaert & Stevens, 2018). Despite these limitations, the present study replicated an important experimental finding and has highlighted important methodological considerations for future experiments examining the subliminal word priming effect.

Appendix

List of Words in Set A: kiosk; ladle; silo; sash; wharf; spade; patio; harp; rake; ruler; arena; spear; rail; sewer; torch; café; sofa; plaza; cloth; razor; shelf; spoon; hose; yacht; bench; coin; glove; shed; tools; medal; vault; robot; cigar; blade; toys; brush; rifle; fence; flag; tent; socks; steel; boots; purse; cage; cable; rope; tower; belt; doll; tank; bike; sword; bread; gate; toast; mail; paint; coat; drug; petal; gully; dingo; otter; twig; llama; sloth; husky; snail; pansy; vine; moth; coral; squid; chimp; fern; lime; cobra; berry; poppy; grape; finch; melon; crow; camel; leaf; toad; peach; mice; mule; seed; soil; deer; creek; worm; whale; puppy; frog; hawk; goose; daisy; cave; corn; grass; tiger; cliff; snake; apple; coast; wood; plant; snow; lake; bird; river; beach; fish; rock; horse; water.

List of Words in Set B: cake; desk; bell; roof; shoe; wire; taxi; deck; bowl; pipe; mall; sink; fort; soap; barn; lamp; pole; pill; dish; boot; jeep; oven; cord; pier; comb; tomb; raft; vase; tyre; pram; candy; wheel; plate; piano; couch; trash; chain; cabin; motel; wagon; drill; motor; brick; skirt; porch; arrow; stove; jeans; ferry; broom; scarf; crate; canoe; linen; apron; flute; stair; flask; canon; tongs; land; tree; bear; rose; hill; bull; dirt; duck; wolf; lion; bush; lamb; goat; pony; tuna; crab; swan; slug; peas; reef; clam; hare; plum; moss; boar; wasp; pear; earth; stick; stone; storm; ocean; fruit; bunny; shark; sheep; shell; lemon; cloud; eagle; swamp; olive; wheat; flood; moose; onion; trout; skunk; maple; herbs; zebra; panda; rhino; mango; stork; hyena; hippo; gorge; pecan; tulip.

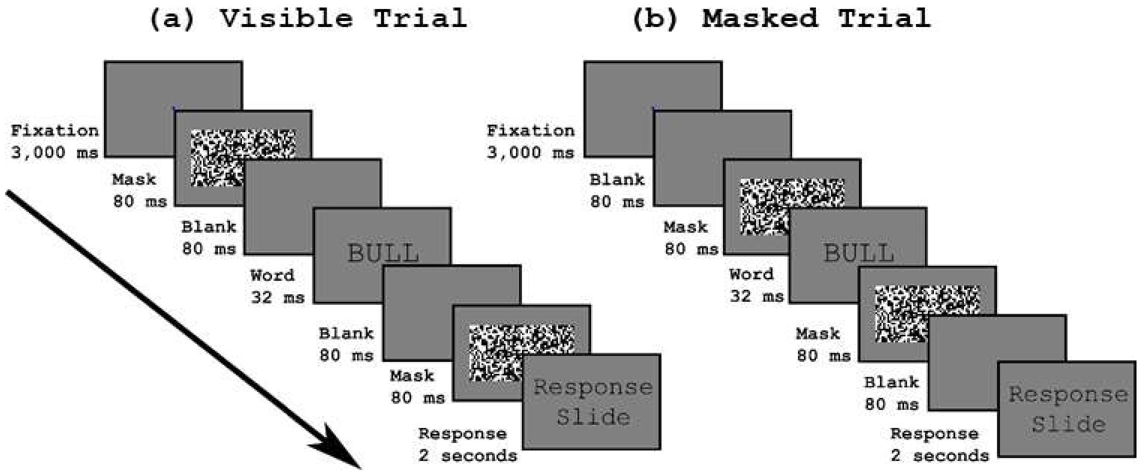

Figure 1. Visual depiction of the (a) visible and (b) masked trials. On visible trials, the words had two blank screens (as opposed to masks) flanking their presentation. Under these presentation parameters, it was expected that participants would be consciously aware of the words. In contrast, on masked trials, the presence of two masks consisting of visual noise (as opposed to blank screens) flanked the words, rendering the latter perceptually invisible.

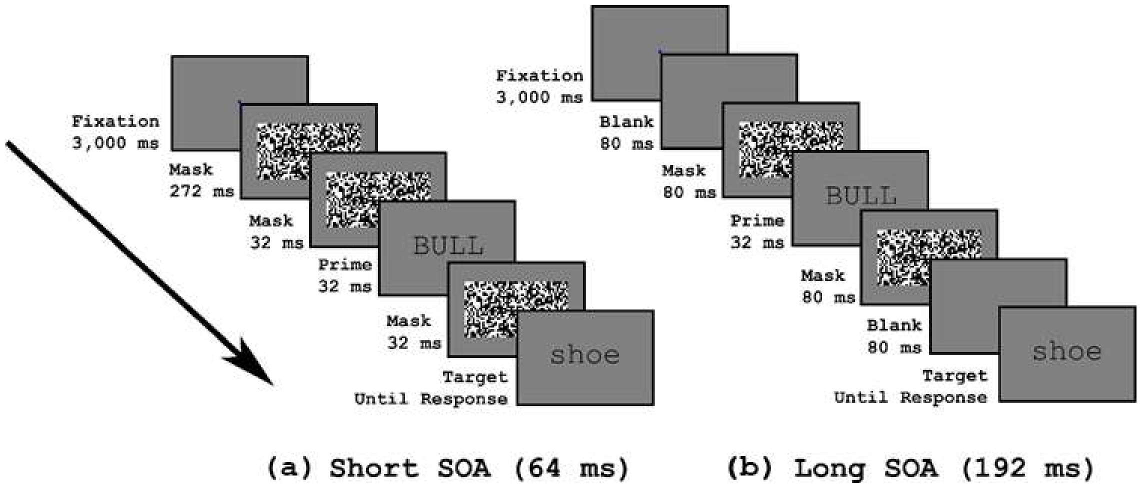

Figure 2. Visual depiction of the short (a) and long (a) SOA conditions. Both a and b depict a non-repeated word/different-case trial. The prime is 'BULL' from the natural semantic category and is in uppercase while the target is 'shoe' from the man-made category and is in lowercase.

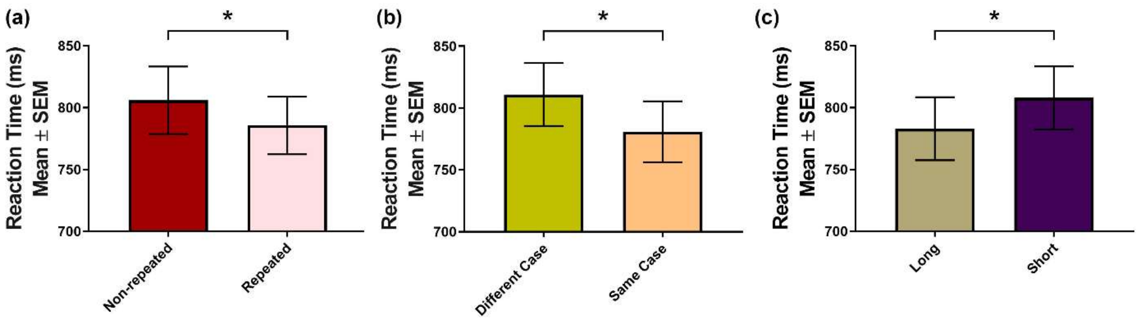

Figure 3. The figure depicts the three main effects that were significant from the analyses. Panel (a) displays a main effect of word congruency, which demonstrates subliminal priming. Panel (b) displays the main effect of case congruency, which demonstrates the influence of case in subliminal word processing. Panel (c) displays the main effect of SOA, which shows that participants were slower overall on the short compared to long SOA conditions. Asterisks (*) denote significant effects at $p < .05$.

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