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Eye Movements and the Use of Parafoveal Word Length Information in Reading

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Abstract

Eye movements were monitored in 4 experiments that explored the role of parafoveal word length in reading. The experiments employed a type of compound word where the deletion of a letter results in 2 short words (e.g., *backhand*, *back and*). The boundary technique (K. Rayner, 1975) was employed to manipulate word length information in the parafovea. Accuracy of the parafoveal word length preview significantly affected landing positions and fixation durations. This disruption was larger for 2-word targets, but the results demonstrated that this interaction was not due to the morphological status of the target words. Manipulation of sentence context also demonstrated that parafoveal word length information can be used in combination with sentence context to narrow down lexical candidates. The 4 experiments converge in demonstrating that an important role of parafoveal word length information is to direct the eyes to the center of the parafoveal word.

Keywords

eye movements; reading; parafoveal length information

In modern alphabetic writing systems, blank spaces segment strings of letters into meaningful units (words) that contribute to the efficiency of reading. When spaces are deleted or masked, reading is significantly slowed (Epelboim, Booth, & Steinman, 1994; Fisher, 1976; Malt & Seamon, 1978; McConkie & Rayner, 1975; Morris, Rayner, & Pollatsek, 1990; Pollatsek & Rayner, 1982; Rayner, Fischer, & Pollatsek, 1998; Spragins, Lefton, & Fisher, 1976). There are three reasons why interword spaces facilitate reading. First, blank spaces reduce lateral masking of the beginning and ending letters of words (Bouma, 1973) making them easier to see. Second, interword spaces specify the length of upcoming words and provide effective targets for eye movements (Rayner, 1979). Third, word length may be used to constrain the number of possible word candidates. The present article explores the relative importance of these different factors.

There are, of course, writing systems, such as Chinese and Thai, which do not contain interword spacing in which readers still read effectively. However, research on Thai (Kohsom & Gobet, 1997) indicated that inserting spaces between words actually increases the reading rate in that language, and research on Chinese (Bai, Yan, Liversedge, Zang, & Rayner, in press) indicated that inserting spaces between characters interfered with reading, whereas inserting spaces between words did not (see also Sainio, Hyönä, Bingushi, & Bertram, 2007, for research on spacing in Japanese). Also, work with German three-lexeme compound words has shown that inserting spaces between the lexemes actually reduces overall reading time on the compounds (Inhoff, Radach, & Heller, 2000), even though it is orthographically illegal to do so.

To better understand why interword spaces are beneficial to reading, it is important to consider characteristics of the visual system. In reading, a line of text can be divided into three regions: the foveal, parafoveal, and peripheral regions. The foveal region comprises the area 1° on each side of the current fixation point (usually 6–8 letters). In the fovea, visual acuity is greatest and letters can be easily identified. Visual acuity drops off markedly outside of the fovea, and letters are hard to identify (Balota & Rayner, 1991). McConkie and Rayner (1975, 1976) showed that the perceptual span, the region from which information can be obtained during a single fixation, extends roughly 15 characters to the right of fixation, but only 3–4 letters to the left of fixation when reading English (see also Rayner & Bertera, 1979; Rayner, Well, & Pollatsek, 1980). The word identification span is smaller than the overall perceptual span, usually only extending 8 characters to the right of fixation (Rayner, Well, Pollatsek, & Bertera, 1982).

Research using the boundary technique (Rayner, 1975) has identified different types of information that are integrated across eye movements and which serve as the basis for the preview benefit effect (i.e., readers spend less time fixating on a word when they have a preview of the word than when they do not). In the boundary technique, readers' eyes are monitored and an invisible boundary is specified in the sentence. Prior to fixating this target word, a preview of the word is given that is replaced by the target when the reader's eyes cross over the boundary. This change occurs during an eye movement (saccade) when vision is suppressed. Research using this technique has demonstrated that information about the first few letters of the parafoveal word (Rayner, 1975; Rayner, McConkie, & Zola, 1980) is critically important for preview benefit, though readers do get some benefit from other letters in the word (Inhoff, 1990; Johnson, Perea, & Rayner, 2007). Information about the phonology of the parafoveal word (Ashby, Treiman, Kessler, & Rayner, 2006; Chace, Rayner, & Well, 2005; Henderson, Dixon, Peterson, Twilley, & Ferreira, 1995; Pollatsek, Lesch, Morris, & Rayner, 1992) also yields preview benefit. Finally, several studies have found that semantic information¹ (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Hyönä & Häikiö, 2005; Rayner, Balota, & Pollatsek, 1986) and morphological information² (Kambe, 2004; Lima, 1987) are not the basis of the preview benefit effect.

The boundary technique can also be used to assess how spacing information is used within the perceptual span. As noted above, interword spaces may make reading efficient because they specify the length of the upcoming word in the parafovea (Inhoff, Radach, Eiter, & Juhasz, 2003; Inhoff, Starr, Liu, & Wang, 1998; White, Rayner, & Liversedge, 2005). To demonstrate this, Inhoff et al. (1998) provided participants with either a correct length preview (e.g., *prinsvirp*) of an upcoming target word (e.g., *movement*) in the parafovea, or an incorrect length preview (e.g., *prin virp*). Reading times on the target word were longer when a length incorrect

¹This is not to say that the word to the right of fixation is not ever identified; word $n + 1$ can often be identified while still fixated on word n , particularly when it is a short word or a highly predictable word (see Rayner, 1998) for a review. In such cases, word $n + 1$ is typically skipped. A more contentious issue is whether or not word $n + 1$ influences processing time on word n (see Rayner & Juhasz, 2004), but that issue is not relevant for the present experiments.

²Interestingly, in Hebrew there is evidence that morphological information does serve to provide preview benefit (see Deutsch, Frost, Peleg, Pollatsek, & Rayner, 2003; Deutsch, Frost, Pollatsek, & Rayner, 2000, 2005).

parafoveal preview was provided. This length preview effect was subsequently replicated by Inhoff, Radach, Eiter, and Juhasz (2003) and White et al. (2005). Thus, interword spaces provide information about an upcoming word's length in the parafovea. One reason why this may be the case has to do with where the eyes typically land in words (the *landing position*). Rayner (1979) demonstrated that readers' eyes typically land halfway between the middle of a word and the beginning of that word (the *preferred viewing location*). Research suggests that readers attempt to target the center of words but often fall short (McConkie, Kerr, Reddix, & Zola 1988; Rayner, 1979). When readers' eyes land at a nonoptimal position in a word, they are more likely to refixate that word (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; O'Regan, 1990; Rayner, Sereno, & Raney, 1996). Thus, by providing readers with an incorrect length preview of an upcoming word in the parafovea, they launch their eyes to what will turn out to be a nonoptimal position in the parafoveal word. This will then increase reading time on the word once fixated.

Clark and O'Regan (1999; see also Haber & Haber, 1983; O'Regan, 1979) argued for an alternative way that parafoveal word length information is used in reading. They suggested that information about a parafoveal word's letters in combination with its length can be used to constrain the possible lexical candidates for that word before it is fixated. Inhoff, Radach, Eiter, and Juhasz (2003) referred to this possibility as the *length constraint hypothesis*, which they specifically tested in two experiments. In the first experiment, participants read sentences containing a critical target word of 5–10 letters (e.g., *subject*). Prior to fixating the target word either a correct or incorrect length preview was provided. In addition, either a (mostly) correct orthographic preview was provided, or else random letters were provided in the preview. This resulted in four preview conditions (*subtect*, *sub ect*, *mivtirp*, *miv irp*). According to the length constraint hypothesis, an accurate length preview should be more beneficial when the target word's letters are also available in the parafovea, as this should allow the reader to narrow down the possible lexical candidates for the target word prior to its fixation. Contrary to this hypothesis, Inhoff, Radach, Eiter, and Juhasz (2003) found that the effects of accuracy of the length preview and availability of orthographic information were completely additive. In the second experiment, the frequency of the target words was also manipulated. There was no interaction between frequency of the target words and accuracy of the parafoveal length preview. Thus, neither experiment supported the length constraint hypothesis.

The results of Inhoff, Radach, Eiter, and Juhasz (2003) can be contrasted with those of White et al. (2005). Unlike Inhoff, Radach, Eiter, and Juhasz (2003), White et al. (2005) used target words that were all four letters (e.g., *rose* or *bomb*) and the inaccurate length preview was created by adding an *s* between the target and posttarget word (e.g., *bombsunder*, *rosesunder*). In addition, the target word was either predictable from the beginning sentence context, or else was not predictable. In fixation times, there were main effects of both predictability and accuracy of the length preview. However, these two factors interacted such that the predictability effect was only significant when the length preview was accurate (however, see Drieghe, Brysbaert, Desmet, & De Baecke, 2004).

Thus, a discrepancy currently exists as to whether the length of a parafoveal word can be used to narrow down the set of potential lexical candidates. Inhoff, Radach, Eiter, and Juhasz (2003) failed to find any evidence for the length constraint hypothesis, while White et al. (2005) found an interaction between accuracy of parafoveal length information and sentence predictability, suggesting that both sources of information were used in combination to narrow down the set of lexical candidates for the parafoveal word. However, there were many differences between the studies that make direct comparison between them difficult. The purpose of the present experiments was to further explore the role of parafoveal word length information in reading. Does parafoveal word length simply act as a cue for the eye movement system to target an upcoming word at an optimal position? Or can parafoveal length

information be used in some circumstances to constrain lexical candidates? The results of Inhoff, Radach, Eiter, and Juhasz (2003) and White et al. (2005) also raise the possibility that there may be differences in the use of parafoveal length information for long and short words (see also Kennedy, Pynte, & Ducrot, 2002). To answer these questions, we utilized a particular type of compound word in which the deletion of the first letter of the second lexeme results in two short words (e.g., *backhand*, *back and*). In this way, we were able to manipulate the length accuracy of a parafoveal word and combine the two manipulations of Inhoff, Radach, Eiter, and Juhasz (2003; deletion of a letter) and White et al. (2005; insertion of a letter) into a single experiment.

Experiment 1

In Experiment 1, readers were presented with sentences that either contained a target compound word (e.g., *backhand*) or two short words (e.g., *back and*). Target word length was either correctly or incorrectly specified in the parafovea.

Method

Participants—Thirty-two University of Massachusetts community members participated in the experiment. They received extra course credit or were paid \$8 per hour. All were native speakers of American English with normal vision or soft contacts.

Apparatus—A Generation V Dual-Purkinje Eye-Tracking System (Fourward Technologies) was used to record eye movements. This eye-tracker samples eye position every millisecond and has a resolution of less than 10 min of arc. Eye movements were recorded from the right eye, though viewing was binocular. The eye-tracker was interfaced with a PC. The sentences were displayed on a 15-in. (38.1-cm) NEC MultiSync 4FG monitor, which was set at a distance of 61 cm away from the participant. At this distance, 3.8 characters equaled 1 degree of visual angle.

Procedure—Participants were provided with written instructions, and a bite bar and headrests were used to stabilize participants' heads during the experiment. Prior to the experiment, the eye-tracker was aligned and calibrated on a single line by presenting nine boxes that participants were instructed to fixate. This took approximately 5 min and was followed by five practice sentences. After each sentence the experimenter checked the accuracy of the calibration, and if necessary recalibrated. Comprehension questions were asked after 25% of the sentences by visually presenting a question and two possible choices. Participants pressed one of two buttons to indicate the answer. The average accuracy was over 94%.

Materials—Forty compound words were selected as the long word targets. In these 40 compounds, the deletion of the first letter of the second lexeme resulted in two short words (e.g., *backhand/back and*; *baseball/base all*). These two short words served as the two-word condition. In the following, the two types of items will be referred to as the *compound word* and *two-word* conditions, respectively. Compound words ranged from 6 to 10 characters with an average of 8.3 characters. The first lexeme in the compounds ranged in length from 2 to 6 characters with an average of 4.23. For a given pair of targets, a neutral sentence was written that was the same up until the target but then formed a meaningful completion. The sentences were all presented on a single line containing less than 80 characters. Participants read 40 experimental sentences (see Appendix A) and 97 filler sentences. Figure 1 provides an example.

Two ratings on sentence context were conducted. In the first rating, 17 participants (none of whom took part in the eye movement experiment) were given the beginning of the sentence and were asked to provide a word that could fit as the next word. Responses were scored based

on whether the compound word or the first word of the two-word target was written down by the participants. Predictability was very low overall and did not differ for compound word targets and two-word targets (.97% vs. 1.09%, respectively; $t < 1$). An additional 20 participants were presented with the beginning of the sentence up through the compound word or the first word of the two-word target and were asked to rate how plausible the sentence beginning was on a 7-point scale (with higher numbers indicating a greater degree of plausibility). Sentence pairs were split into two lists, so that each participant only viewed one version of a pair. Overall, plausibility was quite high and did not significantly differ as a function of type of target (5.58 for compound word targets vs. 5.80 for the first word of the two-word targets; $p > .2$).

The boundary technique (Rayner, 1975) was used to manipulate parafoveal preview. An invisible boundary was set immediately after the pretarget word. Prior to fixating a compound word (e.g., *backhand*), either a correct length preview was given in the parafovea that consisted of the word itself (*backhand*) or an incorrect length preview was given that consisted of the two-word target from the item pair (*back and*). Prior to fixating a two-word target (*back and*), either a correct preview was provided consisting of the two words themselves (*back and*) or an incorrect length preview was provided consisting of the paired compound word (*backhand*).

Design and data analysis—A 2 (target type) $\times 2$ (parafoveal preview) counterbalanced design was used so that each participant viewed an equal number of sentences in each condition but only read one sentence for each paired item. Data were analyzed through repeated measures analyses of variance (ANOVAs) on both participants' means (F_1) and items' means (F_2).

Results

Trials were excluded from analysis if there was a track loss or blink in the pretarget, target, or posttarget regions or if the display change did not occur at the appropriate time. This resulted in approximately 15% of the trials being removed. In addition, in this and subsequent experiments, fixations that fell on adjacent characters and were very short (80 ms or less) were pooled into a single fixation. Nonadjacent short fixations (100 ms or less) and very long fixations (over 1000 ms) were eliminated by the analysis software.

Data were analyzed using two different definitions of the target region. In the first set of analyses, the target region was defined as either the entire compound word or the entire two-word target. In the second set of analyses, the target region was defined as either the first lexeme of the compound word or the first word of the two-word target. Thus, the actual target was the same for a given pair of items (e.g., *back* for both *backhand* and *back and*), with the only difference being whether it was part of a compound word or a word by itself. In all cases, the space before the target region was included with the target.

A number of dependent measures were computed in order to investigate the time course of processing. These measures include first fixation duration (the duration of the first fixation on the target region irrespective of number of fixations), the initial fixation location, and first-pass reading time on the target region (the sum of all fixations on the target region prior to the reader moving his/her eyes off of the target region; this is referred to as *gaze duration* when the target region consists of a single word) and total fixation duration (the sum of all the fixations on the target region, including regressions). Although total fixation duration is in the tables below for completeness, we will not discuss this measure further since it is not critical to the issues at hand. For the analyses on the first lexeme, we computed first fixation duration, gaze duration, and the probability of fixating the first lexeme.

Entire Target Region Analyses

The means and standard deviations for analyses using the entire target region are presented in Table 1.

First fixation duration—When the correct length preview of the target was provided in the parafovea, fixation durations were 13 ms shorter on average than when an incorrect preview was provided, $F_1(1, 31) = 6.34$, $MSE = 887$, $p = .017$; $F_2(1, 39) = 6.29$, $MSE = 1,282$, $p = .016$. This main effect was qualified by a significant interaction between type of target and the accuracy of the parafoveal length preview, $F_1(1, 31) = 6.94$, $MSE = 675$, $p = .013$; $F_2(1, 39) = 4.57$, $MSE = 1,394$, $p = .039$. While there was no effect of the accuracy of the parafoveal length preview for the compound target (1 ms; both t s < 1), there was a large effect for the two-word target region (27 ms), $t_1(31) = -3.12$, $p = .004$; $t_2(39) = -2.96$, $p = .005$.

Landing position—For initial landing position, there was a significant crossover interaction between type of target and the accuracy of the parafoveal length preview, $F_1(1, 31) = 12.50$, $MSE = 0.581$, $p = .001$; $F_2(1, 39) = 20.33$, $MSE = 0.345$, $p < .001$. Readers' eyes landed further into the target region if they were provided with a parafoveal preview of a long word (the compound word) as opposed to a short word, $t_1(31) = 3.54$, $p = .001$; $t_2(39) = 4.51$, $p < .001$.³

First-pass reading time—First-pass time was 36 ms shorter for a correct length preview than an incorrect preview, $F_1(1, 31) = 16.64$, $MSE = 2,541$, $p < .001$; $F_2(1, 39) = 18.01$, $MSE = 2,619$, $p < .001$. Unlike first fixation duration, there was no interaction; the size of the effect was the same for compound words and two-word targets. There was also a main effect of target type. Compound word targets received 24-ms shorter first-pass times on average compared to two-word targets, $F_1(1, 31) = 6.33$, $MSE = 2,951$, $p = .017$; $F_2(1, 39) = 4.64$, $MSE = 6,829$, $p = .038$.

First Lexeme Analyses

For the next set of analyses, only fixations on the first lexeme of the compound word and the first word of the two-word target were included in the analyses. In this way, the target region was identical for the compound and the two-word condition. The means and standard deviations are presented in Table 2

First fixation duration—Similar to the data for the entire target region, there was a main effect of accuracy of the parafoveal length preview on the first lexeme. First fixations were 13 ms shorter when a correct length preview was provided in the parafovea than when an incorrect length preview was provided, $F_1(1, 31) = 4.29$, $MSE = 1,221$, $p = .047$; $F_2(1, 39) = 5.68$, $MSE = 2,097$, $p = .022$. There was also a significant interaction between target type and accuracy of the parafoveal length preview, $F_1(1, 31) = 10.16$, $MSE = 1,146$, $p = .003$; $F_2(1, 39) = 7.14$, $MSE = 1,762$, $p = .011$. The nature of the interaction was also the same as for the first set of analyses. There was no correctness effect for compound targets (-7 ms; t s < 1) while there was a strong effect for two-word targets (32 ms), $t_1(31) = 4.31$, $p < .001$; $t_2(39) = 3.48$, $p = .001$.

Gaze duration—The pattern of data in the gaze durations on the first lexeme mirrored the first fixation measure, although the 15-ms main effect of accuracy of the parafoveal preview was not significant by participants, $F_1(1, 31) = 3.57$, $MSE = 1,979$, $p = .068$; $F_2(1, 39) = 5.89$, $MSE = 2,509$, $p = .02$. Also, while there was still a much larger effect for the accuracy of the

³The position from which the saccade was initiated (launch site) was also analyzed. There were no significant effects of target type or preview and no interaction (all p s $> .1$).

length preview for two-word targets (27 ms), $t_1(31) = 3.25, p = .003$; $t_2(39) = 3.07, p = .004$, compared to compound targets (2 ms; $t_s < 1$), the interaction was not significant, $F_1(1, 31) = 2.72, MSE = 1,972, p = .109$; $F_2(1, 39) = 3.21, MSE = 2,157, p = .081$.

Probability of fixation—There was a significant interaction in the probability of fixating the first lexeme or first word of the two-word target, $F_1(1, 31) = 5.83, MSE = 180, p = .022$; $F_2(1, 39) = 6.27, MSE = 173, p = .017$. Readers were less likely to fixate the first lexeme if they had received the compound word in the parafovea, irrespective of what the target turned out to be, $t_1(31) = -2.41, p = .022$; $t_2(39) = -2.50, p = .017$. This is most likely because readers were targeting their eyes toward the middle of the upcoming word, which would be further into the word in the case of a compound word.

Discussion

The results from this experiment are very clear. Readers used parafoveal length information to direct their saccade toward the middle of the upcoming word. Thus, they landed further into the target when they received a preview of the compound and were less likely to fixate the first lexeme in these cases. What is also unsurprising is that there was a main effect of accuracy of the parafoveal length preview in all fixation duration measures. What is more intriguing is the interaction of type of target and accuracy of length preview that was observed in first fixation duration in the initial set of analyses and in first fixation duration and gaze duration on the first lexeme of the compound word in the second set of analyses.

An explanation of this interaction, which we will refer to as the *beginning letter visibility hypothesis* in the remainder of the article, is that the space after the first few letters makes those letters more visible in the parafovea due to a reduction in lateral masking from additional letters. The beginning letters of words have been found to be very important for word recognition in reading (e.g., Inhoff & Tousman, 1990; Rayner, McConkie, & Zola, 1980). When considering the compound word targets, the incorrect length preview may have afforded extra beginning letter visibility due to the parafoveal interword space. This extra beginning letter visibility may have provided a sufficient benefit to outweigh disruption due to the incorrect length information on first fixation durations on the compound target. However, when an incorrect length preview was given, readers' eyes would still land in a nonoptimal position in the compound word. Readers would therefore be more likely to refixate the compound word, resulting in an increase in first-pass reading time in the incorrect length preview condition.

According to the beginning letter visibility hypothesis, the interaction in first fixation duration should be observed whenever a space is used to segment the first few letters of an upcoming word in the parafovea. Another possibility is that the observed interaction is specific to compound words; the first part of the long word segmented by the space was always the first lexeme of a familiar compound word. Eye movement research on reading compound words has shown that compound words are decomposed into their two lexemes during recognition (Andrews, Miller, & Rayner, 2004; Hyönä & Pollatsek, 1998; Juhasz, 2007; Juhasz, Starr, Inhoff, & Placke, 2003; Pollatsek & Hyönä, 2005; Pollatsek, Hyönä, & Bertram, 2000). According to the dual-route theory of compound word recognition (Pollatsek et al., 2000), the first stage in compound word recognition is accessing the representation of the first lexeme. Thus, the interaction in the present experiment may be specific to compound words and occur because the space has provided a strong cue by which to segment the first lexeme. It thus would be a type of morphological parafoveal processing. This is controversial, because there is no evidence for morphological parafoveal processing in English (Kambe, 2004; Lima, 1987). This possibility, the *morphological preview hypothesis*, will be considered in more detail in the discussion of Experiment 3. These two hypotheses will be directly tested in Experiment 4.

Experiment 2

Experiment 1 provided evidence for the importance of the extraction of word length information from the parafovea in reading. There is, however, an alternative interpretation of the results. Specifically, the effects in Experiment 1 could arise as a consequence of an orthographic mismatch between the preview and the target. In Experiment 1, the previews always differed from the target words in terms of both length and orthographic similarity (i.e., there is one letter, an *h*, missing in the preview for *backhand*). Thus, it is possible that the pattern of results in Experiment 1 was not due to word length information but was instead due to the mismatch between the orthography of the target and the preview.⁴ There is a large body of evidence demonstrating that readers encode the orthography of the parafoveal word prior to its fixation (e.g., Rayner, 1975; Rayner, McConkie, & Zola, 1980) and individual letters near the beginning of words provide preview benefit (Drieghe, Rayner, & Pollatsek, 2005; Pynte, Kennedy, & Ducrot, 2004; White & Liversedge, 2006a). A recent experiment by Johnson et al. (2007) demonstrated that when two letters within the middle of a five- or seven-letter word were substituted with different letters, readers did extract this information from the parafovea. Thus, it is possible that readers extracted orthographic information from the middle of the compound words.

In order to test the explanation that the results in Experiment 1 were due to the extraction of incomplete orthographic information, the boundary technique was again employed and four different previews of the compound targets were used. In order to replicate Experiment 1, the same identical (*backhand*) and length incorrect previews were used (*back and*). In addition, two previews were constructed where the first letter of the second lexeme was replaced by either a visually similar letter (*backband*) or a visually dissimilar letter (*backxand*). If the results of Experiment 1 were due only to the length information being encoded in the parafovea, and not due to differences in orthography, then the three length correct previews (*backhand*, *backband*, *backxand*) should pattern together and should differ from the length incorrect preview.

Method

Participants—Twenty-eight participants from the same pool as Experiment 1 participated for extra course credit or payment.

Apparatus—The apparatus was identical to Experiment 1.

Procedure—The procedure was identical to Experiment 1 except each reader was presented with 114 sentences: 40 of the sentences were experimental, and 74 were fillers. Comprehension questions were asked on approximately 22% of the trials. The average accuracy was 92%.

Materials—The compound word targets and sentences were identical to those used in Experiment 1. For each target compound word, four previews were created. These consisted of an identical preview, a preview where the first letter of the second lexeme was replaced by a visually similar letter, a preview where the first letter of the second lexeme was replaced by a visually dissimilar letter, and a preview where the first letter of the second lexeme was replaced by a space. The boundary to trigger the display change was positioned immediately after the pretarget word. The sentences and parafoveal previews can be found in Appendix A.

Design and data analysis—As in Experiment 1, data were analyzed through repeated measures ANOVAs on both participants' (F_1) and items' means (F_2). One-way ANOVAs were

⁴We thank an anonymous reviewer for suggesting this alternative interpretation.

first computed to assess whether there was a significant difference between the four preview conditions. Planned comparisons were performed to assess whether the incorrect space preview differed from the three length correct previews.

Results

Approximately 19% of trials were excluded in the same manner as for Experiment 1. In addition, data points that were 2.5 standard deviations above the condition means were removed. This led to the removal of an additional 2.6% of trials for first fixation duration, 3% for gaze duration, and 0.45% for landing position. Means and standard deviations of the conditions are in Table 3.

First fixation duration—There were no effects of parafoveal preview condition on first fixation duration (both $F_s < 1$).

Gaze duration—There was a significant effect of parafoveal preview condition on the target compound word, $F_1(3, 81) = 3.08$, $MSE = 2,340$, $p = .032$; $F_2(3, 117) = 2.94$, $MSE = 2,997$, $p = .036$. The length incorrect parafoveal preview condition resulted in longer gaze durations compared with the average of the three length correct preview conditions, $t_1(27) = 2.72$, $p = .011$; $t_2(39) = 2.34$, $p = .025$.

Landing position—Parafoveal preview condition significantly influenced initial landing position, $F_1(3.81) = 6.17$, $MSE = 0.459$, $p = .001$; $F_2(3, 117) = 7.81$, $MSE = 0.714$, $p < .001$. Initial fixations landed significantly closer to the beginning of the compound word when a length incorrect parafoveal preview was provided, compared to the three length correct previews, $t_1(27) = -4.12$, $p < .001$; $t_2(39) = -4.95$, $p < .001$.

Discussion

The purpose of Experiment 2 was to test whether the results of Experiment 1 were due to parafoveal extraction of orthographic information as opposed to parafoveal extraction of length information. The results supported the original interpretation of Experiment 1 in terms of the importance of parafoveal length information. There were no significant effects on first fixation duration, replicating the compound condition in Experiment 1. Also, the three length correct preview conditions produced similar gaze durations and landing positions on the target compound word. These three conditions differed from the length incorrect preview. Thus, this experiment suggests that orthographic information from the middle of a long word is not precisely encoded in the parafovea. Therefore, although single letters can provide preview benefit at the beginning of words (Drieghe et al., 2005; Pynte et al., 2004; White & Liversedge, 2006a), these results show that single-letter information is not extracted from the middle of long words. Note that Johnson et al. (2007) did find an effect on fixation durations when two letters are substituted in the parafoveal preview of a five- or seven-letter words. However, the words used in the Johnson et al. experiment were shorter than in the present experiment (5 letters or 7 letters vs. 8.3 letters), and 2 letters were replaced as opposed to a single letter.

Experiment 3

The results from Experiment 1 suggest that interword spaces in the parafovea may differentially impact the processing of long and short words. However, the results do not provide evidence for or against the length constraint hypothesis. In Experiment 3, the predictability of the targets from the beginning sentence context was manipulated in an attempt to replicate and extend the findings of White et al. (2005). Previous studies have shown that predictable words are read more quickly and are more likely to be skipped than unpredictable words. In some of these studies, each item appeared with the same sentence context and different predictable and

unpredictable critical words (Balota, Pollatsek, & Rayner, 1985; Binder, Pollatsek, & Rayner, 1999; Drieghe et al., 2005; Rayner, Binder, Ashby, & Pollatsek, 2001; Rayner & Well, 1996; White et al., 2005). In other studies, different contexts were used to make the same critical word either predictable or unpredictable (Ehrlich & Rayner, 1981; Rayner, Ashby, Pollatsek, & Reichle, 2004). The present experiment uses the latter technique in order that the orthographic information is equivalent across the conditions.

Method

Participants—Thirty-two participants from the same pool as the previous experiments participated for extra course credit or money.

Apparatus—The apparatus was identical to Experiments 1 and 2.

Procedure—The procedure was identical to Experiment 1 except each reader was presented with 149 sentences in all: 101 fillers and 48 experimental sentences. Comprehension questions were asked on approximately 16% of the trials. The average accuracy was approximately 96%.

Materials—Twenty-four compound words were selected where the deletion of the first letter of the second lexeme results in two short words. These items were paired for the compound condition and two-word condition as in Experiment 1. The compounds ranged from 7 to 10 letters in length overall, with a mean of 8.63. The first lexemes in the compound ranged from 4 to 6 characters in length with a mean of 4.40. For each compound and two-word target, two sentence frames were written, resulting in four sentences for each pair of items. In one sentence frame, the compound or the first word of the two-word target was predictable from the beginning sentence context. In the other sentence frame, the compound or first word of the two-word target was not predictable from the beginning sentence context.

Predictability of the targets was assessed through four rating studies. In all rating studies, participants were instructed to provide a word that could fit as the next word in the sentence. A total of 55 participants were in the rating studies (9–14 rated each sentence). After these four rating studies, the average percentage of completions for the compound words in the compound predictable sentence was 67.2% ($SD = 22.7$). The average percentage of completions of the first lexeme in the compound predictable sentence was 1.3% ($SD = 4.6$). The average percentage of completions for the first lexeme in the lexeme predictable sentence was 70.7% ($SD = 21.4$). For these lexeme predictable sentences, the paired compound word was never provided as a possible completion. Targets were never provided as possible completions in the neutral sentences. The items are provided in Appendix B.

As in Experiments 1 and 2, prior to fixating the compound or two-word target, the length of the target was either accurately or inaccurately specified in the parafovea. The boundary was positioned immediately after the pretarget word and once the readers' eyes crossed the boundary, the preview changed into the correct target.

Design and data analysis—A 2 (target type) $\times 2$ (parafoveal preview) $\times 2$ (sentence context type) design was employed. The conditions were counterbalanced so that each participant read an equal number of items in each condition. Participants read one sentence for every target. If they read the compound target in the predictable sentence, they read the paired two-word target in the neutral sentence and vice versa. Data were again analyzed through repeated measures ANOVAs on both participants' means (F_1) and items' means (F_2).

Results

Approximately 11% of trials were excluded in the same manner as for Experiment 1. As in Experiment 1, two definitions of the target region were used in Experiment 3.

Entire Target Region Analyses

Means and standard deviations for the entire target region are presented in Table 4.

First fixation duration—Predictable targets resulted in 15-ms shorter first fixation durations than targets in a neutral sentence, $F_1(1, 31) = 8.65$, $MSE = 1,821$, $p = .006$; $F_2(1, 23) = 5.15$, $MSE = 2,172$, $p = .033$. Targets also received 22-ms shorter first fixation durations on average when their length was accurately specified in the parafovea, $F_1(1, 31) = 14.14$, $MSE = 2,226$, $p = .001$; $F_2(1, 23) = 33.15$, $MSE = 660$, $p < .001$. These main effects were qualified by an interaction between sentence context type and parafoveal preview, $F_1(1, 31) = 6.23$, $MSE = 874$, $p = .018$; $F_2(1, 23) = 4.46$, $MSE = 980$, $p = .046$. The predictability effect was significant when the length of the target was accurately specified in the parafovea (25 ms), $t_1(31) = -3.63$, $p = .001$, and $t_2(23) = -3.04$, $p = .006$, but not when the length of the target was incorrect in the parafovea (6 ms, $ps > .25$). This result replicates White et al. (2005) in showing an effect of predictability only when the length of the target word was accurately specified in the parafovea. In addition, there was an interaction between target type and accuracy of the parafoveal preview, as in Experiment 1, although it was marginal by participants, $F_1(1, 31) = 2.83$, $MSE = 2,651$, $p = .103$; $F_2(1, 23) = 4.41$, $MSE = 1,393$, $p = .047$. There was a larger effect of parafoveal preview for two-word targets (33ms), $t_1(31) = -3.30$, $p = .002$, and $t_2(23) = -5.47$, $p < .001$, than for compound words (10 ms; $ps > .15$). While the three-way interaction between target type, accuracy of the preview, and sentence context did not approach significance ($F_s < 1$), there was an obvious different pattern for neutral sentence contexts compared to predictable sentence contexts in terms of use of the parafoveal preview information. This differing pattern is explored in the *Discussion* section.

Landing position—The only effect that approached reliability was the crossover interaction between target type and accuracy of the parafoveal preview, replicating the effect from Experiment 1, although it did not reach significance by items, $F_1(1, 31) = 5.46$, $MSE = 0.541$, $p = .026$; $F_2(1, 23) = 2.19$, $MSE = 0.633$, $p = .153$. Again, this interaction demonstrated that readers fixated further into the target region when a preview of a compound was present in the parafovea, $t_1(31) = 2.34$, $p = .026$; $t_2(23) = 1.97$, $p = .062$.

First-pass reading time—Predictable targets received 38-ms shorter first-pass reading times than targets that were not predictable, $F_1(1, 31) = 19.05$, $MSE = 5,038$, $p < .001$; $F_2(1, 23) = 15.93$, $MSE = 5,179$, $p = .001$. There was a 44-ms effect of accuracy of the parafoveal length preview, $F_1(1, 31) = 20.31$, $MSE = 6,184$, $p < .001$; $F_2(1, 23) = 19.91$, $MSE = 4,061$, $p = .001$. Also, there was a main effect of target type, $F_1(1, 31) = 14.46$, $MSE = 9,827$, $p = .001$; $F_2(1, 23) = 6.27$, $MSE = 19,182$, $p = .02$. Similar to Experiment 1, two-word targets received 47-ms longer first-pass reading times on average compared to the compound targets. No interactions were significant.

First Lexeme Analyses

As in Experiment 1, the next set of analyses defined the target region as either the first lexeme of the compound word or the first word of the two-word target. These analyses thus compared identical regions for the compound and two-word conditions. Means and standard deviations for analyses on the first lexeme are presented in Table 5.

First fixation duration—There was a 14-ms effect of predictability, $F_1(1, 31) = 5.20$, $MSE = 2,443$, $p = .03$, and $F_2(1, 23) = 5.38$, $MSE = 1,831$, $p = .03$, and a 17-ms effect of accurate length preview, $F_1(1, 31) = 9.24$, $MSE = 2,135$, $p = .005$, and $F_2(1, 23) = 12.00$, $MSE = 1,509$, $p = .002$. There was also an interaction between type of target and accuracy of the length preview that was significant by items, $F_2(1, 23) = 5.09$, $MSE = 1,596$, $p = .034$, but not by participants, $F_1(1, 31) = 2.12$, $MSE = 3,548$, $p = .155$. The pattern of this interaction was the same as in Experiment 1. There was a significant effect for accuracy of the length preview for two-word targets (28 ms), $t_1(31) = -2.55$, $p < .016$, and $t_2(23) = -4.07$, $p < .001$, but not for compound targets (7 ms; $ts < 1$). The three-way interaction did not reach significance ($ps > .25$).

Gaze duration—There was a 21-ms effect of predictability, $F_1(1, 31) = 7.46$, $MSE = 3,763$, $p = .01$, and $F_2(1, 23) = 10.97$, $MSE = 1,751$, $p = .003$, and a 26-ms effect of length preview accuracy, $F_1(1, 31) = 10.55$, $MSE = 3,851$, $p = .003$, and $F_2(1, 23) = 17.71$, $MSE = 2,092$, $p < .001$. There was also a marginal interaction between the type of target and length preview accuracy, $F_1(1, 31) = 3.67$, $MSE = 3,348$, $p = .065$; $F_2(1, 23) = 4.00$, $MSE = 2,385$, $p = .057$. When the target was a compound word, the size of the effect on the first lexeme for the accuracy of the length parafoveal preview was smaller (11 ms; both $ps > .15$) than in the two-word condition (39 ms), $t_1(31) = -3.07$, $p = .004$; $t_2(23) = 4.83$, $p < .001$.

Probability of fixation—Unlike Experiment 1, there were no significant effects on the probability of fixating the first lexeme (all $ps > .15$). White et al. (2005) observed a significant interaction between predictability and accuracy of the parafoveal length preview only when saccades launched from letters close to the target region were considered. We therefore conducted a supplemental analysis only considering two-word targets, as this most closely mimics the design of White et al. (2005). We also only considered cases where the prior fixation was within four characters of the target region.⁵ In this analysis, there was a main effect of predictability that was significant by participants, $F_1(1, 29) = 4.26$, $MSE = 586$, $p = .048$; $F_2(1, 21) = 1.10$, $MSE = 825$, $p > .25$. The first word was fixated 53% of the time when the context was neutral but only 44% of the time when it was predictable from the beginning context. This context effect replicates previous studies that have observed an effect of target predictability on skipping rates (e.g., Balota et al., 1985; Binder et al., 1999; Drieghe et al., 2005; Ehrlich & Rayner, 1981; Rayner et al., 2001, 2004; Rayner & Well, 1996; White et al., 2005). In addition, there was a marginal effect of accuracy of the parafoveal preview by participants, $F_1(1, 29) = 3.74$, $MSE = 806$, $p = .063$, and $F_2(1, 21) = 2.25$, $MSE = 703$, $p = .149$, demonstrating that readers were less likely to fixate the first word of the two-word target when the parafoveal preview of the length was inaccurate. However, even in this analysis, we did not observe an interaction (both $ps > .1$) between sentence context and accuracy of the preview.

Discussion

The results from Experiment 3 provide support for the length constraint hypothesis. Replicating White et al. (2005), an interaction was observed in first fixation duration such that predictability effects were only observed when the length preview was accurate. This suggests that readers were using a combination of sentence predictability and length information in the parafovea to narrow down possible lexical candidates. However, unlike White et al. (2005), this effect was not observed in first-pass reading time. The failure to observe an interaction during first-pass was not due to a weak predictability manipulation, as strong main effects of predictability were observed on all fixation duration measures. The results from the probability of fixating the first word of the two-word target also differ from White et al. (2005). These differences in

⁵Only participants and items that had data contributing to all eight conditions were included in these analyses.

results most likely reflect methodological differences between the two studies.⁶ Based on the present results combined with White et al. (2005) it appears that when a word is highly predictable, this information can be used in combination with parafoveal length information to narrow down the possible lexical candidates for the parafoveal word and also to guide eye movements to an optimal position in a parafoveal word.

Another important finding in Experiment 3 was the replication of the interaction between type of target and accuracy of parafoveal preview in first fixation duration on the entire target region. However, inspection of the target means presented in Table 4 suggests that sentence predictability influenced the use of parafoveal word length information for the compound words. In order to further explore this interaction, we conducted post hoc tests on the compound word targets as a function of accuracy of the parafoveal word length information provided. When the prior sentence context was neutral, there was no influence of parafoveal length accuracy on first fixation durations (1 ms; both $t_s < 1$), replicating Experiments 1 and 2. However, when the prior sentence context predicted the compound word, the effect of parafoveal length accuracy was significant (24 ms), $t_1(31) = -2.27$, $p = .030$; $t_2(23) = -2.18$, $p = .040$. Thus, when the context is highly predictive of a certain word, parafoveal word length information is utilized to a greater extent than when the sentence context is neutral.

According to the morphological preview hypothesis outlined previously, one reason for the failure to find an effect of parafoveal length accuracy on first fixation duration for compound words in a neutral context could be that the letter sequence segmented in the incorrect length preview case was always the first lexeme of a familiar compound word. Previous studies in English have suggested that morphological information is not accessed in the parafovea (Kambe, 2004; Lima, 1987). One possible reason why morphological information may not be used in parafoveal processing in English may be because it is difficult to extract a morpheme (whether it is a prefix or the first lexeme of a compound word) from a parafoveal word, given that visual acuity in the parafovea is limited. Perhaps the current experiments provided a strong enough parafoveal preview of the first lexeme of the compound, due to the reduction in lateral masking, such that a parafoveal morphological effect was observed. Some research (see Footnote 2) suggests that readers of Hebrew do obtain parafoveal morphological information that provides preview benefit. Thus, readers of English may also be able to use parafoveal morphological information in some situations.

Experiment 4

In Experiments 1 and 3, a correct word length preview facilitated processing of monomorphemic words even for very early measures of processing. However, for compound words, first fixation durations showed little or no facilitation of processing from a correct parafoveal word length preview in a neutral context. We have outlined two possible hypotheses for this interaction: the beginning letter visibility hypothesis and the morphological preview hypothesis. According to the morphological preview hypothesis, in clearly distinguishing the first lexeme of a compound by following it with a space, the initial lexeme could be processed without having to first decompose it from the second lexeme using lexical knowledge. According to the beginning letter visibility hypothesis, the fact that the long target word was

⁶The present experiment employed first lexemes that ranged in length between four and six letters as opposed to all being four letter words, as in the White et al. (2005) study. As the meta-analysis by Brysbaert, Drieghe, and Vitu (2005) demonstrates, word length is a very important factor in word skipping. In addition, the nature of the context manipulation differed between the present study and that of White et al. (2005). In the present experiment, the target word was always the same (e.g., *back*) and what differed between the neutral and predictable conditions was the context preceding the target. In White et al. (2005), the context was always the same (e.g., *The explosives expert planted the. . .*), and what differed between the predictable and neutral conditions was the target word (e.g., *bomb* vs. *rose*). Thus, it is possible that the control of sentence context in the White et al. (2005) study may have provided a more powerful design to find an interaction in word skipping.

a compound word is irrelevant. A third possibility is that the addition of the space may have facilitated processing of the compounds simply because the initial letter string formed a word (e.g., *back and*) rather than a nonword.

Experiment 4 was designed to test these three possible interpretations. In Experiment 4, single monomorphemic words were selected that were the same length as the compound words. For both the compound and monomorphemic conditions, a space was added in the incorrect parafoveal length preview conditions. Therefore, Experiment 4 provides a clear test of whether a correct length preview provides any parafoveal preview benefit compared to an incorrect length preview (with an additional space) for compound and monomorphemic words. If the interaction shown for first fixation durations in Experiments 1 and 3 is specific to compound word processing, then a similar interaction should occur in Experiment 4. In contrast, if the reduced preview benefit in neutral sentences for compound words in Experiments 1 and 3 is due to facilitated processing as a consequence of reduced lateral masking, then compound and monomorphemic words should both show minimal preview benefit for first fixation durations. Furthermore, Experiment 4 manipulated whether the initial letter string of the incorrect length preview was a lexeme (e.g., *pop orn*) or a nonword (e.g., *popc rn*). If the reduced preview benefit for compound words in Experiments 1 and 3 is due to the preview of an actual word, then the incorrect lexeme previews should produce less preview benefit.

Method

Participants—Forty-two University of Massachusetts community members participated in the experiment.

Apparatus—The apparatus was identical to the prior experiments.

Procedure—Comprehension questions were asked after one third of the sentences, and the average accuracy was 94%. Participants viewed 209 sentences: 84 experimental and 125 fillers.

Materials—Forty-two compounds (e.g., *popcorn*) and 42 monomorphemic words (e.g., *diploma*) served as targets. They ranged from 7 to 11 characters long with an average of 7.9 characters. The monomorphemic words began with a letter string that, if presented alone, formed a lexeme (e.g., *dip* in *diploma*). Items were paired such that the monomorphemic and compound words were the same length⁷ and began with lexemes of the same length (e.g., *dip* and *pop*).⁸ The initial lexeme ranged in length from 3 to 5 characters with an average of 3.7. For a given pair of targets, a neutral sentence was written that was the same up until the target but then formed a meaningful completion. Sentences are provided in Appendix C.

Word frequencies were calculated from Francis and Kučera (1982) with no differences in whole word frequency between compound ($M = 6$, $SD = 14$) and monomorphemic ($M = 8$, $SD = 12$) conditions ($t < 1$). There were also no differences in the frequency of the initial lexeme between compound ($M = 167$, $SD = 344$) and monomorphemic ($M = 160$, $SD = 307$) conditions ($t < 1$). The number of words containing the initial lexemes (assessed via the Educators Word Frequency Guide; Zeno, Ivens, Hillard, & Duvvuri, 1995) did not significantly differ between compound ($M = 94$, $SD = 75$) and monomorphemic ($M = 106$, $SD = 151$) conditions ($t < 1$).

Similar to Experiment 1, predictability (10 participants) and plausibility ratings (20 participants; 10 per sentence) were conducted. Neither the compound nor monomorphemic words were predictable from the sentence contexts (0% completions). There was no difference

⁷In Experiment 3, there was one item (see Item 42 in Appendix C) in which word length between the compound and monomorphemic condition differed by one character.

⁸We will refer to this as the *initial lexeme*, even though it is not a lexeme within the context of a monomorphemic word.

in plausibility ratings (1–7 scale) between the compound ($M = 5.1$, $SD = 2.2$) and monomorphemic ($M = 5.3$, $SD = 2.1$) conditions ($t < 1$).

Prior to fixating the target word, one of three different parafoveal previews was presented: correct length (*popcorn* or *diploma*), incorrect length with initial letter string forming a lexeme (*pop orn* or *dip oma*), and incorrect length with initial letter string forming a nonword (*popc rn* or *dipl ma*). Across the experiment, the items were matched such that (for example) for every item that had a three-letter initial word letter string and a four-letter nonword letter string there was another with a four-letter word letter string and a three-letter nonword letter string.

Design and data analysis—A 2 (target type) $\times$ 3 (parafoveal preview) design was employed. The sentence beginnings were very neutral, and the sentence endings were quite different in each of the conditions. Consequently, participants read both the compound and monomorphemic condition versions of each sentence. The variable of preview was counterbalanced following a Latin square design.

Results

Trials were excluded from analysis as detailed in Experiment 1 such that 16% of trials were removed. Nonadjacent short fixations (80 ms or less) and extremely long fixations (1,200 ms or longer) were eliminated by the analysis software. The data were analyzed using one definition of the target region comprising the entire target word and the space preceding it. The mean reading times and landing position are shown in Table 6.

First fixation duration—There was a significant main effect for the accuracy of the parafoveal length preview, $F_1(2, 82) = 4.53$, $MSE = 1,246$, $p = .018$; $F_2(2, 82) = 4.18$, $MSE = 1,180$, $p = .019$. There was no main effect of target type and no interaction between target type and preview ($F_s < 1.1$). There were no differences in the size of the preview benefit between the compound (14 ms) and monomorphemic (12 ms) words, or between the lexeme (13 ms) and nonword (12 ms) incorrect length previews.

Landing position—There was a main effect of preview, $F_1(2, 82) = 12.52$, $MSE = 0.48$, $p < .001$, and $F_2(2, 82) = 13.53$, $MSE = 0.36$, $p < .001$, and no effect of target type ($p_s > .2$) or interaction ($F_s < 1$). Readers fixated further into the target word when the parafoveal preview was correct (3.5 characters) compared to when the parafoveal preview was an incorrect short-letter string that was either legal or illegal (3.1 characters).

Gaze duration—As with first fixation duration, there were main effects of parafoveal length preview, $F_1(2, 82) = 10.81$, $MSE = 3,483$, $p < .001$; $F_2(2, 82) = 23.79$, $MSE = 1,596$, $p < .001$. There were no main effects of target type ($F_s < 1.2$) and no interactions ($F_s < 1$). There were no differences in preview benefit for compound compared to monomorphemic words or for legal and illegal previews (all 37 ms).

Discussion

The results for Experiment 4 clearly show no difference in processing of parafoveal word length information between compound and long monomorphemic words. These findings indicate that the interaction shown for first fixation durations in Experiments 1 and 3 cannot be explained by differences in parafoveal morphological processing. Furthermore, there was no difference in processing of parafoveal word length information between the initial lexeme and the nonword incorrect length previews. These findings suggest that the reduced preview benefit for compound words in Experiments 1 and 3 also cannot be explained by the presence of a parafoveal lexeme that forms part of a longer word. Importantly, Experiment 4 did show a significant preview benefit effect such that the correct length previews facilitated processing

more than the incorrect length previews. However, it should be noted that the size of this first fixation duration preview benefit (13 ms) is comparable in size to the nonsignificant one reported in Experiment 3 (10 ms: the average for neutral and predictable sentences) and is quite small compared with the preview benefits when the spaces were removed in Experiments 1 (25 ms) and 3 (33 ms). Therefore, although Experiment 4 did show a significant difference between the correct and incorrect length previews, it could be that this effect was reduced by the additional space facilitating processing in some way. Consequently, it seems that the interaction shown for first fixation durations in Experiments 1 and 3 can best be explained by the beginning letter visibility hypothesis, according to which the disadvantage of an incorrect word length preview is counteracted by an advantage provided by reduced lateral masking due to the additional space. Of course, one can envision explanations for this interaction other than the beginning letter visibility hypothesis. We return to this issue in the General Discussion.

In line with Experiments 1–3, Experiment 4 showed that initial fixations landed further into previews of long words (correct preview) than previews of two shorter letter strings separated by a space (incorrect preview). There was no effect of whether the target word was a compound or monomorphemic word in Experiment 4. These findings contrast with previous studies that suggest that monomorphemic words are easier to process than compound words (Inhoff, Briehl, & Schwartz, 1996). One possible reason for this difference is that the frequency of the compound word constituents was often quite high. Therefore, it could be that the compound words were easier to process in the present experiment due to high familiarity with the component lexemes.

In Experiment 4, there was no difference in the amount of preview benefit between previews beginning with a lexeme and previews beginning with a nonword. These findings suggest that semantic information is not integrated across fixations such that this influences preview benefits, consistent with prior studies (Altarriba et al., 2001; Rayner et al., 1986).

General Discussion

The purpose of the present set of experiments was to further explore the role of interword spaces in reading alphabetic text. When examined as a whole, the current set of experiments provides a clear picture regarding the role of interword spaces and parafoveal word length information in reading. We first highlight the important findings from the current experiments, briefly detail how these findings relate to morphological processing, and then further discuss conclusions regarding the use of parafoveal word length information in reading.

Experiment 1 combined the parafoveal word length manipulations used by Inhoff, Radach, Eiter, and Juhasz (2003) with long words and by White et al. (2005) with short words into a single experiment. The interaction observed in first fixation duration provided evidence that parafoveal interword spaces are not utilized in the same way for short and long words early in processing. The results from Experiment 2 clearly demonstrate that the effects observed were due to parafoveal encoding of interword spaces and that orthographic information is not precisely encoded in the middle of long parafoveal words. Experiment 3 indicated that the reduced parafoveal length accuracy effect in first fixation durations for compound words is restricted to cases where the sentence frame is neutral. Finally, Experiment 4 showed no difference between previews that were real words compared to previews that were nonwords demonstrating that lexical status of the parafoveal preview did not affect processing on the target word once fixated.

Implications for Morphological Processing

Although interword spaces make reading more efficient in general, there are also cases where interword spaces are deliberately deleted in alphabetic writing systems to represent a new

concept. In English, most novel two-word expressions are written with interword spaces, however, there is a limited set of spatially unified compound words that are written without spaces. Juhasz, Inhoff, and Rayner (2005) investigated the role of interword spaces for spaced and unspaced familiar compound words. They demonstrated that insertion of an interword space into a normally unspaced compound word significantly lengthened gaze durations on these compound words, while deleting the interword space for a normally spaced compound did not significantly affect gaze durations. Juhasz et al. concluded that the deletion of an interword space allows the eyes to be targeted to a more optimal position to view the overall compound word in addition to facilitating access to the meaning of the compound expression. Unlike the foveal space manipulation in Juhasz et al. (2005), the present studies investigated the use of parafoveal word length information for compound words. The results from these studies support Juhasz et al.'s conclusion in showing that when a long compound word is present in the parafovea, readers move their eyes further into the word. When the eyes land closer to a word center, readers are less likely to need to refixate a word before its identification. This is illustrated by the results of Experiments 1 and 3, where compound words were more likely to be refixated when the preview was incorrect (see Table 7).

Another interesting effect in the current experiments was the interaction between type of target and accuracy of the parafoveal length preview in first fixation duration in Experiments 1 and 3. One hypothesis that was entertained was that this interaction indicated parafoveal morphological processing. However, the results from Experiment 4 demonstrated that this interaction was not due either to parafoveal morphological processing or to the fact that the short component in the inaccurate length preview formed a word.

Parafoveal Word Length Information

The beginning letter visibility hypothesis remains a tenable alternative explanation of the results. According to this hypothesis, the small effect of parafoveal length accuracy for long words is due to a trade-off between the increase in visibility of the beginning letters of those words by the addition of the space, and the inaccuracy of the preview. The reason that this interaction is not observed in first-pass reading time is due to readers being more likely to refixate when their eyes deviate from the center of the word. This effect is also highlighted in Table 7. It shows that for both Experiment 1 and 3 (collapsed over sentence context) there is a relatively large increase in refixations for compound words when an inaccurate length preview is given in the parafovea (Experiment 1: $t_1[31] = -2.95, p = .006$; $t_2[39] = -2.93, p = .006$; Experiment 3: $t_1[31] = -2.57, p = .015$; $t_2[23] = -2.56, p = .018$), while for the two-word targets refixations are relatively common whether a correct or incorrect length preview is given in the parafovea, and do not differ between the two conditions (all $ps > .2$).

As mentioned previously, there may be other explanations for the interaction between type of target and accuracy of the parafoveal preview in first fixations. We now consider four alternative explanations for this effect. First is the possibility that short words are often identified in the parafovea in reading while long words are not fully identified in the parafovea.⁹ According to this view, on some trials where the preview was *back and*, readers may have identified *back* in parafoveal vision and this may have led to the pattern of results reported here. However, while we agree that space information does allow short words to be skipped, it is not at all clear that this would necessarily explain our results. In our view, in a situation in which *back* is identified parafoveally, and then the eyes fixate *backhand*, which is a different word with a different semantic meaning, the reader would detect that he or she had misidentified the word, and consequently massive interference should occur. In the present Experiments 1 and 3, the short first lexeme words (which ranged between two and six characters) were skipped

⁹This view was suggested by an anonymous reviewer.

21%–30% on average across conditions.¹⁰ Our view is that skipped short words are typically identified on the prior fixation and there would be no need to further fixate them. Thus, if the short lexeme *back* is identified prior to fixation, it should be skipped. However, the results of Experiment 1 and 3 using the first lexeme (*back*) as the region of analysis show a pattern consistent with the entire target region. Even when the first lexeme is fixated (and therefore not identified on the prior fixation) an interaction is still observed showing larger disruptions when the word in the parafovea was long but the word fixated was short. In addition, the failure to find significant differences in Experiment 4 when a short nonword was present in the parafovea (*popc*) compared to a short word (*pop*) argues against the majority of short words being identified prior to fixation.

A second alternative to the beginning letter visibility hypothesis is related to the optimal viewing position (OVP) in words. As noted in the introduction, most words are fixated between their beginning and center, the preferred viewing location (Rayner, 1979). There is a substantial literature investigating single word naming, which suggests that words are identified fastest when they are fixated at their center (O'Regan & Jacobs, 1992) and that word identification, at least for individuals who are left-hemisphere language dominant, is slowest when they are fixated at their ending letters (see Brysbaert, 1994, 2004; Hunter, Brysbaert, & Knecht, 2007). Thus, according to the OVP account, there may be a larger effect of inaccurate parafoveal length preview for short words on first fixation in Experiments 1 and 3 because having a parafoveal preview of the long word causes readers' eyes to land at the end of the short word. Conversely, when a short word is in the parafovea, this would result in the readers eyes' landing toward the beginning of the long compound words, which the OVP literature demonstrates does not hinder word recognition. While this account does seem plausible at first glance, we believe that this is not a viable explanation of the current data. All studies reporting an OVP effect on word identification have presented words in isolation and experimentally manipulated fixation position. In contrast, to date, no such effects have been shown in normal reading. Moreover, in a study of normal reading where eye movements were recorded, Rayner et al. (1996) did not observe an OVP effect. Fixation durations were statistically equivalent for landing positions on each letter of five-, six-, and seven-letter words. Other studies have reported a slightly different effect, namely an inverted optimal viewing position effect (IOVP; see Vitu, McConkie, Kerr, & O'Regan, 2001; White & Liversedge, 2006b) where fixation durations are longest when fixations are at the center of words. Thus, we are cautious with respect to this account, given that the OVP effect is not generalizable to normal reading and we are therefore reticent to use it to explain our results.

A third alternative has to do with the perceptibility of exterior letters. The beginning letter visibility hypothesis suggests that the interactions in first fixation duration observed in Experiments 1 and 3 are due to the parafoveal space making the beginning letters of the long target word more salient. This leads to an initial processing advantage that is eventually offset due to refixations. Thus, this hypothesis relies on the importance of the beginning letters in word identification. There is, however, currently some debate in the literature over whether it is beginning letters (see Briihl & Inhoff, 1995; Inhoff, Radach, Eiter, & Skelly, 2003) or exterior letter pairs (Jordan, Thomas, Patching, & Scott-Brown, 2003; Jordan, Thomas, & Patching, 2003; see also White et al., in press) that are most important for word recognition. Previous studies have suggested that insertion of spaces increases perceptibility of letters for foveally presented letter strings in certain tasks (Campbell & Mewhort, 1980; Estes & Wolford, 1971; Mewhort, Marchetti, & Campbell, 1982; Shaw, 1969; Wolford & Holingshead, 1974). Thus, another alternative to the beginning letter visibility hypothesis is that the parafoveal interword

¹⁰Consistent with prior research (Rayner & McConkie, 1976; Rayner et al., 1996), the skipping rate was modulated by word length for Experiments 1 and 3. Thus, the skipping rates for two-letter lexemes (of which there was only one item), three-, four-, five-, and six-letter lexemes were 57%, 34%, 24%, 16%, and 5.5%, respectively.

space in the present experiments led to an increase in visibility for an additional two letters when an inaccurate length preview is given for a long word (*b-k-a-d*) compared to the length correct preview (*b—d*). This letter perceptibility advantage would be offset by the eyes landing in a suboptimal location and the consequent need for refixation.

This exterior letter perceptibility account is, thus, a viable alternative to the beginning letter visibility hypothesis. That being said, however, we continue to believe that beginning letter sequences are the most important in parafoveal processing due to their proximity to the fovea. Data do exist suggesting that exterior ending letters are processed in the parafovea. Johnson et al. (2007; Experiment 3) found that changing the exterior ending letter in the parafoveal preview of a seven-letter word is more disruptive to reading compared to changing the fifth and sixth letter. However, the main question for the current debate is whether the ending exterior letter is equally or more important than the beginning letters in a parafoveal word. In fact, Johnson et al. (2007; Experiment 3) had an additional condition where the first two letters of the parafoveal word were changed. Changing the first two letters of the word resulted in significantly longer gaze durations (352 ms) compared to changing the last two letters in the parafovea (323 ms), $t_1(29) = 4.16, p < .001$; $t_2(67) = 2.22, p = .03$.¹¹ This analysis supports our view that beginning letters produce the majority of the parafoveal preview effect in reading, and thus it seems plausible that greater visibility of the beginning letters is more critical than that of the exterior letters between parafoveal lexemes.

One final alternative should also be considered. According to the beginning letter visibility hypothesis, the source of the interaction is a consequence of low-level visual processing, relating to a decrease in lateral masking afforded by the space. Another possibility, however, is that the source of the interaction occurs at a higher level of processing in the lexicon. While the letters in short words are thought to be processed completely in parallel, longer words often require two or more fixations for identification, suggesting a more serial sequential identification process. One consequence of including the space in the parafoveal preview was that the beginning part of the long word was segmented into a smaller “chunk” of letters in the parafovea. Such parafoveal segmenting isolated the beginning portions of the long words, forming smaller linguistic units that may have been easier to process prior to direct fixation (regardless of whether the chunk did or did not comprise the first morpheme of a compound word or whether it formed a word or not). The principal difference between this segmentation explanation and the beginning letter visibility hypothesis is that the segmentation account ascribes the process leading to the interaction as being due to higher level processing related to the recognition of long words.

We suspect that other alternative explanations for this interaction may also exist. What we would like to stress, however, is that in neutral sentences there is a difference in the use of parafoveal word length information for long and short words in early processing measures. Experiment 4 rules out the possibility that this difference is due to parafoveal morphological processing or the lexical status of the preview. Further research will need to disentangle the remaining alternative explanations for this effect.

In conclusion, the present set of experiments supports two roles for interword spaces in reading. First, information about word length is extracted from the parafovea and used to direct the eyes toward the center of the upcoming word (though they typically land short of this at the preferred viewing location). This conclusion is supported by the significant landing position effects in all four experiments. In addition, Experiment 3 indicated that parafoveal word length information can be used in combination with sentence context in some circumstances to narrow

¹¹We thank Rebecca Johnson for doing this additional analysis of Johnson et al. (2007).

down the possible candidates for an upcoming word. Thus, extraction of parafoveal word length information in reading alphabetic texts is a very important aspect of the reading process.

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Appendix A

Experimental Sentences for Experiments 1 and 2

Version (a) shows the compound word target, and version (b) shows the two-word target. For Experiment 1, the two types of preview are shown in parentheses with the correct length preview shown first, followed by the incorrect length preview. For Experiment 2, the additional two length correct previews are shown in boldface after the compound word target sentences.

1a. Kevin reached for Miranda's armband (armband, arm and) when she moved away from him. **(armhand, armxand)** 1b. Kevin reached for Miranda's arm and (arm and, armband) tried to keep her from leaving.

2a. Michael used his strong backhand (backhand, back and) many times during the long tennis match. **(backband, backzand)** 2b. Michael used his strong back and (back and backhand) legs to lift the heavy couch for Suzy.

3a. Martha went to the closest deckhand (deckhand, deck and) and asked him to help her. **(deckband, deckzand)**

3b. Martha went to the closest deck and (deck and, deckhand) looked out over the ocean.

4a. Carrie quickly came downhill (downhill, down ill) when her mother called her for dinner. **(downbill, downzill)** 4b. Carrie quickly came down ill (down ill, downhill) after she played with a sick friend.

5a. Rich read a story about a beautiful fairyland (fairyland, fairy and) where dreams come true. **(fairyband, fairynand)**

5b. Rich read a story about a beautiful fairy and (fairy and, fairyland) her wonderful adventures.

6a. My grandfather bought a small farmland (farmland, farm and) located in western Pennsylvania. **(farmband, farmnand)**

6b. My grandfather bought a small farm and (farm and, farmland) retired from his job last summer.

7a. Terry could see a large fireball (fireball, fire all) shoot out of the burning building. **(firehall, firexall)**

7b. Terry could see a large fire all (fire all, fireball) the way from his apartment building.

8a. Tara drew the circle with freehand (freehand, free and) imprecision for her art class. **(freeband, freezand)**

8b. Tara drew the circle with free and (free and, freehand) broken crayons at the doctor's office.

9a. My old uncle's gravestone (gravestone, grave tone) had been vandalized over night. **(gravectone, graveltone)**

9b. My old uncle's grave tone (grave tone, gravestone) let me know that something was wrong.

- 10a. The kindergarten's handcart (handcart, hand art) was used to transport supplies.
(handsart, handfart)
- 10b. The kindergarten's hand art (hand art, handcart) was hung up all over the school.
- 11a. The queen spoke to the young highland (highland, high and) prince about the current war.
(hightand, highnand)
- 11b. The queen spoke to the young high and (high and, highland) mighty prince with contempt.
- 12a. The fleeing refugee looked back on his beloved homeland (homeland, home and) before he ran away. **(hometand, homenand)**
- 12b. The fleeing refugee looked back on his beloved home and (home and, homeland) wept with sorrow.
- 13a. The young children's horseplay (horseplay, horse lay) made their mother very nervous.
(horseglay, horsevlay)
- 13b. The young children's horse lay (horse lay, horseplay) in the pasture under a tree.
- 14a. In math class we had to complete longhand (longhand, long and) division problems on the final. **(longband, longzand)**
- 14b. In math class we had to complete long and (long and, longhand) difficult homework problems.
- 15a. We stopped at the country's mainland (mainland, main and) after we had vacationed on the island. **(maintand, mainnand)**
- 15b. We stopped at the country's main and (main and, mainland) largest airport after the long flight.
- 16a. Karen watched the young nursemaid (nursemaid, nurse aid) feed the children their lunch.
(nursenaid, nursetaid)
- 16b. Karen watched the young nurse aid (nurse aid, nursemaid) the doctor during the operation.
- 17a. Matthew threw the ball overhand (overhand, over and) to his big brother Andy. **(overband, overzand)**
- 17b. Matthew threw the ball over and (over and, overhand) hit his brother accidentally.
- 18a. Bob's sister threw the cold snowball (snowball, snow all) right at his face yesterday.
(snowhall, snowxall)
- 18b. Bob's sister threw the cold snow all (snow all, snowball) over him as he walked outside.
- 19a. The citizens flocked to the town's stronghold (stronghold, strong old) during the enemy attack. **(strongbold, strongzold)**
- 19b. The citizens flocked to the town's strong old (strong old, stronghold) building to escape the storm.
- 20a. Rebecca had gotten uphill (uphill, up ill) before all of the other children. **(upbill, upzill)**

20b. Rebecca had gotten up ill (up ill, uphill) during the middle of the night.

21a. The girl wanted a smaller waistband (waistband, waist and) on the skirt she tried on in the Gap. (**waisthand, waistxand**)

21b. The girl wanted a smaller waist and (waist and, waistband) so she exercised nightly and dieted.

22a. The couple could see the disgusting wasteland (wasteland, waste and) that stretched beyond their yard. (**wastetand, wastenand**)

22b. The couple could see the disgusting waste and (waste and, waste-land) filth of the large garbage dump.

23a. The modern artist covered the canvas with whitewash (whitewash, white ash) for the new exhibit. (**whitemash, whitekash**)

23b. The modern artist covered the canvas with white ash (white ash, whitewash) from the fireplace.

24a. My father worked on the large woodcraft (woodcraft, wood raft) project all afternoon in his shop. (**woodsraft, woodcraft**)

24b. My father worked on the large wood raft (wood raft, woodcraft) that we would soon use on the lake.

25a. Mary yelled as the young child pulled her armchair (armchair, arm hair) across the hardwood floor. (**armshair, armfhair**)

25b. Mary yelled as the young child pulled her arm hair (arm hair, armchair) so hard that it came out.

26a. Tim damaged his backbone (backbone, back one) during the intense rugby match yesterday. (**backhone, backzone**)

26b. Tim damaged his back one (back one, backbone) day before his important wrestling match.

27a. The frustrated player threw the baseball (baseball, base all) into the crowded stadium. (**basehall, basexall**)

27b. The frustrated player threw the base all (base all, baseball) the way across the field.

28a. Jerry could see the old cowhand (cowhand, cow and) working in the field on the farm. (**cowband, cowzand**)

28b. Jerry could see the old cow and (cow and, cowhand) knew that it would probably soon die.

29a. My mother says that the fireflies (fireflies, fire lies) will die if we keep them in a jar. (**firellies, fireolies**)

29b. My mother says that the fire lies (fire lies, fireflies) too close to our flammable tents.

30a. The manager began her firsthand (firsthand, first and) rendition of the day's events. (**firstband, firstzand**)

30b. The manager began her first and (first and, firsthand) only employee meeting of the day.

31a. Richard kicked his football (football, foot all) through the goal for the extra point.
(**foothall, footzall**)

31b. Richard kicked his foot all (foot all, football) the way through the screen door today.

32a. Before Michelle went to class she put her hairpin (hairpin, hair in) in her jacket pocket.
(**hairgin, hairvin**)

32b. Before Michelle went to class she put her hair in (hair in, hairpin) a ponytail using a ribbon.

33a. Tom's aunt told him about the hardship (hardship, hard hip) she faced before she came to America. (**hardchip, hardlhip**)

33b. Tom's aunt told him about the hard hip (hard hip, hardship) replacement surgery she had recently.

34a. Valerie dropped her headband (headband, head and) into a large mud puddle as she walked to school. (**headhand, headxand**)

34b. Valerie dropped her head and (head and, headband) began to cry when she heard the terrible news.

35a. We had to walk through the lowland (lowland, low and) marshes to get to the secret hunting spot. (**lowtand, lownand**)

35b. We had to walk through the low and (low and, lowland) overgrown branches in the dense forest.

36a. Kim could not wait for nightfall (nightfall, night all) when she would go on her first date with Adam. (**nightlall, nightoall**)

36b. Kim could not wait for night all (night all, nightfall) afternoon since she was excited for the party.

37a. We were told to avoid the quicksand (quicksand, quick and) as we walked through the desert. (**quickcand, quickland**)

37b. We were told to avoid the quick and (quick and, quicksand) dangerous shortcuts on the way.

38a. The author wrote his book in shorthand (shorthand, short and) before he typed it into the computer. (**shortband, shortzand**)

38b. The author wrote his book in short and (short and, shorthand) quick bursts until he was finished.

39a. The new government decided to stonewall (stonewall, stone all) congress until they got support. (**stonemall, stonekall**)

39b. The new government decided to stone all (stone all, stonewall) criminals that committed murder.

40a. The farmer said that the waterfall (waterfall, water all) we were hearing was four miles away. (**waterlall, wateroall**)

40b. The farmer said that the water all (water all, waterfall) around his farm was contaminated.

Appendix B

Experimental Sentences for Experiment 3

Version (a) shows the compound word target in a predictable context, version (b) shows the compound word target in a neutral context, version (c) shows the two-word target in a predictable context, and version (d) shows the two-word target in a neutral context. The two types of preview are shown in parentheses with the correct length preview shown first, followed by the incorrect length preview.

1a. Michael Jordan is considered the most famous basketball (basketball, basket all) player ever.

1b. When I was younger I hated basketball (basketball, basket all) even though I was over six feet tall.

1c. The teens took a hike with their picnic basket all (basket all, basketball) the way to Shyer Falls.

1d. I let my girlfriend carry the heavy basket all (basket all, basketball) the way to our apartment.

2a. Babe Ruth was great at playing baseball (baseball, base all) even though he was unhealthy.

2b. Neighborhood girls gathered to play baseball (baseball, base all) in Paula's backyard.

2c. The pitcher threw the ball to first base all (base all, baseball) the way from the pitcher's mound.

2d. The little girl didn't know which base all (base all, baseball) batters should run to.

3a. Niagara has the nation's largest waterfall (waterfall, water all) and is visited by many tourists.

3b. We were too lazy to hike to the nearby waterfall (waterfall, water all) so we watched TV instead.

3c. The children splashed in the refreshing and clear water all (water all, waterfall) through the day.

3d. Sadly, my mother asked me to water all (water all, waterfall) of her flowers this afternoon.

4a. Invertebrates are creatures without a backbone (backbone, back one) but usually have an exoskeleton.

4b. Marilyn had to have her backbone (backbone, back one) examined by a specialist because of her pain.

4c. After daylight savings I forgot to turn the clock back one (back one, backbone) hour last year.

4d. I think we should walk back one (back one, backbone) block and eat at that Chinese restaurant.

- 5a. The round red candy that burns the mouth is called a fireball (fireball, fire all) and I like them.
- 5b. The sorceress cast a spell that shot a magnificent fireball (fireball, fire all) at her foe.
- 5c. The boss became mad and threatened to fire all (fire all, fireball) of the employees responsible.
- 5d. Dennis opted to hastily fire all (fire all, fireball) of the employees that were late to work.
- 6a. The amateur quarterback passed the football (football, foot all) to his teammate.
- 6b. The wall was discolored from the dirty football (football, foot all) being thrown at it.
- 6c. Lee kicked the ball with her weaker foot all (foot all, football) the way across the soccer field.
- 6d. Michelle plunged her entire foot all (foot all, football) the way into the freezing water.
- 7a. Pitchers throw underhand in softball, as opposed to overhand (overhand, over and) like in baseball.
- 7b. I was never able to learn overhand (overhand, over and) pitching although I tried several times.
- 7c. I was wondering if Mary can come over and (over and, overhand) play with me after school.
- 7d. Stephanie handed the stolen pencil over and (over and, overhand) looked ashamed of herself.
- 8a. In tennis I have a strong forehand and backhand (backhand, back and) so I win most of my matches.
- 8b. Christopher used his powerful backhand (backhand, back and) to win the tennis match against his dad.
- 8c. My dad said to lift heavy objects with your legs instead of your back and (back and, backhand) arms.
- 8d. Robert looked around in the back and (back and, backhand) he found two skunks violently fighting.
- 9a. Bugs with a yellow blinking light are called fireflies (fireflies, fire lies) and are fun to catch.
- 9b. Amy always loved watching the fireflies (fireflies, fire lies) in her yard on warm summer nights.
- 9c. The arsonist who was guilty for setting a small fire lies (fire lies, fireflies) often to her mom.
- 9d. Jane said that near to the fire lies (fire lies, fireflies) the cooking equipment to make breakfast.
- 10a. Instead of tracing a circle, we were asked to draw it freehand (freehand, free and) in art class.
- 10b. Pictures that are not drawn freehand (freehand, free and) always look more professional.

10c. The sign on the box of puppies said they were free and (free and, freehand) could be adopted.

10d. Last summer I worked for free and (free and, freehand) got some great experience in politics.

11a. Unfortunately my wonderful dream turned into a horrible nightmare (nightmare, night are) last night.

11b. Kerry told John about the weird nightmare (nightmare, night are) she had had last week.

11c. Kids who always wake up in the middle of the night are (night are, nightmare) likely to have insomnia.

11d. The people we saw running in the night are (night are, nightmare) probably doing a scavenger hunt.

12a. After cleaning the ice from her car, Kim playfully threw a snowball (snowball, snow all) at her son.

12b. Since we wanted to go skiing, we were hoping it would snow all (snow all, snowball) weekend.

12c. Sarah heard about the potential snow all (snow all, snowball) afternoon as she watched the news.

12d. Mr. Shapiro was angry when a large snowball (snowball, snow all) hit him right in the head.

13a. In order to use the new printer, we needed to download software (software, soft are) from Microsoft.

13b. Olivia refused to purchase software (software, soft are) when she could download it instead.

13c. The feather pillows that are very soft are (soft are, software) kept in the hall closet.

13d. Could you please tell me how soft are (soft are, software) these strange vegetables supposed to be?

14a. Recess is fun since my elementary school built a new playground (playground, play round) last summer.

14b. The kids visited the fancy playground (playground, play round) in Central Park in New York.

14c. The young children did not want to sleep, they wanted to play round (play round, playground) the camp.

14d. The mischievous boy just couldn't play round (play round, playground) his own neighborhood.

15a. The student went to the Sahara to measure its annual rainfall (rainfall, rain all) and temperatures.

15b. Stella could not believe how little rainfall (rainfall, rain all) the midwest received last summer.

15c. The weatherman said that in April it is going to rain all (rain all, rainfall) of the time.

15d. Andy was worried about the rain all (rain all, rainfall) morning since he wanted to go hiking.

16a. The secretary learned a system of writing quickly called shorthand (shorthand, short and) on Tuesday.

16b. Valerie was surprised she had to learn shorthand (shorthand, short and) in her typing class.

16c. Next to his tall brother, Bob seemed too short and (short and, shorthand) did not make the team.

16d. I had always secretly thought that my sister was short and (short and, shorthand) very unattractive.

17a. Sam bought a new screwdriver at the local hardware (hardware, hard are) store last weekend.

17b. Ralph recently purchased some new hardware (hardware, hard are) for his company's computer.

17c. My professor thinks that homeworks that are extremely hard are (hard are, hardware) actually fun.

17d. Sometimes the things that are very hard are (hard are, hardware) the ones you learn the most from.

18a. The desert explorer slowly sank into a patch of quicksand (quicksand, quick and) as he cried for help.

18b. Gina noticed the dangerous quicksand (quicksand, quick and) and warned her friends to avoid it.

18c. Tara wanted to finish her game quick and (quick and, quicksand) then do some studying for her test.

18d. The tacos we ate last night were quick and (quick and, quicksand) easy to make according to Deb.

19a. At the restaurant, the soft music playing in the background (background, back round) set a nice mood.

19b. The workers felt they needed more background (background, back round) information before committing.

19c. On the front of the shirt was a bear, and on the back round (back round, background) objects.

19d. You should check those back round (back round, background) barrels instead of the ones in the front.

- 20a. The doctor said that Pam had an irregular heartbeat (heartbeat, heart eat) and needed medication.
- 20b. The runner checked her strong heartbeat (heartbeat, heart eat) to see if she was reaching her target.
- 20c. The cardiologist said that for a healthy heart eat (heart eat, heartbeat) plenty of vegetables daily.
- 20d. Since you have a bad heart eat (heart eat, heartbeat) lots of vegetables and exercise every day.
- 21a. For the wedding, Sue was going to be a junior bridesmaid (bridesmaid, brides aid) and help with plans.
- 21b. Molly hated the ugly bridesmaid (bridesmaid, brides aid) gown that she had to wear to the wedding.
- 21c. I became a wedding planner to give grooms and brides aid (brides aid, bridesmaid) with their weddings.
- 21d. The travel agent wanted to give brides aid (brides aid, bridesmaid) in selecting the perfect vacation.
- 22a. Instead of depositing money, Todd had to withdraw (withdraw, with raw) a bunch from his account.
- 22b. Christopher's father decided to withdraw (withdraw, with raw) himself from the race for senator.
- 22c. To eat healthier, Sara decided to have a salad with raw (with raw, withdraw) tomatoes and carrots.
- 22d. I ate the greasy hamburger with raw (with raw, withdraw) tomatoes and lots of cheese.
- 23a. We slept in tents at the secluded campground (campground, camp round) in the hills of Montana.
- 23b. Her family always vacationed at a local campground (campground, camp round) rather than going away.
- 23c. The hikers decided to stop and set up camp round (camp round, campground) an old fire pit.
- 23d. Ralph and Marie were told they couldn't camp round (camp round, campground) the west side of the lake.
- 24a. Tom picked the lock using Sally's metal hairpin (hairpin, hair in) before the alarm was sounded.
- 24b. Gail poked the boy with her sharp hairpin (hairpin, hair in) to get him to pay attention.
- 24c. The bratty boy pulled the girl's hair in (hair in, hairpin) all sorts of painful directions.
- 24d. After much thinking, Tina decided to put her hair in (hair in, hairpin) a bun for the fancy party.

Appendix C

Experimental Sentences for Experiment 4

Version (a) shows the compound word target, and version (b) shows the monomorphemic target. The three types of preview are shown in parentheses in the following order: correct preview, lexeme incorrect length preview, nonword incorrect length preview.

- 1a. The student collected the extra popcorn (popcorn, pop orn, popc rn) and ate it while he watched the film.
- 1b. The student collected the extra diploma (diploma, dip oma, dipl ma) and showed it to his proud parents.
- 2a. She complained about the awful backlog (backlog, back og, bac log) that was caused by the broken computer.
- 2b. She complained about the awful mustard (mustard, must rd, mus ard) that was provided in the restaurant.
- 3a. The girl wanted to ask the young midwife (midwife, mid ife, midw fe) if her mother would be okay.
- 3b. The girl wanted to ask the young juggler (juggler, jug ler, jugg er) if she could have a go.
- 4a. The manager knew that the noisy highway (highway, high ay, hig way) was always quieter at night.
- 4b. The manager knew that the noisy factory (factory, fact ry, fac ory) was unpleasant to work in.
- 5a. She decided to put the fresh sawdust (sawdust, saw ust, sawd st) into a pile near the garage.
- 5b. She decided to put the fresh lettuce (lettuce, let uce, lett ce) into a sealed container in the fridge.
- 6a. She wanted to get the special haircut (haircut, hair ut, hai cut) before the party on Saturday.
- 6b. She wanted to get the special costume (costume, cost me, cos ume) before the shop closed on Friday.
- 7a. She thought that the great seafood (seafood, sea ood, seaf od) was beautifully presented at the restaurant.
- 7b. She thought that the great bargain (bargain, bar ain, barg in) was very good value for money.
- 8a. He especially liked the nice postman (postman, post an, pos man) because he always had a friendly smile.
- 8b. He especially liked the nice texture (texture, text re, tex ure) because it reminded him of a pebble beach.
- 9a. In Japan the popular seaweed (seaweed, sea eed, seaw ed) is served as a starter in many restaurants.
- 9b. In Japan the popular lottery (lottery, lot ery, lott ry) is played by many elderly people.

10a. The man stood by the damaged mailbox (mailbox, mail ox, mai box) as he watched the neighbor's children.

10b. The man stood by the damaged shuttle (shuttle, shut le, shu tle) as he waited for the engineer to arrive.

11a. She described the fabulous skyline (skyline, sky ine, skyl ne) as the best view in the world.

11b. She described the fabulous bayonet (bayonet, bay net, bayo et) as a beautiful but dangerous weapon.

12a. He looked for another sandbag (sandbag, sand ag, san bag) because the house was still flooding.

12b. He looked for another tornado (tornado, torn do, tor ado) because of the warnings on the weather forecast.

13a. The woman laughed at the pathetic pancake (pancake, pan ake, panc ke) when she got it stuck to the ceiling.

13b. The woman laughed at the pathetic fanatic (fanatic, fan tic, fana ic) when he fell off the box he was on.

14a. In the story the nervous caveman (caveman, cave an, cav man) went into the forest to hunt.

14b. In the story the nervous steward (steward, stew rd, ste ard) went into the cockpit to see the pilot.

15a. Suddenly he realized that the annoying setback (setback, set ack, setb ck) might cause serious delays.

15b. Suddenly he realized that the annoying settler (settler, set ler, sett er) might be hiding in the woods.

16a. He walked towards the first doorway (doorway, door ay, doo way) where his mother was waiting for him.

16b. He walked towards the first pasture (pasture, past re, pas ure) where the cows were grazing.

17a. He was told that the special lowland (lowland, low and, lowl nd) was home to some rare plant species.

17b. He was told that the special tenancy (tenancy, ten ncy, tena cy) was only a temporary arrangement.

18a. She knew that the simple rosebud (rosebud, rose ud, ros bud) may not flower but she picked it anyway.

18b. She knew that the simple massage (massage, mass ge, mas age) may not soothe her aches and pains.

19a. He knew about the annoying keyhole (keyhole, key ole, keyh le) that was very awkward to use.

19b. He knew about the annoying fatigue (fatigue, fat gue, fati ue) that was a side effect of the treatment.

20a. He needed the other bellboy (bellboy, bell oy, bel boy) to help him move the luggage.

20b. He needed the other bellows (bellows, bell ws, bel ows) to get some more air into the fire.

21a. We spotted the little ashtray (ashtray, ash ray, asht ay) under the pile of magazines.

21b. We spotted the little penguin (penguin, pen uin, peng in) under the platform in the enclosure.

22a. I was worried that the scary bulldog (bulldog, bull og, bul dog) might bite someone.

22b. I was worried that the scary pumpkin (pumpkin, pump in, pum kin) might frighten the little baby.

23a. He was excited about the valuable baseball (baseball, base all, bas ball) because the players had signed it.

23b. He was excited about the valuable painting (painting, pain ing, pai ting) because he would be able to sell it.

24a. My mother really liked the little hotplate (hotplate, hot late, hotp ate) and she used it to cook simple meals.

24b. My mother really liked the little artifact (artifact, art fact, arti act) and she asked to take a photograph.

25a. The boy did not want the boring wishbone (wishbone, wish one, wis bone) to be given to him.

25b. The boy did not want the boring waitress (waitress, wait ess, wai ress) to talk to him when he was eating.

26a. The crowd watched the huge aircraft (aircraft, air raft, airc aft) as it landed on the runway.

26b. The crowd watched the huge carnival (carnival, car ival, carn val) as it moved slowly through the town.

27a. My friend really liked the terrific swimsuit (swimsuit, swim uit, swi suit) that I gave her for her birthday.

27b. My friend really liked the terrific sandwich (sandwich, sand ich, san wich) that she ate in the famous deli.

28a. I heard about the awful dogfight (dogfight, dog ight, dogf ght) that had happened in the small town.

28b. I heard about the awful cataract (cataract, cat ract, cata act) that my friend's grandfather had.

29a. In the night the strange sailboat (sailboat, sail oat, sai boat) silently arrived in the harbor.

29b. In the night the strange smuggler (smuggler, smug ler, smu gler) silently crept down to the beach.

30a. The baby watched the large haystack (haystack, hay tack, hays ack) as the kitten climbed out of it.

30b. The baby watched the large pendulum (pendulum, pen ulum, pend lum) as the grandfather clock ticked loudly.

31a. She waited to know the final deadline (deadline, dead ine, deadl ne) before she started working on the project.

31b. She waited to know the final sentence (sentence, sent nce, sente ce) before she decided to make an appeal.

32a. He was known to be a genuine nobleman (nobleman, noble an, nobl man) who was on good terms with the King.

32b. He was known to be a genuine romantic (romantic, roman ic, roma tic) who always brought his girlfriend flowers.

33a. He showed the scruffy passport (passport, pass ort, passp rt) to the immigration official.

33b. He showed the scruffy bandanna (bandanna, band nna, banda na) to his younger brother who wanted to try it on.

34a. He asked me about the normal watchman (watchman, watch an, watc man) because someone else was on duty tonight.

34b. He asked me about the normal bracelet (bracelet, brace et, brac let) because today I was wearing another one.

35a. She explained that the horrible stonework (stonework, stone ork, ston work) had been completed by the owner.

35b. She explained that the horrible apartheid (apartheid, apart eid, apar heid) had been very difficult for people.

36a. She asked about the famous farmhouse (farmhouse, farm ouse, farmh use) that her parents had told her about.

36b. She asked about the famous billiards (billiards, bill ards, billi rds) that the private club was known for.

37a. The girl liked the little sunflower (sunflower, sun lower, sunf ower) that was growing in the garden.

37b. The girl liked the little armadillo (armadillo, arm dillo, arma illo) that she saw at the zoo.

38a. Everyone knew that the important sandstone (sandstone, sand tone, san stone) was being analyzed today.

38b. Everyone knew that the important messenger (messenger, mess nger, mes enger) was going to visit the house.

39a. He watched the hungry boyfriend (boyfriend, boy riend, boyf iend) as he ate in his sister's kitchen.

39b. He watched the hungry carnivore (carnivore, car ivore, carn vore) as it paced around the cage.

40a. She hated the awful corkscrew (corkscrew, cork crew, cor screw) because the cork never came out in one piece.

40b. She hated the awful pollution (pollution, poll tion, pol ution) because it gave her respiratory problems.

41a. He mended the intricate ultraviolet (ultraviolet, ultra iolot, ultr violet) equipment that was used in manufacturing.

41b. He mended the intricate electronics (electronics, elect onics, elec ronics) equipment that was needed for the project.

42a. I went to the friendly campground (campground, camp round, campg ound) to ask about availability.

42b. I went to the friendly pathologist (pathologist, path logist, patho ogist) to ask for some advice.

Compound Target: Correct Length Preview

Michael used his strong backhand many times during the long tennis match.
*

Michael used his strong backhand many times during the long tennis match.
*

Compound Target: Incorrect Length Preview

Michael used his strong back and many times during the long tennis match.
*

Michael used his strong backhand many times during the long tennis match.
*

Two-Word Target: Correct Length Preview

Michael used his strong back and legs to lift the heavy couch for Suzy.
*

Michael used his strong back and legs to lift the heavy couch for Suzy.
*

Two-Word Target: Incorrect Length Preview

Michael used his strong backhand legs to lift the heavy couch for Suzy.
*

Michael used his strong back and legs to lift the heavy couch for Suzy.
*

Figure 1.

An illustration of the boundary technique using example sentences from Experiment 1. The asterisk indicates the reader's eye position in text. Prior to fixating the target word(s) either a correct or incorrect length preview is provided. Once the reader's eyes cross the invisible boundary located after the pretarget word, the target word is displayed.

Table 1
Entire Target Region Analyses for Experiment 1: Mean First Fixation Duration, First-Pass Duration, Total Fixation Duration, and Initial Landing Position on the Target

Target word and preview	First fixation duration		Landing position		First-pass duration		Total fixation duration	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Compound								
Correct	299	42	3.43	0.85	359	65	405	102
Incorrect	300	40	2.88	0.99	395	80	450	95
Two word								
Correct	287	50	2.92	0.94	383	75	452	123
Incorrect	312	38	3.33	0.84	419	94	520	147

Table 2
Experiment 1: Mean First Fixation Duration, Gaze Duration, and Percentage of Fixations on the First Lexeme for the First Lexeme Analyses

Target word and preview	First fixation duration		Gaze duration		Percentage of fixations	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Compound						
Correct	299	57	314	64	74	20
Incorrect	293	34	316	58	78	18
Two word						
Correct	284	57	303	56	79	20
Incorrect	316	46	330	58	72	17

Experiment 2: Mean First Fixation Duration, Gaze Duration, and Landing Position on the Target Word as a Function of the Four Parafoveal Preview Conditions

Table 3

Preview	First fixation duration		Gaze duration		Landing position	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Correct	278	41	346	61	3.16	.87
Similar letter	284	37	340	46	3.20	1.02
Dissimilar letter	284	42	350	69	3.15	1.10
Length incorrect	283	44	376	78	2.54	.81

Table 4
Experiment 3: Mean First Fixation Duration, First-Pass Duration, Total Fixation Duration, and Initial Landing Position on the Target Word for the Entire Target Region Analyses

Context and preview	First fixation duration		Landing position		First-pass duration		Total fixation duration	
	M	SD	M	SD	M	SD	M	SD
Compound target word								
Predictable								
Correct	267	44	3.59	0.83	311	68	336	84
Incorrect	291	51	3.31	0.96	348	83	375	89
Neutral								
Correct	302	50	3.28	0.97	355	83	406	107
Incorrect	301	60	3.05	1.01	391	97	442	128
Two-word target word								
Predictable								
Correct	263	44	3.08	0.88	348	87	406	130
Incorrect	302	62	3.23	0.79	415	112	523	183
Neutral								
Correct	277	56	3.07	0.85	397	122	475	141
Incorrect	304	67	3.28	0.97	434	130	551	157

Table 5
Experiment 3: Mean First Fixation Duration, Gaze Duration, and Percentage of Fixations on the First Lexeme for the First Lexeme Analyses

Context and preview	First fixation duration		Gaze duration		Percentage of fixations	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Compound target word						
Predictable						
Correct	269	51	279	63	73	24
Incorrect	285	59	299	60	76	24
Neutral						
Correct	297	55	310	57	78	21
Incorrect	294	60	313	68	82	19
Two-word target word						
Predictable						
Correct	268	52	272	55	75	19
Incorrect	295	65	312	72	76	21
Neutral						
Correct	276	64	292	71	79	20
Incorrect	306	69	331	93	73	21

Table 6
Experiment 4: Mean First Fixation Duration, Gaze Duration, Total Fixation Duration, and Initial Landing Position on the Target Word

Target word and preview	First fixation duration		Landing position		Gaze duration		Total fixation duration	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Compound								
Correct	297	96	3.47	1.81	344	129	392	182
Lexeme	308	102	3.02	1.77	380	150	423	174
Nonword	313	100	3.03	1.72	382	147	424	191
Monomorphemic								
Correct	296	95	3.52	1.80	340	150	405	239
Lexeme	311	98	3.18	1.72	377	150	436	226
Nonword	305	98	3.05	1.76	376	177	432	230

Table 7
 Probability of Refixation Over the Entire Target Region (the Compound or Both of the Two Words) for Experiment 1 and Experiment 3 (Collapsed Over Sentence Context)

Target word and preview	Experiment 1		Experiment 3	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Compound				
Correct	0.216	0.188	0.199	0.178
Incorrect	0.347	0.233	0.294	0.132
Two word				
Correct	0.337	0.211	0.323	0.143
Incorrect	0.357	0.235	0.365	0.159