Morphological priming during reading: Evidence from eye movements

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Abstract

We report an eye movement experiment that investigated whether prior exposure to morphologically related and unrelated primes influenced processing of a target word that appeared later in the same sentence. Prime-target pairs had a semantically transparent (e.g., marshy-marsh) or only an apparent morphological relationship (e.g., secretary-secret), or were morphologically unrelated but overlapped in orthography (e.g., extract-extra). Reading times for target words revealed facilitation effects in measures of both early and late processing only for targets that followed semantically transparent morphological primes, providing evidence of semantically mediated priming between words read normally in a sentence. In addition, an increase in target word skipping and in regressions from a post-target region when targets followed primes rather than control words, regardless of the morphological relationship between the words, suggests that prime-target orthographic overlap influences parafoveal processing of target words. We discuss our findings in relation to morphological priming during isolated word recognition and the process of lexical identification during reading.

Key words: Eye movements during reading; word recognition; morphological decomposition; morpho-orthographic processing, masked priming, unmasked priming.
It is widely argued that morphologically complex words are decomposed into their constituent morphemes during visual word recognition, so that a word like *marshy* is recognised in terms of its components parts (i.e., the stem word *marsh* and the grammatical morpheme -y; Feldman, 2000; Feldman & Soltano, 1999; Longtin, Segui, & Hallé, 2003; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Pastizzo & Feldman, 2002; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Rastle, Davis, & New, 2004; Taft, 1981; Taft & Forster, 1975; Stanners, Neiser, Hernon, & Hall, 1979).

This observation has inspired considerable research into the effects of morphological structure on word recognition, much of which has relied on priming methods based on the lexical decision task to reveal the effects of presenting a morphologically complex word as a prime on the recognition of a target word that is its constituent. This research has been conducted in the context of other research showing that orthographic overlap between prime and target words can slow the recognition of target words (e.g., Bijeljac-Babic, Biardeau, & Grainger, 1997; Colombo, 1986; Davis & Lupker, 2006; Davis, Perea, & Acha, in press; Davis & Taft, 2005; De Moor & Brysbaert, 2000; Drews & Zwiterlood, 1995; Grainger, Colé, & Segui, 1991; Grainger & Ferrand, 1994; Lupker & Colombo, 1994; Segui & Grainger, 1990), where the slowdown in word recognition is usually attributed to exposure to the prime providing activation to a lexical competitor for the target. By contrast with these findings, research on morphological priming has shown that priming effects turn facilitatory when prime and target words are morphologically related, so that presenting a morphologically complex word such as *marshy* as a prime actually facilitates recognition of a stem word target such as *marsh*. The reason the effect is facilitatory is thought to be due to decomposition of the prime providing activation to a lexical entry for the root morpheme shared with the target word rather than a lexical competitor, and so aiding rather than impeding word recognition (e.g., Feldman, 2000; Feldman & Soltano, 1999; Longtin et al., 2003; Longtin & Meunier, 2005; Marslen-Wilson et al., 1994; Marslen-Wilson, Bozic, & Randall, 2008; Pastizzo & Feldman, 2002; Rastle et al., 2000; Rastle et al., 2004; for a review, see Rastle & Davis, 2008).
An important issue in this research concerns whether morphological decomposition is mediated by the semantic relationship between a word and its constituents, and an influential account of this process holds that decomposition takes place only when the words are related in meaning (Giraudo & Grainger, 2000; Marslen-Wilson et al., 1994; Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999). Accordingly, exposure to a word such as *marshy* should activate a representation of its stem (i.e., *marsh*), as this is a semantically related constituent, but exposure to *secretary* should not activate a representation of *secret*, as *secret* and *secretary* are unrelated in meaning (in their modern usage).

Support for this account comes primarily from tasks, such as unmasked or cross-modal priming, in which the prime is made available for conscious perception prior to the display of a target word (or nonword). However, while the standard finding in this research is that facilitation is observed only when prime-target pairs have a semantically transparent relationship (e.g., Longtin et al., 2003; Marslen-Wilson et al., 1994; Rastle et al., 2000), other research employing a masked priming procedure (e.g., Forster & Davis, 1984), in which a visual mask is shown first and the prime is presented so briefly that it is unavailable for conscious report, has produced results that are consistent with a process of morphological decomposition that is (at least initially) blind to word meaning (Feldman, 2000; Feldman & Soltano, 1999; Longtin & Meunier, 2005; Marslen-Wilson et al., 2008; Pastizzo & Feldman, 2002; Rastle & Davis, 2003; Rastle et al., 2000; Rastle et al., 2004; for a review, see Rastle & Davis, 2008).

Rastle et al. (2004) reported an experiment that is typical of this masked priming research and that showed that word recognition is facilitated when prime-target pairs have either a semantically transparent morphological relationship (e.g., *marshy-mash*) or only an apparent morphological relationship (e.g., *secretary-secret*), but not when they are morphologically unrelated (e.g., *extract-extra*). Various claims put forward in support of masked priming include that it avoids episodic effects associated with unmasked priming techniques, and that effects in masked priming experiments reflect early stages of word processing and so can reveal what properties of words are
available before they are consciously perceived (e.g., Forster, 1998). In line with these claims, Rastle et al. (2004) argued that their findings, and those from similar studies, reveal that semantically related and unrelated constituents both become activated during early stages of lexical access. It has also been argued that such findings can be reconciled with unmasked priming research if it is assumed that a meaning-independent decomposition procedure operates early in visual word recognition and representations of inappropriate constituents are inhibited only later (Meunier & Longtin, 2007; Rastle & Davis, 2008; Schreuder & Baayen, 1995).

It should be clear that research employing masked and unmasked priming provides important insights into the influence of morphological priming on word recognition. However, a natural extension of this research is to see if similar priming effects are observed in a reading situation in which the prime and target words are read normally as part of a sentence. This was the approach taken in the present research, which used measures of eye movements while reading to assess the influence of prior exposure to a prime word presented earlier in a sentence on the processing of morphologically related or unrelated target words that appeared later in the same sentence. One motivation for this research was simply to see if effects similar to those reported in studies of isolated word recognition occur in silent reading. However, a further reason for conducting this experiment was to establish what influence priming has on eye movements during reading. There is considerable evidence that eye movements are highly sensitive to processes involved in the lexical identification of words, and that the decision about when to move the eyes is strongly associated with difficulty in processing a fixated word (see Liversedge & Findlay, 2000; Rayner, 1998, 2009). Therefore, an important concern for the present research was whether exposure to a prime word earlier in the sentence would affect processes associated with the lexical identification of a target word and, in turn, influence decisions about when to move the eyes. Such findings would make an important contribution to our understanding of the influence of higher order language processing on the identification of words during reading and help to inform the development of models of eye
movement control (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003; Reichle, Warren, & McConnell, 2009).

Previous eye movement research on morphological processing has focused on the effects of morphological complexity on word processing (e.g., Juhasz, Starr, Inhoff, & Placke, 2003; Kambe, 2004; Lima, 1987) and the processing of compound words (e.g., Andrews, Miller, & Rayner, 2004; Bertram & Hyönä, 2003; Hyönä & Pollatsek, 1998; Juhasz, 2007; Pollatsek, Hyönä, & Bertram, 2000), but has not investigated inter-word priming effects. Moreover, other eye movement research that has examined inter-word priming during reading generally has been concerned with semantic or identity/synonym priming (Binder & Morris, 1995; Camblin, Gordon, & Swaab, 2007; Carroll & Slowiaczek, 1986; Morris, 1994; Morris & Folk, 1998; Traxler, Seely, Foss, Kaup, & Morris, 2000). However, there is growing interest in whether lexical (and phonological) relationships between words in sentences also give rise to priming effects and what influence this has on eye movements (Carreiras, Ambrosio, & Meseguer, 2005; Frisson, Jamali, Pollatsek, & Meyer, 2009; Paterson, Liversedge, & Davis, 2009; Williams, Perea, Pollatsek, & Rayner, 2006; Warren & Morris, 2009).

Paterson et al. (2009) reported an experiment typical of this research that provided particularly strong evidence that inter-word lexical priming effects reported in word recognition research are also observed in eye movements during reading. In this experiment, an orthographically related prime word such as blur (or unrelated prime such as gasp) appeared just a few words earlier in a sentence than a target word such as blue, in sentences such as “There was a blur/gasp as the blue lights of the police car whizzed down the street”, and participants were instructed simply to read these sentences as normal. The patterns of eye movements that were observed indicated that participants had more difficulty in processing targets that followed related than unrelated primes. In particular, fixations times were longer, and readers were more likely to make an inter-word regression back to earlier sentence locations, when targets followed a related prime, and Paterson et al. took these findings to show that inhibitory orthographic priming effects similar to those reported in studies of isolated word
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recognition (e.g., Davis & Lupker, 2006; Segui & Grainger, 1990) also occur naturally due to dependencies between words in sentences, and are reflected in eye movements during reading.

Paterson et al. (2009) argued that these findings are theoretically important, because they demonstrate how the brief experience of processing one word (the prime) can rapidly influence the lexical processing of a subsequent word (the target), which in turn affects decisions about when and where to move the eyes. Moreover, the fact that the effect was observed in measures of eye movements for words in sentences that were read normally indicates that eye movements are sensitive to intra-sentential, inter-lexical influences that occur naturally during reading. This has important implications for our understanding of how the process of lexical identification takes place during reading, and is relevant to the ongoing debate about eye movement control during reading (see, e.g., Reichle, Liversedge, Pollatsek, & Rayner, 2009), and whether decisions about when to move the eyes are mediated by cognitive processing (e.g., an early stage of lexical access) or an autonomous saccade generator (c.f., Engbert et al., 2005; Reichle et al., 1998, 2003). A critical question in relation to these effects concerns the psychological mechanism by which these effects are mediated, and the extent to which this mechanism is intrinsic to the system responsible for oculomotor control during reading.

The present experiment employed a very similar procedure as Paterson et al. (2009) to investigate morphological priming during reading, using prime, target, and control words from stimuli used in the masked priming experiment reported by Rastle et al. (2004). As in their study, prime-target pairs had either a semantically transparent morphological relationship (e.g., marshy-mash), an apparent morphological relationship (e.g., secretary-secret), or were morphologically unrelated but overlapped in orthography (e.g., extract-extra). However, unlike in the study by Rastle et al. (2004), the word pairs were embedded in sentence frames so that a prime (or control) word appeared earlier in a sentence than a target word (see Table 1). These sentences were then shown to participants, who were instructed to read them normally and we assessed the effects of the prime
manipulation on eye movement behaviour through the computation of reading time measures.

While an important goal of our research was to replicate a key aspect of Paterson et al.’s (2009) findings by firmly establishing that inter-word priming effects occur in silent reading, it was also important to determine whether any priming effects were modulated by the morphological relationship between prime and target words. This would provide further insights into the nature of information that can carry across intervening words in a sentence to influence the lexical processing of a subsequent word. In particular, the results would reveal whether lexical priming effects between words in a sentence turn facilitatory when prime and target words are morphologically related, as typically happens in word recognition studies (e.g. Rastle & Davis, 2008).

It was also of interest to determine whether priming effects are mediated by the semantic relationship between prime and target words. In masked priming, prior exposure to a prime has been shown to facilitate target word processing irrespective of whether prime and target words have a semantically transparent or only an apparent morphological relationship (e.g., Rastle et al., 2004). However, normal reading is very different to masked priming procedures, in that words that appear early in a sentence are available for full inspection prior to the words downstream in the sentence being read. Given this, it could be argued that normal reading more closely resembles procedures used in unmasked priming, as prime words in this paradigm are made available for conscious perception prior to the target word being processed. Consequently, it seemed likely that effects in the present experiment would reflect circumstances in which readers have the opportunity to consciously identify a prime before viewing the target word, and therefore produce a pattern of effects similar to effects in unmasked priming studies. Therefore, as in unmasked priming research, target word processing should be facilitated only when the morphological relationship between prime-target pairs is semantically transparent. Finally, a major advantage of measuring eye movements during reading is that this method provides a clear measure of the time course of effects. Thus, through the
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computation of a range of eye movement measures we can assess when priming effects first emerge in the eye movement record and how the influence of the prime changes over time and across fixations. This analysis enables an assessment of when different sources of information, including morphological prime information, first exert an influence on the processing of a word, and can shed light on the nature and time course of the priming effects that occur between words during reading.

Method

Participants. Thirty-two native English speakers with normal uncorrected vision who were undergraduates at the University of Leicester participated for course credits.

Design & Materials. Fifty-four sets of words were selected from the stimuli of Rastle et al. (2004). These comprised 18 word pairs that had a semantically-transparent morphological relationship, 18 pairs that had only an apparent morphological relationship, and 18 pairs that were morphologically unrelated but overlapped in orthography. For each prime-target pair, the prime word was matched for length and frequency with a control word that was unrelated to the target word. Thus, two factors were manipulated: morphological priming condition (prime and target words had either a semantically transparent morphological relationship, an apparent morphological relationship, or were morphologically unrelated) and prime type (prime or control word).

Sentence frames were constructed so that prime-target pairs and control-target pairs could be inserted into the same locations in each frame (see Figure 1). Before conducting the experiment, a pre-test was conducted to assess the relative plausibility of sentence frames that contained either prime-target or control-target pairs. Ten participants (who did not participate in the eye movement experiment) rated the plausibility of these sentences on a 7-point Likert scale, where “1” indicated that a sentence was entirely implausible and “7” indicated that it was entirely plausible. The results clearly showed that sentences that contained either prime-target or control-target pairs did not differ significantly in plausibility (6.5 vs. 6.4, \( F < 1 \)). Moreover, the relatively high plausibility ratings suggest that participants found the sentences to be acceptable English constructions. We also ensured
that the textual distance between prime / control words and target words was carefully controlled. This was always identical for sentence frames containing either prime-target or control-target pairs, and the textual distance (measured in alphabetic characters) between the prime / control words and target words did not differ significantly across morphological priming conditions (semantically-transparent morphological relationship = 14.7 characters, apparent morphological relationship = 14.2 characters, morphologically unrelated = 12.1 characters, $F < 1.5$). Finally, the sentences were presented in counterbalanced lists so that each participant saw only one version of each sentence and an equal number of sentences containing prime-target pairs (and control-target pairs) in each morphological priming condition. Each list also contained 2 practice sentences that were presented at the beginning of the experiment and an additional 80 sentences that were stimuli for an unrelated experiment and were pseudo-randomly interleaved with sentences from the present experiment. A full list of the experimental stimuli is included in the Appendix.

**Apparatus.** A Fourward Technologies Dual Purkinje Generation 6 Eye-tracker recorded participants’ right eye movements during stimulus viewing. The eye-tracker has an angular resolution of 10 min of arc and was interfaced with a PC that sampled fixation position every millisecond. Sentences were presented as white text on a black background in Courier font on a 17 inch monitor. At the 80 cm viewing distance used in the experiment, three characters subtended approximately 1 degree of visual angle. The sentences always started in the same location in the upper left quadrant of the screen, and target words were always located close to the middle of a sentence and so appeared near the centre of the screen.

**Procedure.** Before the start of the experiment, participants received an explanation of the procedure. Participants were then seated at the eye-tracker and a bite-bar was used to prevent head movements. A calibration procedure was then completed. Before the start of each trial, a fixation box the same size as one alphabetic character appeared in the upper left quadrant of the screen. When participants fixated this box, the experimenter initiated the presentation of a sentence, with the first
character of the sentence replacing the fixation box. The eye-tracker was re-calibrated if participants’
fixations did not match the fixation box. Participants were permitted to take breaks between trials.
On 25% of trials (including filler items), the presentation of a sentence was followed by a two-
alternative forced-choice question that tested the participant’s comprehension of the sentence
content. Participants answered these questions by pressing the button corresponding to the correct
answer on a button box.

Results

Regions: Analyses were performed for three scoring regions (see Table 1): a pre-target region
comprising the word or phrase preceding the target word (which did not include the prime word), the
target word, and a post-target region that comprised the next word or next two words if the next word
was a short function word.

Analysis: Prior to the analysis of the eye movement data, an automatic procedure incorporated
fixations less than 80 ms into larger fixations within one character and deleted fixations less than 40
ms not within three characters of another fixation. Fixations over 1200 ms were truncated. In
addition, trials on which sentences were not read fully or that had tracker loss were eliminated by
deleting trials in which no first-pass fixations were made in adjacent scoring regions (accounting for
4.2% of trials). Accuracy for the comprehension questions was high, above 90%, indicating that
participants had read and fully understood the sentences. No items were excluded from the eye
movement analyses based on participants’ answers to the comprehension questions. A range of
standard eye movement measures was then computed for each scoring region (see Rayner, 1998,
2009). For each region, we report first fixation durations (duration of the first fixation on a word),
gaze durations (summed duration of all fixations from first fixating a word before a saccade from it -
referred to as first-pass reading times for regions containing multiple words), and total reading times
(the summed duration of all fixations in a region). In addition, single fixation durations (the duration
of the fixation on a word receiving only one first-pass fixation), word skipping (the frequency of
trials in which a word was not fixated) and regressions in (the frequency of regressions into a region) are reported for target words, and the frequency of regressions out of a region are reported for target words and for the post-target region. Analyses of first-pass reading time measures for each scoring region excluded trials in which no fixations were made within that region.

Data for each scoring region were subjected to a 3 (morphological priming condition: semantically transparent morphological relationship, apparent morphological relationship, morphologically unrelated) x 2 (prime type: prime, control) repeated measures ANOVA, computing error variance over participants ($F_1$) and sentences ($F_2$). Sentences in different morphological priming conditions were composed of different words, including different prime and target words. Consequently, any main effects of the morphological priming condition could reflect theoretically uninteresting differences in the processing of these words. Therefore, we will report only main effects of prime type and interaction effects, since these provide the clearest indication of priming effects in each morphological priming condition. Also, in order to present the priming effects most transparently, a mean priming effect (PE) magnitude is included alongside the mean eye movement data for each morphological priming condition (see Table 2).

--- Table 2 about here ---

**Pre-target region:** There were no significant priming effects in this region, $F$s < 1.

**Target word:** There was a main effect of prime type in first fixation durations, $F_1(1,31) = 6.79, p < .05, \eta_p^2 = .18$, and $F_2(1,51) = 4.97, p < .05, \eta_p^2 = .09$, and single fixation durations, $F_1(1,31) = 6.79, p < .05, \eta_p^2 = .22$, and $F_2(1,51) = 8.21, p < .01, \eta_p^2 = .14$, that interacted with the morphological relationship between prime-target pairs (first fixation durations: $F_1(2,62) = 5.93, p < .01, \eta_p^2 = .33$, and $F_2(2,51) = 3.75, p < .05, \eta_p^2 = .13$; single fixation durations: $F_1(2,62) = 4.25, p < .05, \eta_p^2 = .27$, and $F_2(2,62) = 3.16, p = .05, \eta_p^2 = .10$). Tukey tests revealed significant facilitatory priming only when prime and target words were semantically related, $p < .001$. Although the main effect of prime type was marginal in gaze durations for target words, $F_1(1,31) = 3.50, p = .07, \eta_p^2 = \ldots$
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.10, and $F_2(1,51) = 3.80$, $p = .06$, $\eta^2_p = .07$, and not reliable in total reading times for target words, $F_1 < 1.6$, there were significant interactions in both measures (gaze durations: $F_1(2,62) = 3.21$, $p < .05$, $\eta^2_p = .22$, and $F_2(2,51) = 3.33$, $p < .05$, $\eta^2_p = .12$; total reading times: $F_1(2,62) = 4.23$, $p < .05$, $\eta^2_p = .22$, and $F_2(2,62) = 3.95$, $p < .05$, $\eta^2_p = .13$). Again, Tukey tests revealed significant facilitatory priming only when prime-target pairs were semantically related, $p < .01$. Thus, early measures of reading time (i.e., first fixation durations, gaze durations) for target words revealed a semantically mediated priming effect, and this effect was also observed in total reading times for these words.

There was a main effect of prime type in target word skipping, $F_1(1,31) = 5.55$, $p < .05$, $\eta^2_p = .15$, and $F_2(1,51) = 4.08$, $p < .05$, $\eta^2_p = .07$, that did not interact with the morphological relationship between prime-target pairs, $F_1 < 1$. Note that participants will have made the decision to skip target words prior to these words being fixated; that is, based on information about the target word extracted from the parafovea. The word skipping effect showed that target words that followed primes rather than control words were skipped more frequently (regardless of the semantic relation between the prime and target). Finally, although the regression data revealed an increase in regressions to target words that followed primes rather than control words, this effect was not significant, $F_1 < 2.4$. No other priming effects were significant at this region, $F_2 < 2$.

Post-target region: There was a main effect of prime type in regressions from the post-target region, $F_1(1,32) = 9.31$, $p < .01$, $\eta^2_p = .23$, and $F_2(1,51) = 9.47$, $p < .01$, $\eta^2_p = .18$, that did not interact with the morphological relationship between prime and target words, $F_1 < 1$. More regressions were made from the post-target region when target words followed primes than control words. Other research has reported an increase in regressions following word skipping (Drieghe, Brysbaert, Desmet, & De Baecke, 2004) and, in line with this observation, further analyses showed that more regressions were made from the post-target region when target words were skipped (38%) than when target words received a first-pass fixation (24%; $t_1(32) = 3.30$, $p < .01$, and $t_2(53) = 2.14$, 2004).
p < .01). However, it should be clear that word skipping cannot fully account for the regression effect at the post-target region, as an analysis of regressions from this region when target words were not skipped also produced a significant main effect of prime type, $F_1(1,32) = 8.68, p < .01, \eta_p^2 = .22$, and $F_2(1,51) = 7.27, p < .01$, that did not interact with the morphological relationship between prime and target words, $Fs < 1$. Thus, it appears that the progression of the eyes through the sentence was disrupted on a proportion of trials, even when the target words was fixated, indicating that orthographic overlap between prime and target words disrupted target word identification, and that this disruption did not occur exclusively in cases where the target word was skipped.

The main effect of prime type in first-pass reading times for the post-target region was not significant, $Fs < 1.7$. However, a marginal interaction in first-pass reading times, $F_1(2,62) = 2.92, p = .06, \eta_p^2 = .18$, and $F_2(2,51) = 3.52, p < .05, \eta_p^2 = .12$, and a marginal main effect of prime type in total reading times, $F_1(1,31) = 3.60, p = .07, \eta_p^2 = .10$, and $F_2(1,51) = 3.73, p = .06, \eta_p^2 = .06$. The effect in first-pass reading times was of particular interest, and post-hoc Tukey tests confirmed that it was driven primarily by post-target difficulty when target words followed morphologically unrelated primes rather than control words ($p = .06$), and no significant priming effects were observed in the other morphological priming conditions ($ps > 12$). Thus it appears that orthographic similarity between prime and target words disrupted processing of the post-target region, but only when prime-target pairs were morphologically unrelated. No other priming effects were significant, $Fs < 1$.

Discussion

Perhaps the most immediately striking feature of our data was the priming effect in fixation times for target words. This revealed that fixation times were substantially shorter for targets that followed a morphologically related prime than a control word, but only when prime-target pairs were related in meaning. The experiment therefore provides very clear evidence for a semantically mediated priming effect in silent reading. Moreover, as this effect emerged in eye movement measures that reflect early word processing (i.e., first fixation durations, single fixation durations,
and gaze durations for target words), it seems clear that prior exposure to a morphologically complex word in a sentence can fairly immediately facilitate processing of a semantically related stem word that appears a few words later in the same sentence.

This aspect of our findings accords well with other experiments showing that lexical priming effects reported in studies of word recognition occur naturally, and perhaps frequently, between words in sentences that are read normally (e.g., Carreiras et al., 2005; Carroll & Slowiaczek, 1986; Paterson et al., 2009), and that the brief experience of processing a prime word can carry across intervening words to influence the processing of a target word that appears later in the same sentence. Moreover, this inter-word priming has a very rapid influence on the lexical identification process, and this in turn affects decisions about when to move the eyes. Most importantly, the current data provide further compelling evidence that eye movements during reading are sensitive to intra-sentential, inter-lexical priming influences. Such findings are highly relevant to the on-going debate about eye movement control during reading (e.g., Reichle et al., 2009) and indicative of the centrality of lexical identification to decisions regarding saccade initiation during reading.

The pattern of results in fixation times for the target words is complementary to findings from research on isolated word recognition. Where this research has used masked priming, it has shown that morphological priming effects are not mediated by word meaning (e.g., Rastle et al., 2004). However, other research in which prime words are presented without a mask at durations that allow them to be consciously identified prior to a target word being displayed has shown that word recognition is facilitated only when prime-target pairs have a semantically transparent morphological relationship (e.g., Longtin et al., 2003; Marslen-Wilson et al., 1994; Rastle et al., 2000). That the pattern of fixation times in our experiment most closely resembles the findings from unmasked priming is unsurprising as, in both paradigms, the prime words are fully visible, and are therefore available for conscious identification prior to fixation on the target word. It is argued that conscious identification of the prime in unmasked priming research results in inappropriate constituents being
inhibited prior to a response being made for the target word (e.g., Meunier & Longtin, 2007; Rastle & Davis, 2008; Schreuder & Baayen, 1995). Thus, as readers in our experiment were able to consciously identify prime words before encountering the target, it seems likely that this resulted in representations of inappropriate prime word constituents being inhibited prior to fixation on the target word, and this would explain why facilitatory priming effects were observed in fixation times for target words in the present experiment only when the relationship between the prime and target words was semantically transparent. However, it has been important in morphological priming research to separate the influence of the morphological, orthographic, and semantic relationships between prime and target words (see, e.g., Marslen-Wilson et al., 1994; Rastle et al., 2000), particularly as words in English that have a derivational morphological relationship are also orthographically and semantically related. This is also a concern in relation to the present experiment. Although it is clear from the present results that the morphological priming effect we observed in fixation times for target words is not driven by the orthographic relationship between prime and target words, further research is needed to disentangle whether this effect derives from the morphological or semantic relationship between these words or both.

The priming effect in fixation times for target words was clear and makes sense in the context of previous research on isolated word recognition. However, effects that emerged in other eye movement measures provided an unexpected insight into other aspects of inter-word priming influences on eye movements during reading. In particular, there was very clear evidence of a priming effect both in skipping rates for target words and in regressions from the post-target region. These showed that target words that followed a prime rather than a control word were less likely to be fixated during first-pass processing and, in addition, that readers were more likely to make a regressive saccade from the post-target region back to earlier sentence locations when targets followed primes rather than control words. As these priming effects were not mediated by the morphological relationship between prime-target pairs, and emerged primarily in target word
skipping and regressions from the post-target region (and only to some extent in first-pass reading times for this region), it seems likely that they represent an influence that is independent from the semantically mediated morphological priming observed in fixation times for target words. Instead, the effects may have been due solely to the orthographic relationship that existed between prime and target words in all three priming conditions. To be clear, it was fundamental to the logic of our experiment that prime-target pairs (but not control-target pairs) overlapped in orthography, not only when these words had a semantically transparent relationship or an apparent morphological relationship, but also when they were unrelated either semantically or apparently morphologically (e.g., *extract* & *extra*). Given that a priming effect occurred in all three conditions, it appears that this orthographic overlap, rather than any higher order relationship between the prime and target words, was responsible for the skipping and regression effects. Moreover, as these effects emerged in eye movement behaviours that are typically prevalent during text reading, and are not present in standard isolated word recognition experiments, they may reveal aspects of lexical processing that are unique to normal text reading.

Word skipping, in particular, provides an insight into the processing of words in parafoveal vision. Considerable evidence suggests that readers extract information about the identities of words to the right of fixation in parafoveal vision, and that this information is used to plan the next saccade and to begin processing of the next words in a sentence (Balota, Pollatsek, & Rayner, 1985; Binder, Pollatsek, & Rayner, 1999; Rayner, 1975; Juhasz, White, Liversedge, & Rayner, 2008). Moreover, research has shown that readers typically do not fixate all of the words in a sentence and it is widely argued that words that are highly predictable and easy to identify in parafoveal vision do not have to be fixated (e.g., Binder et al., 1999, Balota et al., 1985; Dreighe, Brysbaert, Desmet, & Debaecke, 2004; Dreighe, Rayner, & Pollatsek, 2005; Rayner, Binder, Ashby & Pollatsek, 2001; Rayner & Well, 1996; White, Rayner, & Liversedge, 2005; for a review, see Brysbaert, Dreighe, & Vitu, 2005). The present findings add to this research by revealing that words are also more likely to be
skipped if they closely follow another word that overlaps substantially in orthography. Indeed, it seems that the brief experience of processing a word just a few words earlier in a sentence can carry over intervening words to influence parafoveal processing of a subsequent word, and to the extent that words are more likely to be identified (or possibly misidentified) in parafoveal vision, they are less likely to be initially fixated.

Research on word skipping has also revealed that when a word is skipped this often is quickly followed by a regression back to earlier sentence locations and researchers have attributed this pattern of behaviour to the initiation of an error-correcting procedure (Drieghe et al., 2004; see also Brysbaert et al., 2005). Consistent with this observation, we found that readers made more inter-word regressions from the post-target region when target words were skipped compared to when they were fixated. Thus, it seems likely that word-skipping in our experiment might also have led to the initiation of an error-correcting procedure. Indeed, and as we have already suggested, target words that follow an orthographically similar prime may sometimes be misidentified in parafoveal vision, and the subsequent detection of this misperception may increase the likelihood of readers making a regression to re-process preceding text. However, this argument is qualified by the finding that readers also made more regressions from the post-target region when targets followed prime than control words, even when the target word was not skipped. Thus, it should be clear that the word skipping effect does not fully account for word misperception effects that occurred during reading, and that orthographic overlap between prime and target words appears to have disrupted target word identification even in cases where target words were fixated.

The effect observed in first-pass reading times for the post-target region may add to our understanding of the influence of orthographic overlap on target word perception. This effect showed that reading times were inflated when targets followed primes only when prime-target pairs were morphologically unrelated, and so appears to reveal that orthographic overlap was most harmful when prime and target words were morphologically unrelated. One possibility is that the
morphological relationship between prime-target words in the other conditions helped overcome misidentification of the target words by facilitating access to the target word’s representation following the initial misidentification, but that readers had a harder time recovering from misidentification when the words were morphologically unrelated because access to target word representations was not facilitated in this case.

That intra-sentential, inter-word orthographic priming causes words to be misidentified in parafoveal vision may not be surprising, and is consistent with growing evidence that words are misperceived in reading quite frequently (e.g., Perea & Pollatsek, 1998; Pollatsek, Perea, & Binder, 1999; Slattery, 2010). Much of this evidence comes from eye movement research that has assessed the influence of a word’s orthographic neighbourhood on word processing, where a word’s orthographic neighbours are usually defined as words that differ by just one letter while preserving letter order and length (e.g., Coltheart, Davelaar, Jonasson, & Besner, 1977; but for an expanded definition, see Davis et al., 2009; Davis & Taft, 2005). The approach taken in this research has been to examine eye movements for sentences that contain a target word such as spice that has a higher frequency neighbour (e.g., space), and has shown that these words receive longer fixations and more fixations after a regression than control words that do not have a higher frequency neighbour (Perea & Pollatsek, 1998; Pollatsek, Perea, & Binder, 1999; Slattery, 2010). These effects are usually explained in terms of readers initially mistaking the target word for its higher frequency neighbour, and thus causing disruption to subsequent processing of the sentence. One possibility is that exposure to an orthographically similar word just a few words earlier in the sentence might also cause readers to sometimes misperceive a similar upcoming word in parafoveal vision, and this misperception might disrupt sentence processing. Such an account could explain the findings from our experiment. Note, however, that the degree of orthographic overlap between prime-target words, and the fact that this overlap was always at the beginnings of words, may have been fundamental to eliciting the effects we observed. Indeed, it is widely argued that beginning letter information is particularly
important in parafoveal pre-processing of words (e.g., Briihl & Inhoff, 1995; Rayner, McConkie, & Zola, 1980; Rayner, Well, Pollatsek, & Bertera, 1982; White & Liversedge, 2005), but that parafoveal pre-processing is insensitive to semantic or morphological word information (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Bertram & Hyönä, 2007; Juhasz et al., 2008; Kambe, 2004; Lima, 1987; Rayner, Balota, & Pollatsek, 1986). These findings are directly relevant to the current results. It seems likely that the considerable overlap in orthography at the beginnings of words in all three priming conditions drove the word skipping effect, and consequently, this effect held for stimuli in all conditions regardless of the semantic or morphological relationships that may also have existed between primes and targets (although the disruption this effect caused may have been less severe when there was a morphological relationship between prime and target words). Nevertheless, the contribution of orthographic priming to word skipping remains to be fully determined, particularly since skipping rates have not always been reported in studies examining inter-word lexical priming during reading (e.g., Camblin et al., 2007; Carreiras et al., 2005; Paterson et al, 2009; Traxler et al., 2000). Further research clearly is needed to establish the full range of circumstances in which word skipping occurs and how pre-processing of words in parafoveal vision contributes to the phenomenon.

Another issue for future research concerns the source of inter-word lexical priming effects. Paterson et al. (2009) argued that effects in their experiment could be explained by two different mechanisms. The first was that the effects were due to ongoing patterns of activity in the reader’s mental lexicon, consistent with the account of priming effects in competitive network models of word recognition (e.g., Davis, 1999, 2003; Grainger & Jacobs, 1996, McClelland & Rumelhart, 1981). A fundamental assumption of these models is that activation of a lexical entry decays over time and is inhibited when other lexical entries become activated as other words are read. Therefore, these models can explain priming effects that carry over intervening words so long as the activation of a prime word’s lexical entry has not decayed or been inhibited substantially in the interval
between identification of the prime and fixation on the target word. According to this account, the fact that priming effects were observed in the present experiment indicates that there was sufficient ongoing activation of a prime word’s lexical entry for this to affect the activation of the related, but different, target word such that identification was influenced. Furthermore, this pattern of activation must have been maintained throughout the period between processing of the two words (i.e., when the prime and target words were separated by only small number of completely independent words). In the present experiment the prime and target words were on average 2.6 words apart. However, our priming effects may also be explained by episodic memory accounts which propose that when prime and target words are read separately (as in the present experiment), the processing of one word (the prime) instantiates an episodic memory trace which subsequently impacts on identification during processing of a similar word (the target) read downstream in the sentence. In this way, the memory trace that is evoked at the target influences current word processing (and for a review of the episodic approach to lexical priming, see Tenpenny, 1995). Clearly, a comprehensive account of inter-word priming during reading must be able to discriminate between these alternative accounts and research underway in our, and probably other, laboratories will attempt to do this. Indeed, there is also considerable interest in establishing the degree to which priming effects can carry across intervening words in word recognition experiments (Forster, 2008).

In sum, the present research has produced novel evidence relating to morphological and orthographic priming effects in eye movements during reading. This research has revealed some similarities with findings from studies of isolated word recognition. However, where the present results differ from isolated word recognition findings, they reveal an influence of inter-word priming on aspects of lexical processing that are unique to reading text and cannot manifest in isolated word recognition research. In this way, our findings extend current understanding and provide insight into the process of lexical identification as it occurs normally during natural reading.
Footnote

1. Further analyses were conducted to determine if regressions were made back to the prime word. There were negligible differences in the frequency of regressions in prime and control word conditions in either semantically transparent (19.9% vs. 19.6%), apparent (28.1% vs. 24.7%), or morphologically related conditions (25.4% vs. 26.7%), and neither the main effect of prime type nor the interaction of prime type and morphological relationship was statistically reliable ($F$s < 1).
References


Davis, C. J., Perea, M., & Acha, J. (2009). Re(de)fining the orthographic neighbourhood: The role of...


De Moor, W., & Brysbeart, M. (2000). Neighborhood-frequency effects when primes and targets are of different lengths. *Psychological Research/Psychologische Forschung*, 63, 159–162.


across an intervening word? *Journal of Memory and Language*, 60, 36-49.


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Appendix

Sentences are shown with prime and control words in brackets and target words underlined but were displayed normally in experiment.

Semantically transparent morphological relationship

1. The Cabinet said in a written statement that the tax was due to the current (government / situation) but they could not govern unless people were willing to pay.
2. The sculpture in the park fascinated one (viewer / ranger) but spoiled the view of the dale.
3. Because she broke her arm, the (trainee / cookery) teacher could not train until the beginning of the next academic term.
4. The forest had a (marshy / thorny) path leading to a marsh where students studied wildlife.
5. There was only one (mourner / tripper) to mourn the final sailing of a famous cruise ship.
6. On the sofa was a cream (tufted / silken) throw with a tuft of red in each corner.
7. To avoid appearing (inhibitory / amateurish), he would always inhibit his actions and opinions.
8. Next door to John lived a (widowed / beastly) lady, who became a widow when her husband died in an accident.
9. The teachers saw advantages to the (agreement / equipment), but couldn’t agree on who would be responsible for it.
10. At the end of her road trip, the (northern / friendly) girl headed up north back to her home.
11. The man bought a (creamy / watery) tea and some cream scones at the cafe.
12. Because the defendant looked so (guilty / formal), his guilt seemed obvious to everyone in the court.
13. The critics thought that the (artistry / calmness) of the artist was evident in the waves in the painting.
14. When we arrived at the (chilly / finely) restored barn the chill kept us awake despite warm clothes and hot drinks.
15. Looking at the cottage, she said, “It may be (greenery / snobbish), but I hate green around the door.”
16. The new (teacher / trainee) finally started to teach her group after they settled down.
17. Although the company had a new (employer / addition), they would still employ the current workers.
18. Although they expected a harsh (reaction / physical), to react the way the woman did was entirely unreasonable.

Apparent morphological relationship

19. It was true that the company (secretary / obviously) believed the secret and didn’t know what to do.
20. The search for the perfect wedding cake became (fruitless / alcoholic), as fruit cake made with brandy was all that was available.
21. The sound of the (trumpet / chatter) would trump the singer’s poor performance.
22. The policeman investigated the old (crooked / pottery) shop, but the crook had not taken anything.
23. He left the house with the (courteous / developer) apprentice then went to court to collect the legal documents.
24. The garden was lovely, apart from the (thick / scruffy) bush that was thick and overgrown.
25. Jane was told to resign from the music (department / production) and to depart without notice.
26. Depending on the budget and (boarder / factual) information, full board may be an option.
27. The electrical (flicker / advisor) warned that a flick of the switch could be fatal.
28. Only by (rational / steadily) thinking can the ration of supplies be distributed fairly amongst the
needy people.
29. If the man had kept the key (number / really) safe he would not be numb with sorrow now.
30. It was argued that setting an essay (question / actually) aids the quest to find the best applicant for a management position.
31. You can buy (brandy / safely) from a range of brand new suppliers through secure web sites.
32. The vendor said it would make an excellent (brisket / foundry) ensuring brisk business with the customer.
33. Hazardous situations are not outlined by the (treaty / angler), so ensure you treat them with caution.
34. The hockey player performed well and was (plucky / winger) today, so to pluck her from the team would be a mistake.
35. During the search, the police found the (coaster / muffler) on the far coast of the island.
36. The girl wanted a toy, so asked the (trolley / naughty) boy to get a troll off the shelf.

Morphologically unrelated

37. The man complained about the (rabbit / weekly) hunt to the Rabbi in the local village.
38. The lady wore a dress made of a (plush / filmy) material, plus a shawl to keep her warm.
39. Jane thought the boy looked very (weird / manly) standing by the weir in the stream.
40. She left the dance (studio / gently) holding the stud earring that she had found.
41. I made the Christmas decorations (twinkle / cheaply) for my twin sisters and their friends.
42. Although it was a (stubborn / moisture) stain, the stub of soap removed it.
43. The meeting discussed the (international / revolutionary) plan, but the intern didn’t understand.
44. When he examined the (glade / cuffs), he was glad to see there was no evidence of the scuffle that had taken place.
45. The girl sat in the corner was (sight / happy) reading and gave a sigh when she turned.
46. Jo kept quiet about her involvement in the (brothel / warfare) and ate her broth in silence.
47. They were stopped in their tracks by the (squawk / oddity), but the squaw who emerged from the wigwam was not to be feared.
48. A boy pulled at the brown (jerkin / twisty) fabric with a jerk to get the man’s attention.
49. It took some (shovel / tricky) work to shove the beehive from the tree without upsetting the bees.
50. The junior doctor was told about the (candidacy / epileptic) and was candid in the interview.
51. More time was allowed to (extract / justify) the extra information that was needed.
52. The researcher conducted a (phonetic / dreadful) analysis by phone, rather than in person.
53. The boy felt pain in his foot at the (surface / medical) as the surf had caused him serious injury.
54. Despite the order being (heaven / firmly) sent, he couldn’t heave the sword from the rock.
Table 1: Example stimuli and region divisions

Sentences are shown with prime and control words in brackets and target words underlined but were displayed normally in experiment. Vertical lines denote region boundaries.

**Semantically transparent morphological relationship**

The forest had a (marshy / thorny) path| leading to a| **marsh**| where| students studied wildlife.

**Apparent morphological relationship**

It was true that the company (secretary / obviously)| believed the| **secret**| and didn’t| know what to do.

**Morphologically unrelated**

More time was allowed to (extract / justify)| the| **extra**| information| that was needed.
Table 2: Mean eye movement measures for each condition (PE indicates size and direction of priming effect*)

<table>
<thead>
<tr>
<th>Morphological Relationship of Prime and Target Words</th>
<th>Semantically-Transparent</th>
<th>Apparent</th>
<th>Unrelated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prime</td>
<td>Control</td>
<td>PE</td>
</tr>
<tr>
<td><strong>Pre-Target Region</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First fixation durations</td>
<td>264</td>
<td>259</td>
<td>-5</td>
</tr>
<tr>
<td>First pass reading times</td>
<td>345</td>
<td>352</td>
<td>+7</td>
</tr>
<tr>
<td>Total reading times</td>
<td>427</td>
<td>432</td>
<td>+5</td>
</tr>
<tr>
<td><strong>Target Region</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First fixation duration</td>
<td>243</td>
<td>280</td>
<td>+37</td>
</tr>
<tr>
<td>Single fixation duration</td>
<td>245</td>
<td>286</td>
<td>+41</td>
</tr>
<tr>
<td>Gaze durations</td>
<td>272</td>
<td>308</td>
<td>+36</td>
</tr>
<tr>
<td>Total reading times</td>
<td>327</td>
<td>374</td>
<td>+47</td>
</tr>
<tr>
<td>Word skipping (%)</td>
<td>20.0</td>
<td>14.2</td>
<td>+5.8</td>
</tr>
<tr>
<td>Regressions in (%)</td>
<td>15.3</td>
<td>13.2</td>
<td>-2.1</td>
</tr>
<tr>
<td>Regressions out (%)</td>
<td>7.5</td>
<td>12.7</td>
<td>+5.2</td>
</tr>
<tr>
<td>Post-Target Region</td>
<td>First fixation durations</td>
<td>251</td>
<td>257</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td>First pass reading times</td>
<td>434</td>
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<tr>
<td></td>
<td>Total reading times</td>
<td>557</td>
<td>546</td>
</tr>
<tr>
<td></td>
<td>Regressions out (%)</td>
<td>17.8</td>
<td>13.8</td>
</tr>
</tbody>
</table>

* Shorter reading times, greater word-skipping rates, and lower regression rates in prime versus control conditions are labelled as positive values and vice versa.