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Competition between orthographically and phonologically similar words during sentence reading: Evidence from eye movements

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ABSTRACT

Two eye movement experiments tested the effect of orthographic and/or phonological overlap between prime and target words embedded in a sentence. In Experiment 1, four types of overlap were tested: phonological and orthographic overlap (O+P+) occurring word initially (strain–strait) or word finally (wings–kings), orthographic overlap alone (O+P/C0, bear–gear), and phonological overlap alone (O–P+, smile–aisle). Only O+P+ overlap resulted in inhibition, with the rhyming condition showing an immediate inhibition effect on the target word and the non-rhyming condition on the spillover region. No priming effects were found on any eye movement measure for the O+P/C0 or the O–P+ conditions.

Experiment 2 demonstrated that the size of this inhibition effect is affected by both the distance between the prime and target words and by syntactic structure. Inhibition was again observed when primes and targets appeared close together (approximately 3 words). In contrast, no inhibition was observed when the separation was nine words on average, with the prime and target either appearing in the same sentence or separated by a sentence break. However, when the target was delayed but still in the same sentence, the size of the inhibitory effect was affected by the participants’ level of reading comprehension. Skilled comprehenders were more negatively impacted by related primes than less skilled comprehenders. This suggests that good readers keep lexical representations active across larger chunks of text, and that they discard this activation at the end of the sentence. This pattern of results is difficult to accommodate in existing competition or episodic memory models of priming.

Introduction

There is a great deal of evidence from studies of isolated word recognition that reading involves a process of competition between form–related words. Much of this evidence has come from the masked priming paradigm in which a prime word is presented for a very short time (below the threshold of conscious awareness) and a response, often a lexical decision, is made on a following target word (Forster & Davis, 1984; see also Kinoshita & Lupker, 2003). It has been found that when a target word is primed by an orthographic neighbor, i.e. a word that differs from it by only one letter (see Coltheart, Davelaar, Jonasson, & Besner, 1977), the response to the target word can be slowed, especially when the prime is of a higher frequency than the target (e.g. Davis & Lupker, 2006; Grainger, 1990; Grainger & Ferrand, 1994; Nakayama, Sears, & Lupker, 2008; Segui & Grainger, 1990). Our interest was in how these effects...
might influence processing in a more natural reading task, i.e., normal sentence reading. Fluent reading must require the constant activation and suppression of word candidates and success in this task may be related to one’s level of reading skill (e.g., Andrews & Hersch, 2010; Andrews & Lo, 2012; Gernsbacher, 1993). However, very little research has investigated the effect of form overlap on lexical access during sentence reading (but see Paterson, Liversedge, & Davis, 2009). The experiments we report were designed to look for evidence of form-based competition between words in sentences. We examined whether different types of overlap, orthographic and/or phonological, resulted in different degrees of competition (Experiment 1), and whether the distance between the overlapping words and the syntactic structure they appear in affected the competition effect (Experiment 2). In addition, we examined whether the size of the competition effect was related to reading skill (e.g., Andrews & Hersch, 2010; Andrews & Lo, 2012), and we return to this issue in Experiment 2.

A large body of research has now demonstrated that word reading processes are influenced by the availability of form-related words, although the nature of this influence remains an issue for debate (see Andrews, 1997, and Grainger, 2008, for reviews). Words with large orthographic neighborhoods can be processed more quickly than words with small neighborhoods in lexical decision and naming tasks (e.g., Andrews, 1989). However lexical decision can be slowed by the existence of a high-frequency orthographic neighbor (e.g., Grainger, O’Regan, Jacobs, & Segui, 1989) and by the presence of a high-frequency embedded word such as ‘car’ in ‘scar’ (Bowers, Davis, & Hanley, 2005, see also Weingartner, Juhasz, & Rayner, 2012, for evidence from eye movements). Indeed, what actually constitutes a neighborhood is also a matter for debate, with evidence of effects of neighborhoods that are defined in a number of different ways, including letter deletion (e.g., last–blast; Davis & Taft, 2005) transposed letters (e.g., clam–calm, Andrews, 1996), and phonological overlap (e.g., soup–hoop, Yates, Locker, & Simpson, 2004).

In priming tasks, the shared neighborhoods of primes and targets have also been shown to affect processing speed (e.g., Van Heuven, Dijkstra, Grainger, & Schriefers, 2001). These effects in sentence reading are much more rare. Fast priming or priming of formally similar words. Studies of similar effects in sentence reading are much more rare. Fast priming experiments, that have examined orthographic neighbor priming, show facilitation or null effects rather than inhibition (e.g., Nakayama, Sears, & Lupker, 2010). In this methodology, participants read normal text in which one word is initially presented as a random letter string. Once the participant “lands” on this target region, the random letters are replaced by the prime word for a very short period before being replaced again by the target word and eye fixation data are recorded (Sereno & Rayner, 1992). This paradigm is, therefore, very similar to masked priming, but it uses a more natural linguistic environment. Nakayama et al. (2010) tested orthographically overlapping items that had previously shown inhibition in a masked priming paradigm (Nakayama et al., 2008). At a prime duration of 60 ms, they found facilitation when prime and target were presented in lower-case (Experiment 1) and no difference when the prime was presented in capitals. Similarly, Frisson, Bélanger, and Rayner (2014), using prime durations of 32 and 50 ms, found facilitation when prime and target overlapped both at the orthographic and phonological level, slightly less priming when the overlap was only at the orthographic level, and hardly any priming when the overlap was phonological.

In an eye movement study of silent sentence reading, which serves as the inspiration for the current experiments, Paterson et al. (2009; see also Paterson, Alcock, & Liversedge, 2011, for related findings) tested sentences such as There was a blur as the blue lights of the police car whizzed down the street, which contains the prime blur and the target blue. They showed increased gaze durations on blue when preceded by an orthographic neighbor prime word (blur) compared to a control prime word (gasp). In contrast to single-word research which showed inhibition mainly when the masked prime was of higher-frequency than the target (Davis, 2003; Davis & Lupker, 2006) and when the unmasked prime was of lower-frequency than the target (Colombo, 1986; Lupker & Colombo, 1994; Segui & Grainger, 1990), the inhibition observed by Paterson...
et al. (2009) did not interact with the relative frequencies of prime and target words. The lack of a frequency interaction in sentence reading might suggest that the task taps into a different processing stage.

One aspect that has been largely ignored in this research is the impact that different types of overlap have on word recognition, in particular the effect of phonological overlap. While orthographic neighbors obviously overlap at the orthographic level, they also very often, though not always, exhibit a high degree of phonological overlap. Phonology and phonological awareness plays a central role in theories of reading acquisition (e.g. Bradley & Bryant, 1983; Harm & Seidenberg, 2004; Perfetti, 2011). Moreover, a large amount of research has shown that during silent reading, phonological codes of the words in a text are accessed quickly and automatically. These data come from studies using a variety of techniques including EEG (e.g. Ashby, 2010; Ashby, Sanders, & Kingston, 2009) and MEG (e.g. Wheat, Cornelissen, Frost, & Hansen, 2010), as well as behavioral studies (see an overview, see Rayner, Pollatsek, Ashby, & Clifton, 2012). For example, masked priming studies have shown facilitatory effects of phonological overlap when orthographic overlap is held constant (e.g. brein–BRAIN compared to brain–BRAIN, e.g. Lukatela & Turvey, 1994; Perfetti & Bell, 1991). Evidence from sentence reading studies shows that when words start with the same sounds, as can be found in tongue twisters such as The press published the poem and promised to pay for permission (from McCutchen & Perfetti, 1982), reading is slowed down, both in overt and silent reading (e.g. Corley, Brocklehurst, & Moat, 2011; Hanson, Goodell, & Perfetti, 1991; Zhang & Perfetti, 1993). More recently, Acheson and MacDonald (2011) used a self-paced reading task to show that participants read more slowly, and comprehended less accurately, when they read relative clauses containing phonologically similar words (e.g. the baker that the banker sought bought the house). We therefore wanted to determine the extent to which the inhibition effects found in sentence reading (e.g. Paterson et al., 2009) are related to phonological or orthographic factors. In order to examine this, we distinguish between three different types of overlap: prime and targets that overlap both at the orthographic and the phonological level, only at the orthographic, or only at the phonological level (see below for examples). If Paterson et al.’s results merely reflect some kind of tongue twister effect, then we would not expect to find an inhibition effect when the overlap is only orthographic (e.g. bear–gear).

A second, related aspect that has not received much attention is the type and place of the non-overlapping letter of two neighbors. For example, mismatching letters at word offset (blue–blur), word onset (royal–loyal), and mid-word (axle–able) are all treated the same way: neighbor words can differ in the number of consonants, vowels, and syllables (unit–kint; tree–trek), and the sound quality of the vowel does not need to be preserved (step–stew) (all examples taken from Paterson et al., 2009). This variation is inconsequential if one assumes that phonology plays no critical part and that all letters contribute equally in the priming effect. However, research using transposed and/or substituted letters has shown that letter identity is more important for exterior letters (at the end and, even more so, at the beginning of the word) than word-internal letters (e.g. Johnson, Perea, & Rayner, 2007; Rayner, White, Johnson, & Liversedge, 2006). In addition, evidence suggests that words with begin overlap are processed differently from words with end overlap. For example, experiments using the phonological priming paradigm tend to show facilitation for end overlap (rhyming) items, while begin overlap items are more likely to show inhibition (for an overview, see Dufour, 2008). In contrast, using the fast priming paradigm during reading, Lee, Binder, Kim, Pollatsek, and Rayner (1999) found stronger facilitatory priming effects the more prime and target overlapped at the beginning. We therefore decided to examine begin and end overlap items separately.

The main aim of Experiment 1 was therefore to examine effects of form-based competition between different words in a sentence during silent reading. In particular, we examined the effects of different types of orthographic and phonological overlap. In Experiment 2, we extended our findings by investigating if the priming we observed in Experiment 1 varied as a function of the delay between prime and target words, the syntactic structure in which they were embedded, and individual differences in reading skill. We postpone our motivation for these manipulations until we have reported the results of Experiment 1.

Experiment 1

Method

Participants

Twenty-six Undergraduate and final year secondary school students participated in the Experiment for course requirement. All participants were native British English speakers.

Materials

A total of 128 item pairs were constructed, 32 per overlap type (see Table 1 for examples and Appendix A for a full list of items; see also Frisson et al., 2014, for a similar manipulation). Four overlap types between prime and target were distinguished: O+P+ (end) prime and targets have the same orthographic and phonological end overlap (i.e. they rhyme; e.g. wings–kings) but a different first letter; O+P+ (begin) prime and targets have the orthographic and phonological end overlap at the beginning but a different last letter (e.g. strain–strait); O+P– primes and targets rhyme and, thus, have a large phonological overlap, but are spelled differently (e.g. smile–aisle). The O+P– prime words are exception words (Glushko, 1979) in that they do not

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1 It's unclear whether rhyming words during normal reading facilitate or inhibit reading. Using rhyming and (modified) non-rhyming fragments from Dr. Seuss books, we observed faster reading times on rhyming words, but only when presentation was blocked (i.e. all rhyming and all non-rhyming fragments presented separately). When presentation was not blocked, no effects emerged (Frisson, Jamali, Pollatsek, & Meyer, in preparation).
adhere to simple spelling-sound rules and do not rhyme with most other words with the same end overlap. All items were 1 sentence long and contained a target word that was preceded by either a prime word or a control word. Identical sentence frames were used for the prime and control condition. The control word was always of the same length as the prime word and frequency (taken from the CELEX database, Baayen, Piepenbrock, & Van Rijn, 1993, using N-watch, Davis, 2005) was controlled both within ($t(127) = 1.12, p > .26$) and between ($F(3,124) < 1$) overlap types. Similarly, the distance between the target/control word and the prime word was controlled between overlap types (number of letters: $F(3,124) < 1$; number of words: $F(3,124) = 1.15, p > .33$). The prime word was always of higher-frequency than the target word (average frequency prime/control: 42.6, target: 3.2). Given the restrictions on item selection, it was impossible to control on all neighborhood variables (see Table 2). For example, while there was no difference between the different overlap types in terms of the number of phonological neighbors for the target (all $ts < 1$), the number of all orthographic neighbors varied across overlap type; unsurprisingly, the O/$P+$ overlap type had significantly fewer orthographic neighbors than the O/$P+$ (end) and the O/$P-$ overlap types ($ps < .01$). The number of shared overlapping neighbors between the prime and target also differed across overlap type. For example, the O/$P-$ prime and targets were de-

Table 1
Sample experimental sentences in the four priming conditions of Experiment 1.

<table>
<thead>
<tr>
<th>Overlap type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>O+/P+ end</td>
<td>The birds ruffled their <strong>wings</strong> [tails] as the kings watched from their palace</td>
</tr>
<tr>
<td>O+/P+ begin</td>
<td>The captain found it a <strong>strain</strong> [burden] to negotiate the strait at the end of a long voyage</td>
</tr>
<tr>
<td>O+P-</td>
<td>On noticing the giant <strong>bear</strong> [tree] John changed gear and pedalled away quickly</td>
</tr>
<tr>
<td>O-+P</td>
<td>The husband had a big <strong>smile</strong> [fight] walking down the aisle of the local supermarket</td>
</tr>
</tbody>
</table>

Notes: The prime [control] word is in bold, the target word is in italics. O+/P+ stands for orthographic and phonological overlap, O+P- stands for orthographic-only overlap, and O-+P+ stands for phonological-only overlap.

Table 2
Item characteristics for the experimental words tested in Experiment 1.

<table>
<thead>
<tr>
<th>Overlap type</th>
<th>Log frequency</th>
<th>Length (letters)</th>
<th>Number of orthographic substitution neighbors</th>
<th>Total number of orthographic neighbors</th>
<th>Number of overlapping orthographic substitution neighbors between prime and target</th>
<th>Total number of overlapping orthographic neighbors between prime and target</th>
<th>Number of overlapping phonological neighbors</th>
<th>Distance (letters)</th>
<th>Distance (words)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O+/P+, end</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime</td>
<td>1.60 (1.82)</td>
<td>5.0 (.5)</td>
<td>5.4 (3.6)</td>
<td>8.2 (4.5)</td>
<td>12.5 (7.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.55 (1.62)</td>
<td>5.0 (.5)</td>
<td>3.8 (3.2)</td>
<td>5.7 (3.7)</td>
<td>11.6 (6.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target</td>
<td>.80 (.82)</td>
<td>5.0 (.5)</td>
<td>5.3 (3.1)</td>
<td>7.3 (3.7)</td>
<td>11.5 (6.4)</td>
<td>1.4 (2.0)</td>
<td>2.0 (2.1)</td>
<td>3.6 (3.7)</td>
<td>14.0 (4.7)</td>
</tr>
<tr>
<td>O+/P+, begin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime</td>
<td>1.61 (1.63)</td>
<td>5.1 (.5)</td>
<td>4.1 (2.2)</td>
<td>6.3 (2.8)</td>
<td>10.4 (5.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.62 (1.64)</td>
<td>5.1 (.5)</td>
<td>3.8 (3.5)</td>
<td>5.9 (4.6)</td>
<td>10.0 (5.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target</td>
<td>.75 (.74)</td>
<td>5.1 (.5)</td>
<td>4.3 (2.7)</td>
<td>6.1 (3.1)</td>
<td>10.1 (4.9)</td>
<td>.8 (1.0)</td>
<td>.9 (1.1)</td>
<td>1.5 (1.9)</td>
<td>13.9 (4.0)</td>
</tr>
<tr>
<td>O+P-,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime</td>
<td>1.70 (1.85)</td>
<td>5.0 (.8)</td>
<td>6.4 (4.1)</td>
<td>8.9 (5.0)</td>
<td>10.6 (6.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.65 (1.78)</td>
<td>5.0 (.8)</td>
<td>5.4 (5.2)</td>
<td>7.3 (5.9)</td>
<td>11.4 (8.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target</td>
<td>.77 (1.03)</td>
<td>5.0 (.8)</td>
<td>6.5 (4.4)</td>
<td>8.7 (5.3)</td>
<td>11.4 (9.0)</td>
<td>2.9 (3.0)</td>
<td>3.2 (3.1)</td>
<td>.25 (.5)</td>
<td>14.0 (4.1)</td>
</tr>
<tr>
<td>O-P,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime</td>
<td>1.63 (1.60)</td>
<td>5.1 (.7)</td>
<td>3.6 (4.6)</td>
<td>5.7 (5.1)</td>
<td>11.6 (9.6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.63 (1.54)</td>
<td>5.1 (.7)</td>
<td>3.9 (3.9)</td>
<td>6.1 (4.4)</td>
<td>10.2 (7.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target</td>
<td>.76 (.82)</td>
<td>5.1 (.7)</td>
<td>2.7 (3.7)</td>
<td>4.3 (4.6)</td>
<td>10.2 (9.2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>2.1 (3.5)</td>
<td>14.2 (3.2)</td>
</tr>
</tbody>
</table>

Notes. Frequency is the number of occurrences per million words, based on CELEX. Neighborhood estimates are obtained from N-Watch (Davis, 2005). Number of substitution neighbors is also known as Coltheart N. Total number of neighbors is the sum of all substitution, deletion, and addition neighbors. Overlapping neighbors refers to the number of neighbors the prime and target have in common. Distance refers to the distance between the prime/control and the target word. Standard deviations can be found in brackets.
signed not to share any orthographic neighbors; conversely, the O+P– prime and targets hardly shared any phonological neighbors (<1%). We will return to the issue of neighborhoods in the analyses.

Item specifics can be found in Table 2. Yes/no questions appeared after 50% of the trials. Accuracy was 95.1%.

Procedure
The critical sentences, together with 36 filler sentences of comparable length, were divided over two lists, with an equal number of items per condition per list. Presentation was counterbalanced so that each participant only saw one version of an item pair. Control words did not have a high orthographic or phonological overlap with the target words.

An Eyelink 1000 eye-tracker was used for testing, which measured eye position every millisecond. Viewing was binocular, but only data from the right eye was recorded. The distance between the head and the monitor was 70 cm. A chin and forehead rest was used to minimize head movements. Sentences were presented in Courier New non-antialised font, size 14 pt. There were approximately 3 characters per degree of visual angle.

A standard 5-point calibration procedure was performed before the start of the experiment, and repeated whenever the experimenter deemed necessary. Between each trial a drift correction check was performed, and the presentation of the sentence was controlled by a trigger placed just left of the first word. Only when a fixation was detected in this location was the next sentence presented. Participants read each sentence at their own pace, and pressed a button when they had finished reading. The whole experiment lasted about 25 min.

Analyses
An automatic procedure combined short fixations (<80 ms) with another fixation if these were within one character space from each other; fixations <40 ms and not within 3 character spaces from another fixation were deleted. Trials with a blink on the target word and trials that showed tracker loss were deleted from all analyses (3.2%). Fixations <100 ms were removed from the analyses. Outliers over 1400 ms per word were removed from the gaze duration data (<1%).

Three regions of analysis are reported: the prime/control word region (e.g. wings), the target region (e.g. kings), and a spillover region (e.g. watched) defined as the next word if at least four characters long, otherwise the next two words. The same measures as discussed in Paterson et al. (2009) are reported: first fixation duration (the duration of the first fixation on a word or region), gaze duration (the sum of fixation durations on a word or region during first-pass reading), first-pass regressions (the percentage of backward saccades out of a region during first-pass reading), regression-path duration (the sum of all fixation durations on a word/region from first entering the region until going past it, this can include fixations on previously processed text; this measure is also known as the go-past time), and total time (the sum of all fixation durations on a word/region). In addition, we report single fixation duration (the fixation duration on a word/region during first-pass reading if there’s only one fixation) and skipping rate (when the target word was not fixated during first-pass reading).

All analyses were carried out using R (R Development Core Team, 2010) and the lme4 package, version 0.999999-0 (Bates, Maechler, & Bolker, 2012). Linear mixed-effect models were constructed for each dependent variable, with participants and items as random effects (Baayen, 2008). Following Barr, Levy, Scheepers, and Tily (2013), we included both random intercepts and random slopes. For the random slopes, we first tried the maximally-appropriate structure. However, since this frequently resulted in non-convergence, we used a reduced model in which we estimated random intercepts and slopes for all relevant terms but assumed a constant covariance rather than estimating covariance (as suggested by Bates, 2009). Model comparisons examining main effects of Priming and Set (the 4 overlap types) and the interaction between Priming and Set were tested. A main effect of Set (the 4 overlap types) is not very informative because prime, control, and target words were controlled between the sets, but other factors (e.g. discourse content) were not. Hence, we will not discuss this effect further. Main effects were tested by comparing the base model (which includes an intercept and the random factors) to the same model but with the factor Prime or Set added. The interaction was tested by comparing the full model to a model containing the two main effects. For the first-pass regression data, which are binomial (either a regression happened or not), we carried out a logistic regression using a generalized linear mixed effect model.

Results and discussion
Average reading times are shown in Table 3. Mixed-effect model analyses for the measures showing significant effects can be found in Appendix B (Table B1). We will discuss each region in turn.

Prime/control word region
No significant effects emerged for any of the reading measures (all ps > .17).

Target word region
We first examined whether the number of orthographic substitution neighbors, total number of orthographic neighbors (substitution + deletion + addition neighbors), and number of phonological neighbors of both the prime and the target affected target word reading times (neighborhood values were obtained from N-Watch; Davis, 2005). To this end, we compared two models, one including the neighborhood value in both fixed and random terms and one with no fixed effect term. None of these comparisons showed a significant improvement in model fit (all ps > .18, except for total gaze: ps > .07). The finding that the number of neighbors mainly affected a late
measure such as total reading times is somewhat unexpected if one assumes neighborhood size affects early processing stages. However, Pollatsek, Perea, and Binder (1999) also failed to find immediate effects of neighborhood size during reading. We will not discuss this further.

For the main analyses, we examined whether the addition of Set, Prime, or its interaction improved model fit. No significant effects were found for the skipping rate, single fixation, first fixation, and first-pass regression measures (all \( p > .28 \)). Analyses of the gaze duration measure showed that model fit was significantly improved by including the interaction with prime type (\( \chi^2 = 7.87, p < .05 \)). Separate model comparisons conducted for each set showed that this interaction reflected significant inhibition for the O+P+ end set only (Estimate = 23.3, \( SE = 10.2, t = 2.3 \)), and no significant effects for the other three sets (all \( p > .16 \)) (see Appendix B, Table B1, for details). The same pattern was observed for the regression-path reading times: including the interaction with prime type significantly improved model fit (\( \chi^2 = 8.34, p < .05 \)), reflecting significant inhibition for the O+P+ end set (Estimate = 49.9, \( SE = 16.6, t = 3.0 \)) and no significant effects for the other sets (all \( p > .27 \)). The total reading time measure did not show significant effects.

Spillover region

No significant effects were found for the skipping, single fixation and first fixation duration measures (all \( p > .11 \)). The gaze duration measure showed no significant interaction, nor an effect of Prime or Set. The 26 ms inhibition found for the O+P+ begin items, while suggestive, failed to reach significance (\( p > .20 \)). The first-pass regression analyses showed no significant interaction, no main effect of Set, but model fit was marginally improved when Prime was added to the model (\( \chi^2 = 3.41, p < .07 \)). Separate analyses of each set revealed a near-significant higher percentage of regressions for the primed version of the O+P+ begin items compared to their unprimed counterpart.

<table>
<thead>
<tr>
<th>Region</th>
<th>Prime/control word</th>
<th>O+P+ end</th>
<th>O+P+ begin</th>
<th>O+P-</th>
<th>O--P+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skip</td>
<td>Prime</td>
<td>15.6</td>
<td>13.5</td>
<td>15.4</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>16.0</td>
<td>13.9</td>
<td>15.4</td>
<td>14.7</td>
</tr>
<tr>
<td>Single fixation</td>
<td>Prime</td>
<td>25.2</td>
<td>24.6</td>
<td>24.9</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>25.5</td>
<td>24.9</td>
<td>24.9</td>
<td>24.5</td>
</tr>
<tr>
<td>First fixation</td>
<td>Prime</td>
<td>34.6</td>
<td>34.2</td>
<td>33.9</td>
<td>33.9</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>34.9</td>
<td>34.2</td>
<td>33.9</td>
<td>33.9</td>
</tr>
<tr>
<td>Gaze duration</td>
<td>Prime</td>
<td>51.8</td>
<td>52.1</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>51.9</td>
<td>52.1</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Regressions</td>
<td>Prime</td>
<td>38.9</td>
<td>39.3</td>
<td>38.9</td>
<td>39.3</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>39.1</td>
<td>39.3</td>
<td>38.9</td>
<td>39.3</td>
</tr>
<tr>
<td>Total time</td>
<td>Prime</td>
<td>125.8</td>
<td>125.5</td>
<td>125.5</td>
<td>125.5</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>125.9</td>
<td>125.5</td>
<td>125.5</td>
<td>125.5</td>
</tr>
</tbody>
</table>

Table 3
Eye movement data for Experiment 1.

Table 4
Sample experimental sentences in the three lag conditions of Experiment 2.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>The students had a late \textbf{start [class]} and showed a \textit{stark} contrast in talent. They couldn’t wait to finish school for the day</td>
</tr>
<tr>
<td>Long-1 sentence</td>
<td>The students had a late \textbf{start [class]} at the community school and showed a \textit{stark} contrast in talent. They couldn’t wait to finish school for the day</td>
</tr>
<tr>
<td>Long-2 sentence</td>
<td>The students had a late \textbf{start [class]} at the community school. They showed a \textit{stark} contrast in talent. They couldn’t wait to finish school for the day</td>
</tr>
</tbody>
</table>

Notes. The prime [control] word is in bold, the target word is in italics.
(Estimate = 0.4, SE = 0.2, t = 1.9). The other sets did not show an inhibitory priming effect (all ps > .34). The regression-path analyses mirror this trend: a non-significant interaction or main effect of Prime, though the model was significantly improved with the addition of Set ($\chi^2 = 8.99$, p < .05). Separate analyses for each set showed significant inhibition for the O+P+ begin set (Estimate = 64.8, SE = 29.0, t = 2.2), but no effects for the other sets (all ps > .42). The total duration analyses showed a main effect of Set ($\chi^2 = 12.65$, p < .01) but no other effects.

The pattern of results is clear for three out of the four sets. First, no differences were found for the prime/control word region, indicating that these were well controlled, but also that prime words were not reread more often than control words. Second, a clear and early inhibition effect, with the target word taking longer to process when preceded by an overlapping prime word than when preceded by a non-overlapping control word, was observed for the O+P+ end-overlap target word, which was also noticeable in the later measures. Third, no significant or near-significant effects were observed for any measure at any region for the O+P– and the O–P+ sets, indicating that when the prime and target word overlapped only at the orthographic or at the phonological level, no inhibition ensues. The pattern for the O+P+ begin words is more difficult to interpret. The data indicate longer (but non-significant) gaze durations for the primed condition on the spillover region, but also a nearly significant larger percentage of first-pass regressions. These two tendencies might have influenced each other, making it harder to find a significant effect. The regression-path measure takes both tendencies into account to some degree, and the analyses of this measure indicate that there was indeed significant inhibition for this condition. Why the effect was slightly delayed is puzzling, but could possibly be related to rhyme exerting a stronger phonological cue than begin overlap. We will return to this issue in the discussion of Experiment 2.

We also checked whether the number of orthographically and phonologically shared neighbors between the prime and target influenced target word reading. We contrasted, for each reading measure, a model containing the shared neighborhood size to one without. None of the model comparisons showed a significant difference (all ps > .30), indicating that shared neighborhood size did not affect the reading time measures.

**Experiment 2**

The aim of Experiment 2 was to further investigate the inhibitory priming effect we observed in Experiment 1. First we wanted to test an important prediction of interactive-activation accounts. According to all available models of word recognition, activation levels of lexical candidates decay over time. Although the exact time course is unknown, it is generally assumed to be relatively short. We tested this prediction by comparing the inhibition effect when the distance between the prime and target word in a sentence was varied. We expected to find a reduced inhibition effect when the prime and target were at a greater distance from each other, due to the decay of prime activation over time and, therefore, reduced competition when processing the target word.

We also examined whether syntactic structure plays a role in the degree of activation of the prime word. Evidence from eye movement studies suggests that readers spend more time on a word at the end of a sentence compared to when that word is not sentence-final (sentence “wrap-up” effect; e.g. Just & Carpenter, 1980; Mitchell & Green, 1978; Rayner, Kambe, & Duffy, 2000; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989; see also Hirotani, Frazier, & Rayner, 2006), indicating the operation of integrative processing, e.g. relating sentences of a text to each other. Moreover, Carroll and Slowiaczek (1986) demonstrated priming between semantically associated words in a sentence reading task when the words appeared in the same clause but not when they appeared in different clauses. We hypothesized that at a sentence boundary, low-level information, such as the residual activation of lexical representations, is discarded so that orthographic overlap effects will disappear if the prime and target appear in different sentences. We tested this by inserting a syntactic break in the longer delay sentences.

These manipulations also allowed us to test an alternative explanation for the inhibition effect, suggested by Paterson et al. (2009), which is related to episodic memory effects. According to episodic theories of word identification, which have mainly been proposed to explain (longer term) repetition priming effects, words are stored as episodic memory traces, containing both visual and phonological features. When the same word is presented again, the availability of the memory trace will speed up processing (see Tenpenny, 1995, for an overview, but see Bowers, 2000, for an alternative view). In theory, it’s possible to modify this view such that when a neighboring word is presented, this memory trace will interfere with the identification of the target, leading to an inhibition effect (see Paterson et al., 2009). In practice, it can be difficult to distinguish a theory based on episodic memory traces and an account that posits competition between orthographic neighbors. However, one could tentatively suggest that while the inhibition effect should disappear quite quickly in the competition account, the episodic memory account would predict longer-lasting inhibition (repetition priming effects can be seen over several days’, or even months’, delay, e.g. Jacoby, 1983; Kolers, 1976). In addition, an episodic account, as well as a competition account, would predict that syntactic structure should not affect the degree of priming, as long as the time between prime and target is held roughly equivalent.

Finally, Experiment 2 also tested for a relationship between inhibitory priming and individual differences in reading skill. Masked orthographic neighbor priming has been shown to vary as a function of reading skill, even within groups of highly skilled readers. Andrews and Hersch (2010) found that differences in reading and spelling ability among university students affected neighborhood priming results, such that high-frequency word neighbor primes slowed lexical decision responses for good spellers but speeded responses for poorer spellers. This finding was replicated and extended by Andrews and Lo (2012), who demonstrated that higher spelling ability is also associated
with stronger facilitation from nonword neighbor primes. This pattern of results was attributed to differences in the quality of orthographic lexical representations such that more precise lexical representations can more quickly inhibit their lexical competitors.

While we didn’t test spelling ability, we were interested in the relationship between reading skill and the persistence of the priming effect. Gernsbacher (1993) suggested that less skilled readers are poorer at suppressing certain types of information than more skilled readers. She demonstrated that while both skilled and less skilled readers show inhibition at a short ISI (100 ms) when they need to reject a word related to the (unintended) meaning of a sentence-final homophone (e.g. rejecting calm after patients [homophone of patience]), only the less skilled readers show an inhibition effect when the ISI was 1 second (Gernsbacher & Faust, 1991). This would suggest that less skilled readers might show a more pronounced inhibition effect than more skilled readers when prime and target are further apart. On the other hand, less skilled readers tend to lose access to more superficial or surface features faster than more skilled readers (e.g. Gernsbacher, Varner, & Faust, 1990). This loss of form information should predict faster than more skilled readers (e.g. Gernsbacher, Varner, & Faust, 1990). The ISI of 1 second was chosen because it is a relatively short delay that is sufficiently short to allow for the initial inhibition effect to be observed.

To summarize, in Experiment 2 we manipulated the delay between prime and target words, testing priming at both a short and a long lag (an average of approximately 3 and 9 intervening words, respectively). We also investigated the effect of syntactic structure by comparing priming within the same sentence to priming across a sentence boundary. Finally we post-tested our participants’ level of reading skill to examine whether there was a relationship between reading skill and inhibitory form priming. Only O+P+ items were tested, as the O+P− and O−P+ items did not show any sign of a priming effect in Experiment 1.

Method

Participants

Fifty-four undergraduate, native British English speaking students from the University of Birmingham participated in the Experiment for course credit.

Materials

Sixty items were constructed, all with the prime and target words overlapping in both orthography and phonology and the control and target words not overlapping. Thirty of the primes exhibited begin overlap, and all item pairs were taken from Experiment 1. For each item, six different conditions were constructed (see Tables 4 and 5; all items can be found in Appendix A). The target word was either preceded by a prime word or a control word, which were always of higher frequency than the target word (average frequency prime/control: 40.0, target: 5.2). The prime and control words were of the same length and did not differ in terms of frequency (t < 1). For the close (short) conditions, the prime/control and target words were separated by an average of 3.0 words (13.8 characters). For the two long conditions, the distance was 8.8 words (44.0 characters) when prime and target appeared in the same sentence, and 8.8 words (44.3 characters) when they were separated by a full stop (ts < 1.4). All items were either 2 (short and long – 1 sentence conditions) or 3 (long – 2 sentence condition) sentences long, and comprehension questions followed 33% of the items. Accuracy was 90.0%.

A fit-in-context test was carried out in order to check whether the target word fitted equally well following the prime or the control word. Forty-eight new participants from the same subject pool, divided over 6 lists, took part for credit. Participants were asked to indicate, using a 7-point scale, how well they thought an underlined word in a sentence fitted in the sentence, with 1 meaning “does not fit at all” and 7 “fits perfectly”. In addition to the 60 critical items, 60 filler items were constructed in which the underlined word did not fit the context to different degrees in order to have the participants use the entire scale. After this test, participants completed the Gray Silent Reading Test (GSRT; Wiederholt & Blalock, 2000, 4th Edition). This standardized test, which we also used with the participants in the eye movement experiment, measures reading comprehension; participants read six short passages and answered multiple choice questions, differing in difficulty, related to these passages. Together, the fit-in-context and the GSRT tests took approximately 55 min to complete.

The results of the fit-in-context test revealed no differences between the primed and unprimed conditions: Short: 5.8 (primed) vs. 5.8 (unprimed), t < 1; long – 1 sentence: 5.8 vs. 5.9, t(59) = 1.00, p > .30; long – 2 sentence: 5.8 vs. 5.7, t < 1. We also correlated the fit-in-context scores with the participants’ GSRT comprehension score (mean = 22.9, range = 11–29). While there were no significant correlations between the two measures (r = .10, p > .50 for all items tested, and r = .257, p > .07 for the critical items), there was a trend for good comprehenders to rate the targets as fitting better into the contexts.

Table 5

<table>
<thead>
<tr>
<th>Target</th>
<th>Log frequency</th>
<th>Length (letters)</th>
<th>Number of orthographic substitution neighbors</th>
<th>Total number of orthographic neighbors</th>
<th>Number of phonological neighbors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime</td>
<td>1.39 (.5)</td>
<td>5.1 (.5)</td>
<td>4.8 (3.1)</td>
<td>7.2 (3.9)</td>
<td>11.5 (6.7)</td>
</tr>
<tr>
<td>Control</td>
<td>1.39 (.5)</td>
<td>5.1 (.5)</td>
<td>3.8 (3.3)</td>
<td>5.8 (4.2)</td>
<td>10.9 (6.4)</td>
</tr>
<tr>
<td>Target</td>
<td>.65 (.3)</td>
<td>5.1 (.5)</td>
<td>4.9 (3.0)</td>
<td>6.8 (3.4)</td>
<td>11.3 (5.5)</td>
</tr>
</tbody>
</table>

Notes. Frequency is the number of occurrences per million words, based on CELEX. Neighborhood estimates are obtained from N-Watch (Davis, 2005). Number of substitution neighbors is also known as Coltheart N. Total number of neighbors is the sum of all substitution, deletion, and addition neighbors.
However, and more importantly, there was no significant correlation with the fit-in-context differences for the primed and unprimed items ($r = .128, p > .38$), suggesting that good and poorer comprehenders did not differ in how well they thought primed targets fitted vis-a-vis unprimed targets.

We also tested whether there were any differences in predictability of the target word. Sixty new participants, equally divided over 6 lists, took part in a Cloze test in which the sentences up to but not including the target word were provided and participants had to complete the sentence with the first word or words that came to mind. Predictability was very low for all conditions (short – primed: 2.5%, short – control: 3.5%; long – 1 sentence primed: 3.5%, long – 1 sentence control: 3.0%; long – 2 sentence primed: 3.9%, long – 2 sentence control: 3.0%), and there were no significant differences between the primed and control versions of each condition: short: $t(59) = 1.14, p > .25$; long – 1 sentence: $t < 1$; long – 2 sentence: $t(59) = 1.00, p > .32$.

**Analyses**

The same three regions (prime, target, spillover) as for Experiment 1 were analyzed.

**Procedure**

The critical items were intermixed with 54 filler items of comparable length and divided over six lists. Item presentation was counterbalanced so that each participant saw only one version of an item, and an equal number of items per condition.

The procedure was identical to Experiment 1, except that after completing the experiment, participants were also administered the Gray Silent Reading Test (GSRT), using the procedure as above. We used individuals’ reading comprehension scores to examine whether the size of the inhibition effect was related to reading comprehension level.

**Results and discussion**

Average reading times are shown in Table 6, linear and generalized linear mixed-effect analyses can be found in Appendix B, Table B2. We will discuss each region in turn. The data were again analyzed using linear mixed-effect modeling, and generalized linear mixed-effect modeling for the first-pass regression data. Prime (primed vs. control), Distance (short, long – 1 sentence, and long – 2 sentence), and Overlap Type (O+P+ begin vs. O+P+ end) were coded as predictor variables. We first tested whether a model containing overlap type (begin or end overlap) produced a better fit for the target word reading measures than a model without. Since this was not the case (all $p > .12$), we used the simpler model without overlap type in the remainder of the analyses.

The main effect of Prime was tested as in Experiment 1. The main effect of Distance was not tested as it is not informative with respect to the research question since it can merely indicate that words later in a sentence take longer or shorter to process. The interaction between Prime and Distance is indicative of differential processing for the different distance conditions and was tested by comparing
the full model to a model with the two main effects, but without the interaction.

**Prime/control word region**

No significant effects were observed for the skipping, single fixation, first fixation, gaze duration, first-pass regression, and total reading time measures ($p > .11$). Model fit for the regression-path duration measures showed a significant improvement when Prime was included ($\chi^2 = 4.01$, $p < .05$), with the control word taking 18 ms longer to process than the prime word.

**Target word region**

The skipping data did not show any significant effects ($p > .88$). The single fixation duration measure showed a significant interaction between Prime and Distance ($\chi^2 = 6.04$, $p < .05$; see Appendix B, Table B2, for details). Separate model comparisons for each distance condition revealed that the target word took longer to process in the primed compared to the control condition, but only for the short distance condition (Estimate = 10.2, $SE = 5.1$, $t = 2.0$; all other conditions: $p > .11$). The same pattern was found for the first fixation duration data: a significant model fit improvement with the inclusion of the interaction ($\chi^2 = 6.37$, $p < .05$), with the inhibitory priming effect restricted to the Short distance condition (Estimate = 11.9, $SE = 4.7$, $t = 2.6$; all other conditions: $p > .25$). There were no significant effects for the gaze duration data, but the first-pass regression data revealed a significant interaction ($\chi^2 = 6.14$, $p < .05$). While no differences were found for the two Long distance conditions ($p > .56$), more regressions were found for the control condition in the Short distance condition (Estimate = $-0.6$, $SE = 0.2$, $t = -2.9$). The finding that more regressions occurred for the control condition is surprising, but the regression data on the spillover region do show a difference in the expected direction. The regression-path and total reading time analyses did not show significant effects.

**Spillover region**

No significant main effects or interactions were found for the skipping, single fixation and first fixation duration data, though planned comparisons revealed significant inhibition for the Short distance condition in the first fixation data (Estimate = 13.2, $SE = 6.7$, $t = 2.0$), but not for the two Long distance conditions ($p > .74$). No significant effects were found for the gaze duration measure. The first-pass regression measure showed a marginal effect when Prime was included in the model ($\chi^2 = 3.10$, $p < .08$). While the interaction with Distance was not significant, an inspection of the means indicated that a difference between primed and control condition could only be observed for Short distance condition. This was confirmed in the separate comparisons for each distance condition, with a higher number of regressions for the primed Short condition compared to the unprimed Short condition (Estimate = 0.4, $SE = 0.2$, $t = 2.4$). The difference for both Long conditions was not significant ($p > .72$). The same pattern was observed for the regression-path data: there was a non-significant model fit improvement when the interaction was added and a marginal improvement when Prime was added ($\chi^2 = 2.98$, $p < .09$), with only a significant inhibition effect for the Short distance condition (Estimate = 53.8, $SE = 23.6$, $t = 2.3$) but not the two Long conditions ($p > .29$). Finally, the total reading time data showed that the addition of Prime significantly improved model fit ($\chi^2 = 4.25$, $p < .05$), with only the Short distance condition showing significant inhibition, but not the Long – 1 sentence condition ($p > .87$). There was some suggestion that the Long – 2 sentence condition also showed an inhibition effect (Estimate = 25.2, $SE = 13.5$, $t = 1.9$), though it should be noted that this is considered a “late” measure and only approached significance on the region following the target word.

The pattern found for the Short distance condition replicates the findings of the O+P+ conditions of Experiment 1, with early inhibition effects on the target word and the spillover regions. Experiment 1 also showed immediate early effects for the O+P+ end overlap items, and a slight delay for the O+P+ begin overlap items. The items used in Experiment 2 were a mix of both types of O+P+ overlap items, but our analyses did not reveal a clear difference in processing between the two overlap types. The source for this slight discrepancy in the findings is unclear, though one can safely conclude that both end and begin overlap items are capable of generating inhibition during early processing.

We examined whether comprehension skill was related to a number of global processing measures. Reading skill as measured by the GSRT did not affect reading speed (expressed as words per minute), the number of forward fixations, forward fixation duration, forward saccade length, the number of forward saccades, regressive fixation duration, the number of regressive fixations, or the number of regressive saccades (all $p > .42$). However, it did impact the regressive saccade length ($\chi^2 = 6.15$, $p < .05$) and, as a consequence, the average saccade duration ($\chi^2 = 4.54$, $p < .05$), with better comprehenders tending to make somewhat longer regressive saccades than poorer comprehenders. While there is good evidence that reading skill can have an effect on these global eye movement measures (for example, beginning readers tend to have longer fixation durations and shorter saccades than more skilled readers; see Rayner, 1998, for an overview), it might not be that surprising that for the participants tested here (highly skilled undergraduates) hardly any of these global measures showed a significant effect of comprehension skill.
In order to test whether reading skill affected the inhibitory priming effect, we constructed a model containing GSRT and priming as fixed effects, and random slopes containing Prime in the subject term and Prime and GSRT in the item term. We will concentrate on the interaction between GSRT and Prime. There were no significant effects for the Long – 2 sentence condition (all $p > .10$). For the Short condition, the interaction was significant for the first-pass regressions data ($\chi^2 = 7.88$, $p < .05$), due to the tendency for better comprehenders to make fewer regressions when the prime and target overlapped (see Fig. 1). None of the other measures approached significance (all $p > .16$). More interestingly, the Long – 1 sentence condition showed a trend towards a significant interaction for the gaze duration ($\chi^2 = 4.97$, $p < .09$), and significant interactions for the first-pass regression and the regression-path measures ($\chi^2 = 8.66$, $p < .05$ and $\chi^2 = 13.96$, $p < .001$, respectively). As can be seen from the plots in Fig. 1, these interactions were driven by good comprehenders showing a larger inhibition effect (longer reading times, more regressions) than poorer comprehenders (who were more likely to show facilitation). Inspection of the plots also shows that participants who show an inhibition effect were concentrated towards the higher end of the GSRT scale while participants showing facilitation exhibited a broader range of scores. In order to further examine the interaction between the GSRT scores and the priming/inhibition effect, we divided up the participants into two roughly equal-sized groups: good comprehenders ($N = 25$, average GSRT score of 26, range 24–29) and less good comprehenders ($N = 29$, average GSRT score of 20, range 13–23). For the gaze duration measure, the inhibition effect was 16 ms for the good comprehenders and −2 ms for the less good comprehenders; for the first-pass regressions measure, the good comprehenders showed a 7.1-point increase while the less good comprehenders showed a 2.7-point decrease; and for the regression-path measure, the inhibition effect was 71 ms for the good comprehenders while the less good comprehenders showed a 25 ms facilitation. Hence, the interaction seems to be driven by an increased inhibition effect for the good comprehenders, and a smaller tendency towards facilitation for the less good comprehenders.

There are two main conclusions that can be drawn from the data patterns. First, early inhibitory effects, with longer reading times when the prime overlapped both orthographically and phonologically with the target, were restricted to the Short distance condition. When the prime

**Fig. 1.** Interaction plots GSRT and priming effect.
and target appeared in different sentences, but with the same distance as the other long distance condition, no significant inhibition effects were observed. This result can easily be accounted for in an interactive activation account in which an activated representation will rather quickly decay.

Second, analyses including reading measures and individuals’ comprehension level indicated that good comprehenders showed a larger inhibition effect than less good comprehenders for the Long – 1 sentence condition. This suggests that good comprehenders were affected by the prime-target overlap for longer than less good comprehenders. Interestingly, when the prime and target were separated by the same distance but appeared in adjacent sentences, no effect of comprehension skill was observed, suggesting that the presence of an overlapping prime word no longer affected processing of the target word for either the good or the less good comprehenders.

These results pose challenges to both lexical competition and episodic memory accounts of inhibitory priming. First, a competition account, which generally assumes the decay function to be a constant, would need to explain why decay of lexical representations is slower for better comprehenders. Since the time taken to get from the prime to the target word was not significantly correlated with reading skill (r = .23, p > .09), it’s unlikely that the good comprehenders showed an inhibition effect in the Long – 1 sentence condition because they just arrived at the target faster than less good comprehenders. A simple competition model would also struggle to explain why the inhibition effect was there for good comprehenders at the Long – 1 sentence condition, but not at the Long – 2 sentence condition. An analysis of the (first-pass) time it took to read the text in-between the prime and target revealed no differences between the Long – 1 sentence and the Long – 2 sentence conditions (1197 ms vs. 1194 ms, t s < 1), indicating that the disappearance of the effect for the good comprehenders was not due to participants taking more time to get to the target word in the Long – 2 sentence condition. While an episodic account could explain why good and less good comprehenders differ at the Long – 1 sentence condition by assuming that the episodic memory trace is stronger for better comprehenders, it cannot provide a straightforward explanation for why this advantage disappears across sentence boundaries. We will return to this in the General Discussion.

**General discussion**

Both experiments yielded a number of significant effects that help our understanding of inter-word priming effects during reading. Experiment 1 showed that the inhibitory priming effect is restricted to word pairs that overlap both at the orthographic and phonological level, e.g. wings–kings; strain–strait. When the pairs overlap only at the orthographic (e.g. bear–gear) or only at the phonological (e.g. smile–aisle) level, no inhibitory nor facilitatory priming was observed. An account that maintains that the inhibition effect is solely caused by the presence of an orthographic neighbor can explain the lack of an effect for the phonological-only overlap, but cannot explain why there was no inhibition effect for the orthographic-only overlap. Since item pairs in this (O+P–) overlap condition were, by definition, the same kind of orthographic neighbor pairs as the O+P+ conditions, the difference in results indicates that it’s the presence of phonological overlap that is necessary for inhibition. However, given that the phonological-only condition did not show a priming effect, it must have been the combination of orthographic and phonological overlap that drove the inhibition and that overlap at only one level was not sufficient.

Hence, at least in a regular reading task, the inhibition effect cannot be explained by a simple account in which the spelling of a previously activated word competes during the recognition of one of its orthographic neighbors. At least, such an account needs to be augmented with a mechanism that restricts inhibitory effects to words that not only look the same, but sound the same as well. It should be noted that this does not necessarily hold for single word tasks. As has been demonstrated by Rastle and Brysbaert (2006), phonological priming effects in lexical decision tasks tend to be very small, leading them to argue for a weak phonological involvement in LDTs. In contrast, numerous reading experiments have shown an influence of phonology during sentence reading (for an overview, see Rayner et al., 2012), which might indicate that readers rely more on phonological information during normal reading. If this is true, then this would make comparisons between LDT and normal reading less straightforward than is sometimes assumed.

Whether the results of Experiment 1 can be explained by an episodic memory model is a matter of debate. While it has been argued that phonological information is part of an episodic memory trace, it’s unclear whether this information is so crucial that, without it, orthographic information would be ignored. In any case, this theory will need to spell out the relative contributions of orthographic and phonological features in episodic memory and how these are used during normal reading.

Experiment 2 showed that when the distance (and time) between the prime and target is increased (from about 3 to about 9 intervening words), the inhibition effect disappeared, both when the prime and target appeared in the same sentence and in two consecutive sentences. This finding can easily be accommodated in a competition model as it is generally assumed that the activation levels of words decay quickly (Paterson et al., 2009). Our data provide the first evidence that this also happens during a normal reading task. Whether the same prediction would be made by an episodic memory account is less clear. As discussed above, the main aim of this type of account has been to explain long-term priming effects (Tenpenny, 1995), with effects being found weeks, months, or even more than a year later. It is, therefore, unclear why delaying the target by about six words (equivalent to about 1.2 seconds) would result in the eradication of the inhibition effect.

There are, however, two other aspects of the data that could possibly point to some kind of memory effect. Analyses that included a measure of silent reading skill indicated that good and less good comprehenders differed
with respect to how they processed the target when the target word was delayed but still appeared in the same sentence as the prime word. In this case, better comprehenders still showed an inhibition effect while less good comprehenders did not. When the target was delayed for the same distance/time but appeared in separate sentences, no effects of reading skill were observed. This pattern suggests that better comprehenders kept the prime active for longer, or reactivated the prime more readily, than less good comprehenders, as long as both prime and target appeared in the same sentence.

The inhibition effect for better comprehenders at the Long – 1 sentence condition is intriguing as it indicates that the way these readers process information might sometimes lead to a (relative) disadvantage. There are a number of plausible explanations for this inhibition effect for better comprehenders. First, it’s possible that these readers hold onto superficial information for longer than less good comprehenders (e.g. Gernsbacher et al., 1990). Second, it might be that better comprehenders keep the prime activated for longer than less good comprehenders. Specifically, some evidence suggests that skilled readers rely more on phonological codes than less skilled readers (Chace, Rayner, & Well, 2005; Unsworth & Pexman, 2003; but see Landi & Perfetti, 2007). If it is, indeed, the case that inhibitory priming depends on the combined activation of orthographic and phonological information (cf. Experiment 1), and if more skilled readers have stronger and/or longer-lasting phonological representations, then it might be that only the more skilled readers still have both sources of information active or available when encountering the target word. Third, better comprehenders might have superior memory compared to less skilled readers, meaning that the episodic memory trace of already processed words will be stronger. Indeed, more skilled comprehension may involve the ability to combine lexical information across larger chunks of text. One aspect of our findings suggests that the increased inhibition shown by better comprehenders is not simply due to a longer lasting memory trace but may indeed reflect different comprehension processes. This is the finding that no inhibition was observed, even for the better comprehenders, when primes and targets were separated by a sentence break. This finding suggests that the presence of a sentence boundary makes readers discard low-level information, such as the spelling of specific words, and/or erase or suppress their memory trace. Given that a sentence boundary is thought to trigger higher-order, more integrative processes (e.g. relating sentences to each other; Rayner et al., 1989), this seems to be the obvious place to dispose of low level information.

These results are difficult to accommodate in existing models. A simple account, whether it is competition or memory based, that explains the size of the effect merely in terms of the time/distance between the prime and the target, can’t account for the full set of data. Such an account would predict comparable inhibition effects for both long distance conditions, which was not what was found for the better comprehenders. Hence, a realistic explanation of our data will need to allow for individual differences, the impact of syntactic structure on the activation levels of words in a sentence, and how those two combine.

Clearly, more research is needed to determine exactly what it is that makes more skilled readers continue to show an inhibition effect in the Long – 1 sentence condition. While the Gray Silent Reading Test measures individual’s silent reading comprehension, this skill might also be related to memory and/or precision in lexical representations (e.g. Andrews & Hersch, 2010). Indeed, if we assume that good comprehenders are also likely to be better spellers, then the present data fit well with the lexical precision theory, again resulting in the somewhat counterintuitive finding that better comprehension/precision can lead to greater interference effects during reading.

In conclusion, our data show how words within a sentence can influence each other, and how these effects wax and wane during normal reading. We found that words that both looked and sounded alike affect each other the most, and that the size of the effect is changed by both distance and syntactic structure. Finally, significant correlations with a measure of reading skill indicated that good comprehenders were negatively impacted by inter-sentence word overlap for longer than less good comprehenders.

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Appendix A

Stimuli used in Experiment 1 by overlap type. The words in bold are the prime words with the control word between square brackets. The target words are in italics.

Overlap Type 1: O+P+, end (wings–kings)

The birds ruffled their wings [tails] as the kings watched from their palace. Michael watched the brush [shelf] fall and crush the spider against the wall. Sarah moved her hand in a circular motion [manner] to apply the lotion to her skin. Ben was watching the storm and the flash [burst] of light and clash of thunder scared him. The woman was walking down the trail [aisle] but she felt frail as she was very old. Playing the lottery John won a grand [prize] and bought a top brand luxury car. Jane read the card [page] on the back of the lard to check the nutritional content. Steve was extremely drunk [silly] and fell over the trunk his mother had left in the hall. The commander of the fleet [craft] didn’t like the sleet that was disrupting communications. When Graham was running on the track [roads] he saw a crack that hadn’t been there yesterday. Nobody knew who to blame [phone] as the flame climbed higher up the wall.
John picked up the small object and threw [flung] it at the shrew to make it run away. The boy went feet first down the slide [shaft] in order to glide down towards the floor. The wolf continued to blink [growl] as it began to slink away into the darkness. The chicken that Jack wanted to pluck [seize] started to cluck when he advanced on it. The lady on the bus was very plump [weary] and she sat in a slump next to John. The boy gave a wink [mint] to the girl on the rink because he liked her. The hunter had set up a spare [dirty] trap to snare the animal that he had been tracking. The deck was large [level] on the barge allowing plenty of room for the crates. The shortage of bread [sugar] caused real dread in the village due to the rationing. As he vacationed by the shore [ocean] he remembered the chore he still had to complete. The poor old whale [goose] was hit by SHALE that fell off an overhanging cliff. Paul acted like he was waking [firing] up but he was faking it because he was still very tired. Although Lucy felt sick [wild] she put a tick on her attendance sheet for the day. It took a certain breed [grade] of people to defend their creed without hesitation. Cleaning the ship’s flank [ports] caused a clank as the anchor suddenly came loose. Laura badly needed a drink [sleep] as she was on the brink of total exhaustion. Simon started to grunt [heave] when the brunt of the weight was placed on him. Last Saturday Dan had a dream [laugh] about a bream swimming in the sea. Jane hoped for a quiet payday [brunch] but a mayday came over the system. James had managed to retain [locate] the documents to detain the criminals in custody. The pipes began to swell [shake] and I started to dwell on the impending problem.

Overlap Type 2: O+P+, begin (strain–strait)

The captain found it a strain [burden] to negotiate the strait at the end of a long voyage. The mother thought it was very sweet [crazy] to see the girl sweep the dirty floor. Because of the steam [fence] the thief could steal the car without being noticed. An admission of guilt [shame] to the guild meant that John would face punishment. Bob knew the item was cheap [vital] and had to cheat to make sure he won the bid. A good supply of grain [wheat] was the holy grail for the farmer following the poor harvest. When Lee proposed to Sue he stroked her cheek [wrist] and a cheer arose from their families. He had to walk to the tower [guard] to get his towel as he’d forgotten it.

Malcolm used a steel [metal] bar to steer the broken bicycle. The young inexperienced scout [troop] helped to scour the countryside for the lost dog. Richard looked in the chest [rooms] for a book about chess which he needed to study. The students had a late start [class] and showed a stark contrast in talent. Ben bumped his knee on the stool [ledge] and then had to stoop to stem the pain. The door of the larder where we keep the cream [seeds] opens with a creak as it is rarely used. Tony wrote a catch phrase for the advert [poster] using the adverb his clients had requested. Sarah searched through the market [houses] for a permanent marker to use in her office. Suddenly everything became blank [noisy] after the bland meal which had been served for dinner. Paul was sitting by the stream [border] and saw a streak of light flash through the sky. Sarah examined scans of the brain [teeth] while twisting the braid in her hair. It’s difficult to train [teach] any dog with the trait of laziness in its breed. In an argument Jane always slung [casts] abuse before she slunk off to hide. The student’s eyes started to gleam [shine] when he could glean the information from the text. The knight received a slap [coin] for his attempt to slay the friendly dragon. The morning’s thin sheet [cover] of snow left a sheen to the pavement that brightened the day. No one would ever use a spoon [blade] instead of a spool for winding thread. Behind the camel he was trying to mount [climb] was a mound of droppings he needed to avoid. The film star was able to swoop [sneak] in and make her swoon with desire as he caught her. New evidence led to the repeat [latest] motion to repeal the man’s sentence. The unexpected storm [turns] made the stark lose touch with its flock. Attempting to balance the plant [block] on the plank of wood was not a good idea at all. The earthquake shook the roof [bush] and caused the rook to take off into the sky. Lee tried not to laugh at the queen [owner] who was wearing a queer hat at the event.

Overlap Type 3: O+P– (bear–gear)

On noticing the giant bear [tree] John changed gear and pedalled away quickly. The supervisor did allow [agree] keeping a fire aglow for much longer than we expected. The reporter thought that a city awash [laden] with drugs should abash the police department. The apprentice started to cough [relax] close to the dough which upset the baker. She had to use gloves [towels] whilst picking the cloves in case they ruined her clothes.
When Adam looked at his pint [fork] he noticed a tint of green on the side.
Rachel began to swear [curse] as the shear cut through her jeans and into her leg.
Lucy wanted to see the ballet [tennis] so she got her wallet and checked how much money she had left.
Gregory was wiping his brow [bike] when the crow lunged at him without provocation.
The hungry and unpredictable bull [cats] stared at the gull which was flying around.
Lynn looks at her daughter [teachers] whose joyful laughter fills the whole room.
Greg enjoys steaks [mutton] and always sneaks home with the best cuts from the butchers.
Eating outside, Bob yells at the wasps [teens] while he rasps the Italian cheese over the pasta.
After Ryan had eaten so many bowls [packs] of crisps his jowls started to hurt.
Laura took a break [glass] and gazed at the bleak surroundings of her office block.
Dan shouted as he fell into the bush [lake] and was told to hush by a passerby.
Wendy and her precious dolls [cargo] passed through some tolls on their way to Canada.
The fact that the art was gross [nasty] took away the gloss from the opening of the gallery.
The foreigner heard [wrote] that his beard had been causing a stir amongst the town folk.
The shark silently moves [turns] through the coves whilst searching for its next meal.
Mary needs to pick the pears [plums] before the sun sears them and they are ruined.
The careful burglar goes and pulls [shuts] the blinds which dulls the light in the room.
The pipe blockage was dislodged with a push [wire] causing water to gush out over the floor.
Bill loves watching doves [hawks] as he roves aimlessly through the countryside.
The archaeologist is in search of tombs [vases] as he combs through the ancient structures.
Sarah loved the soft touch [lines] of the pouch that was stitched on her winter jacket.
Because of the tough [dirty] terrain, dragging a bough from the oak tree was hard work.
When Fred wants [takes] something he rants so everyone knows what it is.
The very expensive watch [radio] was in a batch that they delivered yesterday.
On his farm Joe always wears [picks] boots as he rears a lot of animals and gets muddy.
Tony will use his words [hands] to show how the cords needed to be tied together.
There were a lot of worms [coats] in the dorms where the children were sleeping.
Believe it or not but the truth [issue] is that the booth was removed by Health and Safety.
The soldiers did some indoor [tiring] training for the prewar simulation that had been planned.
Mary had to wipe the grease [stains] off the fleece she was wearing.
Sarah claimed her pies were divine [stolen] and gave a benign kind of smile.
The police started to shoot [panic] after the brute was hit by several bullets.
Leo gave me his design [advice] for fake canine teeth that he wanted to bring on the market.
There was a nice suit [ring] in the burglarly loot that the men brought back.
I heard that the foreign male [king] needed to pay bail so he could be released.
I told Carl that I would salute [summon] him if he could uproot the sturdy tree on his own.
Ben threw the fruit [waste] down the chute because it was rotting and smelly.
Because Brad Pitt funds this cause [hotel] it naturally draws a lot of attention.
After he went inside to greet [scorn] Sue I heard a bleat from an animal just behind me.
The builder accidently hit the drain [ridge] with the crane and broke it.
The sculptures were not the right scale [style] causing Ed to flail his arms in anger.
Accusations of cheating in the game in the saloon [lounge] served to impugn the player’s honesty.
It was clear that the bull was not tame [numb] as it tried to maim the inexperienced matador.
The King walked into the hallway and spoke [shook] as he hung his cloak on the hook.
James must feel insane [shaken] if he does not attain a higher grade in the exam.
I’m afraid he will screw [tense] up and break the taboo of crying in public.
Kate folded the sheet [cloth] to give it the pleat that she wanted.
The sentimental woman cried [waves] after the bride threw her bouquet in the air.
The tourists listened as the guide [agent] began to chide the driver for taking a wrong turn.
It was Ben’s fate [luck] that caused his gait to increase as he had a surge of happiness.
I heard about the ridiculous claim [rules] which brought shame on his family for many years.
The parrot flew up from his perch [slump] as the cat made a lurch towards him.
Before they can equip [shred] the car we need to unzip the covers from the new loudspeakers.
The security men tried to ignore [defeat] the sudden uproar amongst the inmates.
Jenny loved the cake’s taste [shape] but her waist was a concern to her.
Jeff had a dish of soup [rice] and then shot a hoop or two with his friends.
Because of Jennifer’s sore elbow [wrist] lugging her cello to practice was a real ordeal.

Overlap Type 4: 0–P+ (smile–aisle)
Stimuli used in Experiment 2
The words in bold are the prime words with the control word between square brackets, the target words are in italics.

Version a = Short condition.
Version b = Long, 1-sentence condition.
Version c = Long, 2-sentence condition.

1
a The woman was walking down the trail [aisle] but she felt frail as she was very old. She turned eighty last week.
b The woman was walking down the trail [aisle] holding a red umbrella but she felt frail as she was very old. She turned eighty last week.
c The woman was walking down the trail [aisle] holding a red umbrella. But she felt frail as she was very old. She turned eighty last week.

2
a Playing poker Al won a grand [prize] and got a top brand car for himself. He then went to show his girlfriend.
b Playing poker Al won a grand [prize] so he went to the city and got a top brand car for himself. He then went to show his girlfriend.
c Playing poker Al won a grand [prize] so he went to the city. He got a top brand car for himself. He then went to show his girlfriend.

3
a The chicken that Jack wanted to pluck [seize] started to cluck when he advanced on it. He managed to grab it by the feet.
b The chicken that Jack wanted to pluck [seize] was in a bad mood and started to cluck when he advanced on it. He managed to grab it by the feet.
c The chicken that Jack wanted to pluck [seize] was in a bad mood. It started to cluck when he advanced on it. He managed to grab it by the feet.

4
a The lady on the bus was very plump [weary] and she sat in a slump next to John. John decided to move away a bit.
b The lady on the bus was very plump [weary] and seemed really tired as she sat in a slump next to John. John decided to move away a bit.
c The lady on the bus was very plump [weary] and seemed really tired. She sat in a slump next to John. John decided to move away a bit.

5
a Cleaning the ship's flank [ports] caused a clank as the anchor suddenly came loose. All of the sailors looked up in shock.
b Cleaning the ship's flank [ports] for the ship to set sail tomorrow caused a clank as the anchor suddenly came loose. All of the sailors looked up in shock.

6
a Laura needed a drink [sleep] as she was on the brink of near total exhaustion. She poured herself a large glass of water.
b Laura needed a drink [sleep] after her big sponsored run as she was on the brink of near total exhaustion. She poured herself a large glass of water.
c Laura needed a drink [sleep] after her big sponsored run. She was on the brink of near total exhaustion. She poured herself a large glass of water.

7
a When Lee proposed, he stroked Sue's cheek [wrist] and a cheer arose from their families. Sue then showed off her engagement ring.
b When Lee proposed, he stroked Sue's cheek [wrist] as he slid the ring on and a cheer arose from their families. Sue then showed off her engagement ring.
c When Lee proposed, he stroked Sue's cheek [wrist] as he slid the ring on. And a cheer arose from their families. Sue then showed off her engagement ring.

8
a Ben bumped his knee on the stool [ledge] and then had to stoop to stem the pain. His mother had to phone the doctor.
b Ben bumped his knee on the stool [ledge] which was beside of him and then had to stoop to stem the pain. His mother had to phone the doctor.
c Ben bumped his knee on the stool [ledge] which was beside of him. He then had to stoop to stem the pain. His mother had to phone the doctor.

9
a Sarah searched the market [houses] for a permanent marker to use in her office. It took her a long time to get to work.
b Sarah searched the market [houses] just up the street from me for a permanent marker to use in her office. It took her a long time to get to work.
c Sarah searched the market [houses] just up the street. She wanted a permanent marker to use in her office. It took her a long time to get to work.

10
a The knight received a slap [coin] for his attempt to slay those two friendly dragons. The queen told him to leave the city.
b The knight received a slap [coin] from the rest of his friends for his attempt to slay those two

(continued on next page)
friendly dragons. The queen told him to leave the city.

c  The knight received a slap [coin] from his friends. This was due to his attempt to slay those two friendly dragons. The queen told him to leave the city.

11

a  The birds ruffled their wings [tails] as the kings and the queens watched from their palace. The fair-haired princes stroll past.

b  The birds ruffled their wings [tails] elegantly while sitting on the balcony as the kings and the queens watched from their palace. The fair-haired princes stroll past.

c  The birds ruffled their wings [tails] elegantly. They sat on the balcony as the kings and the queens watched from their palace. The fair-haired princes stroll past.

12

a  Rob watched the brush [shelf] fall and crush the spider against the wall. It left a dirty mark.

b  Rob watched the brush [shelf] fall at a rapid speed onto the floor and crush the spider against the wall. It left a dirty mark.

c  Rob watched the brush [shelf] fall at a rapid speed onto the floor. Then crush the spider against the wall. It left a dirty mark.

13

a  Lyn’s hand moved in a circular motion [manner] to apply some lotion onto her skin. She then went off to her lecture.

b  Lyn’s hand moved in a circular motion [manner] while lying on her bed to apply some lotion onto her skin. She then went off to her lecture.

c  Lyn’s hand moved in a circular motion [manner] while lying down. She applied some lotion onto her skin. She then went off to her lecture.

14

a  Graham was running on the track [roads] and saw a crack that hadn’t been there yesterday. He decided to tell the council.

b  Graham was running on the track [roads] next to his old high school and saw a crack that hadn’t been there yesterday. He decided to tell the council.

c  Graham was running on the track [roads] next to his old high school. He saw a crack that hadn’t been there yesterday. He decided to tell the council.

15

a  The boy went down the slide [shaft] in order to glide down towards the floor. He hit the floor and ran to the swings.

b  The boy went down the slide [shaft] in the local playground as he wanted to glide down towards the floor. He hit the floor and ran to the swings.

c  The boy went down the slide [shaft] in the local playground. He wanted to glide down towards the floor. He hit the floor and ran to the swings.

16

The wolf continued to blink [growl] as it began to slink away into the darkness. All that you could see were its glowing eyes.

The wolf continued to blink [growl] when he smelled the rabbits and it began to slink away into the darkness. All that you could see were its glowing eyes.

The wolf continued to blink [growl] when he smelled the rabbits. It then began to slink away into the darkness. All that you could see were its glowing eyes.

17

a  Elsa said it was sweet [crazy] to see the girl sweep the floor on weekends. She decided to give the girl a chocolate for doing it.

b  Elsa said it was sweet [crazy] to see the girl who works in the clothes shop sweep the floor on weekends. She decided to give the girl a chocolate for doing it.

c  Elsa said it was sweet [crazy] to see the girl. They both work in the shop and sweep the floor on weekends. She decided to give the girl a chocolate for doing it.

18

a  Rick looked in the chest [rooms] for a book about chess which he needed to study. He had an important tournament coming up.

b  Rick looked in the chest [rooms] in his old countryside manor for a book about chess which he needed to study. He had an important tournament coming up.

c  Rick looked in the chest [rooms] in his manor. He was looking for a book about chess which he needed to study. He had an important tournament coming up.

19

a  Kate tried to use the spoon [blade] instead of a spool in order to wind thread. She wanted to make her mother a present.

b  Kate tried to use the spoon [blade] that she took from the counter instead of a spool in order to wind thread. She wanted to make her mother a present.

c  Kate tried to use the spoon [blade] that she found. She used that instead of a spool in order to wind thread. She wanted to make her mother a present.

20

a  The terrible storm [turns] made the stork lose touch with its flock. It flew on its own for many miles.

b  The terrible storm [turns] and heavy rain caused
utter confusion which made the stork lose touch with its flock. It flew on its own for many miles.
c The terrible storm [turns] and heavy rain caused utter confusion. This made the stork lose touch with its flock. It flew on its own for many miles.

21  
a Ian admitted that the flash [burst] of light and clash of the thunder scared him. The dogs all started to howl in fear.
b Ian admitted that the flash [burst] of light that suddenly appeared and the clash of the thunder scared him. The dogs all started to howl in fear.
c Ian admitted that the flash [burst] of light suddenly appeared. As always the clash of the thunder scared him. The dogs all started to howl in fear.

22  
a Tina read the card [page] on the back of the lard to check the nutritional content. She found out that it was very high in fat.
b Tina read the card [page] that she had found stuck on the back of the lard to check the nutritional content. She found out that it was very high in fat.
c Tina read the card [page] that she found. It was stuck on the back of the lard to check the nutritional content. She found out that it was very high in fat.

23  
a Joe was extremely drunk [silly] and fell over the trunk his mother had left in the hall. She was very angry the next day.
b Joe was extremely drunk [silly] after a night out and fell straight over the trunk his mother had left in the hall. She was very angry the next day.
c Joe was extremely drunk [silly] after a night out. Once home he fell over the trunk his mother had left in the hall. She was very angry the next day.

24  
a The commander of the fleet [craft] didn’t like the sleet that was now disrupting communications. He couldn’t hear what the captain was saying.
b The commander of the fleet [craft] didn’t like the heavy snow and the dreadful sleet that was now disrupting communications. He couldn’t hear what the captain was saying.
c The commander of the fleet [craft] didn’t like the heavy snow. And the dreadful sleet was now disrupting communications. He couldn’t hear what the captain was saying.

25  
a Nobody knew who to blame [phone] as the flame climbed higher up the wall. They all looked on in fear.
b Nobody knew who to blame [phone] for the fire at the town hall as the huge flame climbed higher up the wall. They all looked on in fear.
c Nobody knew who to blame [phone] for the fire. Everyone watched as the huge flame climbed higher up the wall. They all looked on in fear.

26  
a John picked up the object and threw [flung] it at the shrew to make it run away. He missed by a few inches.
b John picked up the object and threw [flung] it across the large garden at the shrew to make it run away. He missed by a few inches.
c John picked up the object and threw [flung] it across the large garden. The shrew got scared and ran away. He missed by a few inches.

27  
a The boy gave a wink [mint] to the girl on the rink because he liked her. She turned and skated over his toes.
b The boy gave a wink [mint] to the very tall and slim blonde girl on the ice rink because he liked her. She turned and skated over his toes.
c The boy gave a wink [mint] to the very tall blonde girl. She was at the ice rink because she liked skating. She turned and skated over his toes.

28  
a The hunter had set up a spare [dirty] trap to snare the animal that he had been tracking. The animal was too clever and outwitted him.
b The hunter had set up a spare [dirty] trap in the dense woods in order to snare the animal that he had been tracking. The animal was too clever and outwitted him.
c The hunter had set up a spare [dirty] trap in the dense woods. He wanted to snare the animal that he had been tracking. The animal was too clever and outwitted him.

29  
a The deck was large [level] on the barge allowing extra of room for the crates. They made the boat wobble to and fro.
b The deck was large [level] and spacious and only recently been fitted on the barge allowing extra of room for the crates. They made the boat wobble to and fro.
c The deck was large [level] and spacious. It had recently been fitted on the barge allowing extra of room for the crates. They made the boat wobble to and fro.

30  
a The shortage of bread [sugar] caused real dread in the village due to the rationing. Everyone had to cut down a bit.
b The shortage of bread [sugar] in the country during the crisis caused real dread in the village due to rationing. Everyone had to cut down a bit.
c The shortage of bread [sugar] in the country was (continued on next page)
awful. It caused real dread in the village due to rationing. Everyone had to cut down a bit.

31
a He vacationed by the shore [ocean] but remembered the chore he still had to complete. However he decided to leave it until tomorrow.
b He vacationed by the shore [ocean] close to the tiny island but remembered the chore he still had to complete. However he decided to leave it until tomorrow.
c He vacationed by the shore [ocean] close to the tiny island. He remembered the chore he still had to complete. However he decided to leave it until tomorrow.

32
a The poor old whale [goose] was hit by shale that fell off an overhanging cliff. Somebody saw and decided to call a vet.
b The poor old whale [goose] which liked to swim in the water was hit by shale that fell off an overhanging cliff. Somebody saw and decided to call a vet.
c The poor old whale [goose] liked to swim in the water. Sadly it was hit by shale that fell off an overhanging cliff. Somebody saw and decided to call a vet.

33
a Leo acted like he was waking [firing] up but he was faking it since he was still very tired. He’d had a very late night.
b Leo acted like he was waking [firing] up and getting ready for work but he was faking it since he was still very tired. He’d had a very late night.
c Leo acted like he was waking [firing] up and getting ready for work. But he was faking it since he was still very tired. He’d had a very late night.

34
a Lucy felt sick [wild] but still put a tick on her blue attendance sheet for the day. She wanted to try and impress her boss.
b Lucy felt sick [wild] from all the white chocolate she ate but she still put a tick on her blue attendance sheet for the day. She wanted to try and impress her boss.
c Lucy felt sick [wild] from all the white chocolate she ate. But she still put a tick on her blue attendance sheet for the day. She wanted to try and impress her boss.

35
a Last Saturday Dan had a dream [laugh] about a bream swimming in the sea. He’d been fishing the day before.
b Last Saturday Dan had a dream [laugh] when he was lying down. It was about a bream swimming in the sea. He’d been fishing the day before.
c Last Saturday Dan had a dream [laugh] when he was lying down. It was about a bream swimming in the sea. He’d been fishing the day before.

36
a Lily hoped for a quiet payday [brunch] but a mayday came over the system. She was a bit annoyed but tried to stay calm.
b Lily hoped for a quiet payday [brunch] so she could go and relax a bit but a mayday came over the system. She was a bit annoyed but tried to stay calm.
c Lily hoped for a quiet payday [brunch] so she could relax a bit. However a mayday came over the system. She was a bit annoyed but tried to stay calm.

37
a Ed had managed to retain [locate] the documents to detain these two criminals in custody. He was very proud of himself.
b Ed had managed to retain [locate] the important signed documents in order to detain these two criminals in custody. He was very proud of himself.
c Ed had managed to retain [locate] the important signed documents. He was to detain these two criminals in custody. He was very proud of himself.

38
a The pipes began to swell [shake] and I started to dwell on the big impending problem. I wrote a list of all the things that were wrong.
b The pipes began to swell [shake] due to the amount of water and we started to dwell on the big impending problem. I wrote a list of all the things that were wrong.
c The pipes began to swell [shake] due to the amount of water in them. I began to dwell on the big impending problem. I wrote a list of all the things that were wrong.

39
a Andrew found it a strain [burden] to negotiate the strait at the end of a long voyage. He felt like he just wanted to sleep.
b Andrew found it a strain [burden] to negotiate the very challenging and winding strait at the end of a long voyage. He felt like he just wanted to sleep.
c Andrew found it a strain [burden] to negotiate the boat. He came to the winding strait at the end of a long voyage. He felt like he just wanted to sleep.

40
a An admission of guilt [shame] to the guild meant that he would face punishment. He soon regretted his bad behavior.
b An admission of guilt [shame] about the crime that was committed today at the guild meant he
would face punishment. He soon regretted his bad behavior.

c An admission of guilt was felt by John. The crime he committed at the guild meant he would face punishment. He soon regretted his bad behavior.

41

a Ed knew the item was cheap and had to cheat to make sure he won the bid. He had wanted the item for a long time.
b Ed knew the item was cheap yet he still couldn’t afford it and had to cheat to make sure he won the bid. He had wanted the item for a long time.
c Ed knew the item was cheap yet he still couldn’t afford it. He had to cheat to make sure he won the bid. He had wanted the item for a long time.

42

a A good supply of grain was the holy grail for the farmer following the poor harvest. The rest of the village were also thankful.
b A good supply of grain for the harsh winter season was the holy grail for the farmer following the poor harvest. The rest of the village were also thankful.
c A good supply of grain for the winter was vital. It was the holy grail for the farmer following the poor harvest. The rest of the village were also thankful.

43

a He walked back to the tower to get his towel as he had forgotten it again. On the way back a fox ran past him.
b He walked back to the tower of the castle during his day out to get his towel as he had forgotten it again. On the way back a fox ran past him.
c He walked back to the tower of the imposing castle. He wanted to get his towel as he had forgotten it again. On the way back a fox ran past him.

44

a Malcolm used a steel bar to steer the broken bicycle. He had to get back to his friend’s house.
b Malcolm used a steel bar which he had found in a dirty skip to steer the broken bicycle. He had to get back to his friend’s house.
c Malcolm used a steel bar which he had found. He used it to steer the broken bicycle. He had to get back to his friend’s house.

45

a The inexperienced scout helped to scour the very wet countryside for the lost dog. After a while there was a heavy downpour.
b The inexperienced scout who had just finished a nice lunch helped to scour the very wet countryside for the lost dog. After a while there was a heavy downpour.
c The inexperienced scout had just finished a nice lunch. He helped to scour the very wet countryside for his lost dog. After a while there was a heavy downpour.

46

a The students had a late start and showed a stark contrast in talent. They couldn’t wait to finish school for the day.
b The students had a late start at the community school and showed a stark contrast in talent. They couldn’t wait to finish school for the day.
c The students had a late start at the community school. They showed a stark contrast in talent. They couldn’t wait to finish school for the day.

47

a The larder where I keep the cream opens with a creak as it is rarely used. I needed the ingredients to make a dessert.
b The larder where I keep the cream contains a lot of foods and opens with a creak as it is rarely used. I needed the ingredients to make a dessert.
c The larder where I keep the cream contains a lot of foods. It opens with a creak as it is rarely used. I needed the ingredients to make a dessert.

48

a Tom designed the advert using the adverb his clients had requested. The owner of the company really liked the design.
b Tom designed the advert for a new Ferrari and made sure to use the adverb his clients had requested. The owner of the company really liked the design.
c Tom designed the advert for a new Ferrari. He made sure to use the adverb that his clients had requested. The owner of the company really liked the design.

49

a Everything became blank after the bland meal which had been served for dinner. Despite that everyone had a nice evening.
b Everything became blank and we all started to complain after the bland meal which had been served for dinner. Despite that everyone had a nice evening.
c Everything became blank and we started to complain. We hated the bland meal which had been served for dinner. Despite that everyone had a nice evening.

(continued on next page)
Paul rested by the stream [border] and saw a streak of light flash through the sky. This was followed by a clap of thunder.

The morning’s thin sheet [cover] of snow left a sheen to the new pavement that brightened the day. It then began to feel like Christmas.

Ella attempted to balance the plant [block] on a plank of wood but this was not a good idea at all. The wood turned out to be rotten.

The earthquake shook the roof [bush] and caused the rook to take off into the sky. The ground then shook vigorously.

Due to the earthquake, the wood turned out to be rotten.
into the sky. The ground then shook vigorously. The earthquake shook the roof [bush] because it was so forceful. It caused the rook to take off into the sky. The ground then shook vigorously.

60

a Lee didn’t laugh at the queen [owner] who was just arrived by car wearing a queer hat for the event. The event was to raise money for a good cause.
b Lee didn’t laugh at the queen [owner] who had just arrived. She was wearing a queer hat for the event. The event was to raise money for a good cause.

c Lee didn’t laugh at the queen [owner] who had just arrived by car wearing a queer hat for the event. The event was to raise money for a good cause.

Appendix B

See Tables B1 and B2.

Table B1

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<td>No significant improvement ($p &gt; .36$)</td>
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(continued on next page)
### Table B1 (continued)

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</table>

#### Priming effect in individual sets

- **O+P+(end)**
  - (intercept): $\chi^2(1) = 8.17, p < .01$
  - Prime: $2(1) = 8.17, p < .01$
- **O+P+(begin)**
  - (intercept): $\chi^2(1) = 4.62, p < .05$
- **O+P−**
  - (intercept): No significant improvement ($p > .78$)
- **O−P+**
  - (intercept): No significant improvement ($p > .82$)

#### Total time

- **Prime**
  - No significant improvement ($p > .38$)
- **Set**
  - No significant improvement ($p > .43$)
- **Interaction**
  - No significant improvement ($p > .35$)

#### Notes.

Set refers to the different overlap sets: Set 1 = O+P+(end), Set 2 = O+P+(begin), Set 3 = O+P−, Set 4 = O−P+. The values from the linear mixed-effect comparisons are t-values, those from the generalized mixed-effect comparisons (for the regression data) are Wald z-values. A t/z value > 2.0 is considered significant.

### Table B2

Linear and generalized linear mixed-effects analyses of Experiment 2.

<table>
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<th>t/z</th>
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<tbody>
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</table>

#### Single fixation duration

- **Prime**
  - No significant improvement ($p > .84$)
- **Interaction**
  - $\chi^2(2) = 6.04, p < .05$

#### Priming effect in individual conditions

- **Short**
  - (intercept): $\chi^2(1) = 3.76, p = .053$
  - Prime: $2(1) = 2.70, p = .10$
- **Long**
  - No significant improvement ($p > .60$)

#### First fixation duration

- **Prime**
  - No significant improvement ($p > .27$)
- **Interaction**
  - $\chi^2(2) = 6.37, p < .05$

#### Priming effect in individual conditions

- **Short**
  - (intercept): $\chi^2(1) = 6.40, p < .05$
  - Prime: $2(1) = 3.85, p < .05$
- **Long**
  - No significant improvement ($p > .60$)

#### Notes.

The values from the linear mixed-effect comparisons are t-values, those from the generalized mixed-effect comparisons (for the regression data) are Wald z-values. A t/z value > 2.0 is considered significant.
### Table B2 (continued)

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<tr>
<td>(intercept)</td>
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<tr>
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Notes: Short, Long-1, and Long-2 refers to the distance between the prime and the target word: Short distance (in the same sentence), Long-1: longer distance with the prime and target in the same sentence, Long-2: longer distance with the prime and target in separate sentences. The values from the linear mixed-effect comparisons are t-values, those from the generalized mixed-effect comparisons (for the regression data) are Wald z-values. A t/z value > 2.0 is considered significant.

### References


Weingartner, K. M., Juhasz, B. J., & Rayner, K. (2012). Lexical embeddings produce interference when they are morphologically unrelated to the words in which they are contained: Evidence from eye movements. Journal of Cognitive Psychology (Hove), 24, 179–188.


