# Word Recognition During Reading

Wonil Choi

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Approved by:

Peter C. Gordon

Neil Mulligan

Mark Hollins

Joseph Hopfinger

Kelly S. Giovanello

## ABSTRACT

WONIL CHOI: Word Recognition During Reading
(Under the direction of Peter C. Gordon)

Four eye-tracking experiments were conducted to understand how sentential context and lexical factors affect word recognition during reading. Experiment 1 examined whether readers use preceding sentential context to pre-activate a specific word and whether any processing cost is found when the prediction is wrong. The results showed that readers obtain a processing benefit when the target word was expected based on a strongly constraining context, whereas they experienced a processing cost when the target word was not the expected one even though it was semantically plausible into the context. Experiment 2 investigated how word recognition is influenced by prior activation of lexical information due to word repetition within a sentence. The result showed that gaze duration on a target word with many neighbor words was shorter relative to a target word with few neighbors but only when the target word was repeated; when the target word was not repeated gaze duration did not differ as a function of neighborhood size. This interaction indicates that word recognition at the orthographic level can be influenced by repetition-induced lexical activation. The null effect of the orthographic neighborhood size in the unrepeated condition was unexpected. Previous studies using the lexical-decision task have consistently shown a facilitative effect of orthographic neighborhood size. Therefore, Experiment 3 and 4 studied the role of neighborhood size during sentence reading with better controlled stimuli. The results showed an opposite pattern of results between gaze duration and word skipping such that gaze duration was longer when a word had many neighbors than when one had few neighbors, whereas skipping rates were higher in the many neighbor condition than in the few condition. The results indicate that having many neighbor words inhibits processes responsible for precise recognition of a word, but that it facilitates word skipping by increasing global lexical activity.

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## Introduction

Despite years of study, the question of how different types of contextual information affect the operation of cognitive processes remains intriguing. Word recognition during language comprehension is an excellent domain in which to address this question because words are the critical juncture between abundant sources of word-intrinsic linguistic information (e.g., letters, phonemes, letter-clusters, syllables, word neighbors, and lexical meaning) and word-external information (e.g., context at the syntactic, semantic, or discourse levels) which may jointly or independently affect the process of word recognition. The influence of sentential contexts on word recognition can be investigated by employing a sentence-reading paradigm in which subjects read a sentence with an embedded target word. Measurement of subjects' reading, using eye-tracking or electrophysiological measures, provides evidence about word recognition during comprehension of extended linguistic material without the need for meta-linguistic judgments such as those employed in lexical-decision or semantic-judgment tasks. Here I report four eye-tracking experiments that address how the linguistic information activated by preceding sentential contexts and by a currently processed word affects word recognition during sentence reading. These experiments test hypotheses about the level of information that can be activated based on preceding sentential contexts, the manner in which the already activated information and linguistic features of language input interact when recognition of words occurs during sentence reading, and how orthographic characteristics of words influence recognition.

## Characteristics of words that influence recognition

**Letter clusters.** A substantial body of empirical work using methods for studying recognition of isolated words has shown that sublexical components (e.g., frequency of monogram, bigram, or trigram) influence word recognition (Biederman, 1966; Broadbent & Gregory, 1968; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Waters & Seidenberg, 1985). Also, a number of studies using eye-tracking during reading have shown that orthographic familiarity of the letter clusters affects fixation durations and positions on words (Hyönä, 1995; Lima & Inhoff, 1985; Pynte, Kennedy, & Murray, 1991; Radach, Inhoff, & Heller, 2004; Vonk, Radach, & van Rijn, 2000; White & Liversedge, 2004, 2006a, 2006b). For example, White & Liversedge (2004) showed that the orthographic familiarity of the word's initial letter cluster affects the fixation position for the word. White (2008) also found the orthographic familiarity of letter clusters influences fixation durations on target words.

**Word Frequency**. Frequent words are recognized faster than infrequent words, a robust phenomenon both in sentence reading and in isolated-word recognition tasks. In a reading paradigm, Inhoff and Rayner (1986) observed a clear word-frequency effect during sentence reading even when word length was controlled (see also Rayner and Duffy, 1986). Frequent words have shorter fixation durations (Inhoff and Rayner, 1986; Rayner and Duffy, 1986; Rayner, Sereno, & Raney, 1996; White, 2008) and higher skipping rates than infrequent words (for a review, see Brysbaert, Drieghe, & Vitu, 2005). Because word frequency is correlated with many other factors such as word length, frequency of letters and letter sequences (e.g., monogram, bigram, and trigram frequencies), age of acquisition, and word familiarity, many studies have attempted to isolate word-frequency effects from these related factors. For example, Rayner et al. (1996) reported shorter fixation durations and higher skipping rates on high frequency words relative to low frequency words with monogram- and bigram-type frequency controlled.

**Word familiarity**. One difficulty associated with trying to isolate variables that affect word recognition is that many lexical variables have strong intercorrelations. For example, word frequency is highly correlated with word familiarity, as measured by subjects' ratings. Juhasz and Rayner (2003) used a multiple regression analysis in an attempt to isolate distinct effects of familiarity and frequency. Effects of word familiarity were found on fixation durations even when word frequency and age of acquisition were controlled (see also Williams & Morris, 2004).

**Age of Acquisition (AoA).** Age of Acquisition (hereafter AoA) is also highly correlated with other variables like word frequency, word familiarity, word length, and imageability. Juhasz and Rayner (2003, 2006) tested whether AoA had unique effects on word recognition during sentence reading. Juhasz and Rayner (2006) manipulated AoA while controlling for other confounding variables. They reported a significant AoA effect for first-pass reading time measures, indicating that AoA affects word recognition during reading over and above various measures of word frequency (e.g. K-F frequency (Kucera and Francis, 1967), The Educator's Word Frequency Guide (WFG) reflecting cumulative word frequency (Zeno, Ivens, Hillard, & Duvvuri, 1995)).

**Ambiguity of words.** Since Rayner and Duffy (1986), several experiments have examined how lexical ambiguity is resolved during sentence reading (for a review, see Duffy, Kambe, & Rayner, 2001). When prior context is neutral (unbiased to one meaning of an ambiguous word), fixation durations are longer for balanced ambiguous words (where the alternative meanings are equally frequent, e.g., *break*) relative to unambiguous control words, while fixation durations do not differ between unbalanced ambiguous words (where the alternative meanings differ substantially in frequency, e.g., *bank*), and control words. However, when prior context is biased to the subordinate meaning of the ambiguous word, subjects look longer at the ambiguous word than the control word, which is referred to as the subordinate-bias effect (Pacht & Rayner, 1993; Rayner, Cook, Juhasz, & Frazier, 2006).

Two different models have been suggested to explain the lexical ambiguity phenomenon: the reordered access model (Duffy, Morris, & Rayner, 1988) and the integration model (Rayner & Frazier, 1989). In both models, the meanings of an ambiguous word are available in the order of the frequency for each meaning. In the reordered access model, sentential context also influences lexical access, which means that the predetermined access order based on the meaning frequency of an ambiguous word can be reordered by the sentential context. However, the integration model posits that only meaning frequency of the ambiguous word affects the speed of lexical access, whereas the sentential context influences post-lexical integration processing. Eye-movement data support the reordered access model over the integration model (Dopkins, Morris, & Rayner, 1992; Sereno, O'Donnell, & Rayner, 2006; Sheridan, Reingold, & Daneman, 2009). For example, Sheridan et al. (2009) contrasted the single-meaning context in which the subordinate meaning of the ambiguous word was instantiated by the prior context without excluding the dominant meaning of the word (e.g. "The man with a toothache had a *crown* made by the best dentist in town") with the dual-meaning pun context in which the preceding context supports both the subordinate and dominant meaning (e.g. "The king with a toothache had a *crown* made by the best dentist in town) to test which model can better explain the eye-movements data. The reordered access model predicts longer fixation durations on the ambiguous word in the single-meaning context than in the dual-meaning context. In contrast, the integration model predicts no difference for fixation durations in the two context conditions because the dominant meaning was not excluded even in the single-meaning context. The results clearly supported the reordered access model in demonstrating that first-pass fixation durations on ambiguous words were longer in the single-meaning context relative to the dual-meaning context.

**Word Neighborhood.** A question about whether word recognition is affected by orthographically and/ or phonologically similar words has been one of central aspects in building a word recognition model. Many studies on word recognition have demonstrated the neighbor words affect recognition of a target word. However, the manner in which the neighbors influence word recognition is relatively complicated and empirical results are not conclusive. In this section, I focus on the role of visually similar words (hereafter referred to as orthographic neighbors) on visual word recognition as it is relevant to the current study.

Orthographic neighbor words can be defined as the set of words that can be created by changing one letter of a word while keeping letter positions constant (Coltheart, Davelaar, Jonasson, & Besner, 1977). In alphabetical languages, especially in English, number of neighbor words affect target word processing in some isolated-word tasks (for a review, see Andrews, 1997; Balota, Yap, & Cortese, 2006). For example, in a lexical decision task, reaction times to words with many neighbor words are faster than those to frequency-matched words with few neighbor words, a phenomenon known as the neighborhood size effect (Andrews, 1989; 1992). However, the facilitative effect of orthographic neighbors was rarely observed in perceptual identification tasks or semantic categorization tasks, implying that the effects of orthographic neighbors can be modulated by the specific goals of a given task. Pollatsek, Perea, & Binder (1999) attempted to investigate whether the effects of neighborhood size were observed when a word was embedded in a sentence where no meta-linguistic judgment was needed. When the number of neighbor words was manipulated with the number of higher frequency neighbors controlled, the first-pass fixation duration measures didn't show any difference between the two neighborhood conditions. However, regression analyses showed that increasing the number of higher-frequency neighbors had a strong inhibitory effect but increasing the number of lower frequency neighbors had a very weak facilitative effect on the target word. Taken together, the facilitative effects of neighborhood size are very fragile and not well understood. The current study attempts to further examine the effects of neighborhood size during sentence reading.

Another important issue surrounding the role of neighbor words in recognizing a word is how higher-frequency neighbors influence processes of word recognition. The neighborhood frequency effect that reaction times to low-frequency words with higher frequency neighbors are slower than those to low-frequency words without higher frequency neighbors has been consistently observed in many European languages like French, Spanish, and Dutch (Andrews, 1997). However, in English, the neighborhood frequency effect has been elusive and the pattern of results have been very inconclusive in both isolated word recognition tasks and sentence reading (e.g., facilitative effect in Forster & Shen, 1996; null effect in Sears, Campbell, & Lupker, 2006; inhibitory effect in Perea & Pollatsek, 1998). Sears et al. (2006) concluded "…higher frequency neighbors have little, if any, effect on the identification of English words" (p. 1040). However, a recent study by Slattery (2009) reported that the inhibitory effect of higher frequency neighbors (hereafter HFN) was modulated by the extent to which the HFN was semantically fitted into the preceding contexts. Specifically, the inhibitory effect of a HFN was observed when the sentential context fit well with both a target word and a HFN but the effect disappeared when the context fit only a target word. Although the inhibitory effects of HFN during normal sentence reading seem to be delicate, a few studies using priming paradigms in which the HFN actually appears earlier in a sentence have shown stronger inhibitory effects of HFN during reading (Nakayama, Sears, & Lupker, 2010; Paterson, Liversedge, & Davis, 2009). For example, Paterson et al. (2009) found that reading times were slower on a target word when one of its neighbors appeared earlier in the sentence, but did not find any influence of that neighbor's word frequency.

## Characteristics of context that influence word recognition

**Lexical Repetition Priming.** Word identification is facilitated by repetition of a word, a finding that has been established in a large number of studies using the masked priming technique where a lowercase prime word (e.g., house) is briefly presented at the center of a screen (about 50ms), followed by an uppercase target word (e.g., HOUSE) (e.g., Forster

& Davis, 1984). Recent studies using eye tracking during readings have also shown that repetition priming can occur when there are intervening words between a prime and a target (Choi & Gordon, in press*a*; in press*b*; Gordon, Plummer, & Choi, 2013; Ledoux, Gordon, Camblin, & Swaab, 2007; Liversedge, Pickering, Clayes, & Branigan, 2003; Lowder, Choi, & Gordon, in press; Traxler, Foss, Seely, Kaup, & Morris, 2000). For example, Lowder et al. observed a significant repetition priming effect using an intra-sentential priming technique such that the first-pass fixation durations on the target word (Herman in 1a and 1b) were shorter in the repeated word condition as compared to the unrepeated word condition.

(1a) After lunch, ***Herman*** and Amanda moved the cabinet so that **Herman** …(Repetition)

(1b) After lunch, ***Robert*** and Amanda moved the cabinet so that **Herman** …(New)

A few studies have examined the locus of the repetition priming effect in an intra-sentential priming paradigm. Traxler et al. (2000) assumed that if the repetition priming effect occurs at a discourse (or semantic) level, the effect would be observed when a synonym prime is used (e.g., minister versus pastor). However, Traxler et al. did not find any difference in the first-pass fixation durations on the target word (e.g., pastor) when they compared the synonym priming condition (e.g., The minister greeted the pastor yesterday at the post office) to the unrelated priming condition (e.g. The lawyer greeted the pastor yesterday at the post office), leading to the conclusion that repetition priming does not occur at a discourse (or semantic) level of representation. Although the synonyms used in Traxler et al.'s study are semantically related, they are two independent noun phrases in the sentence, which can generate no semantic (or discourse) overlap between the prime and the target. One could argue that the absence of the synonym priming effect in Traxler et al. was due to the discourse independency between the prime and the target even though they are synonyms. However, Choi & Gordon (in press*a*) compared sentences like 2a and 2b, in which a target word, *bar,* was primed by either *bar* (repetition prime) or *club* (synonym prime). They found the repetition priming effect such that the repetition condition had shorter fixation durations and higher skipping rates as compared to the synonym condition.

(2a) James knew that his friend owned a **bar** in town, … so his friend's **bar** would be closed.

(2b) James knew that his friend owned a **club** in town, … so his friend's **bar** would be closed.

A few studies using a masked priming paradigm have suggested that the repetition priming effect occurs at the sub-lexical orthographic/phonological form level (Holcomb & Grainger, 2006; Perea & Rosa, 2000). As discussed above, the number of neighbors of a word matters in word recognition such that words with many neighbors are processed faster than ones with few neighbors (see Andrews, 1997 for a review). In general, the facilitative effect of neighbors can be interpreted in terms of stronger activation of letter clusters at the pre-lexical level or faster transition from orthographic/phonological patterns to whole-word form (Grainger & Holcomb, 2009). Recent ERP studies using an isolated word recognition paradigm have shown that the facilitative effect of neighbors is captured by the N250 component, reflecting the mapping process of pre-lexical letter or letter clusters onto the whole-word form (Massol, Grainger, Dufau, & Holcomb, 2010). If word repetition affects the level in which the pre-lexical to lexical mapping occurs, we would expect to see an interaction between word repetition and neighborhood size. An interaction was found by Perea & Rosa (2000) in Spanish using a masked priming paradigm such that the magnitude of the neighborhood size effect was smaller when words were repeated as compared to when they were unrepeated, indicating that the effect of neighborhood can be modulated by prime and target repetition. However, Perea & Rose and Grainger and colleagues' studies did not employ an intra-sentential priming paradigm. Further research is needed to establish the exact locus of the effect of repetition priming in an intra-sentential priming paradigm.

**Semantic congruence of a word in context.** The influence of semantic congruence on word recognition is one of the most intriguing subjects in language comprehension, with many studies showing that words are processed more easily when their meaning fits with the meaning of the preceding context than when it does not. This effect might be due to greater ease of integrating the meaning of the word with the meaning of the preceding context. However, semantically-congruent words are often more predictable from preceding sentential contexts than are semantically incongruent words, which leads to the possibility that semantic congruence effects emerge from a process of prediction rather than from a process of integration. The level at which prediction might underlie semantic congruence effects is still debated. Early studies in late 70s and early 80s using traditional behavioral methods such as lexical decision and naming have suggested that the effects of semantic congruence occur at the lexical-semantic level (Fischler & Bloom, 1979; Schuberth, Spoehr, & Lane, 1981; Schwanenflugel & Shoben, 1985; Schwaneflugel & LaCount, 1988; Stanovich & West, 1981; 1983; West & Stanovich, 1982). For example, Stanovich and West (1981) had participants read a sentential fragment and then name a final word of the sentence as quickly as possible. They reported a target preceded by a semantically congruent context was named faster than that by a neutral context. For example, the reaction time for the word *bridge* was faster in the congruent condition like “The boy swam underneath the *bridge*” than in the neutral condition, which consisted of three presentations of the word “the” as in “the the the *bridge*”. Moreover, there was no inhibitory effect for a word (e.g., *bridge*) preceded by a semantically incongruent context (e.g., The clothes hung inside the _____) relative to a neutral context, showing that the reaction times didn’t differ between the two conditions. These results suggest that the processing of target words was facilitated by autonomous semantic activation based on the preceding sentential contexts, not by conscious expectation of the target word. Schwaneflugel & LaCount (1988) attempted to further investigate the extent to which the sentential context activates a target word. They manipulated the degree of sentential constraint (high vs. low) and measured reaction times to a target word in a lexical decision task. Both an expected (e.g., money) and an unexpected but semantically related target word (e.g., coin) were responded to faster in a low constraint condition (e.g., Hank reached into his pocket to get the _______) as compared to in a neutral condition (The last word of this sentence is _______), but reaction times for an unexpected and unrelated word (e.g., watch) did not differ in the two sentential fragment conditions. However, only an expected word (e.g., bath) was faster in a highly constrained condition (e.g., The tired mom gave her dirty child a _______) relative to in a neutral condition. The reaction times for both an unexpected but related word (e.g., shower) and an unexpected and unrelated word (e.g., scolding) did not differ between the highly constrained and the neutral conditions.

These behavioral studies support the view that semantic congruence in context can pre-activate semantic features of an upcoming target, which can affect processing of the target. Schwaneflugel & LaCount (1988) argued that sentential contexts can pre-activate semantic features of the possible target words based on spreading activation, leading to facilitative effects when the actual target is well-fit into the pre-activated semantic features (see Stanovich & West, 1983 for a similar claim). Moreover, the results imply that the scope of semantic activation by sentential contexts is very specific in a highly constraint context, leading to no facilitation for the unexpected but semantically related word. This result suggests that either semantic information pre-activated by the sentential context facilitated target processing, or that the set of word(s) itself was pre-activated by the sentential context. If the latter interpretation is correct, then the word in the unrelated condition (e.g., scolding), when it is preceded by the highly constrained context, should have an inhibitory effect relative to the same word preceded by a neutral context. The result of that comparison, however, did not show any inhibitory effects, supporting the interpretation of the pre-activation of semantic components, and not supporting the interpretation of the pre-activation of specific word(s).

However, other researchers have suggested a different role of semantic congruence in context: ease of semantic integration. This notion argues that sentential context does not predict anything, but creates a more effective integration process (Fodor, 1983; Forster, 1979). For example, early ERP studies have shown that the N400 component is a function of the semantic fit between a context and a subsequent word (Kutas & Hillyard, 1984; Brown & Hagoort, 1993; Hagoort & Brown, 1994). In other words, as a word is semantically better fitted into the prior context, a smaller N400 is observed. Brown & Hagoort (1993) found a semantic priming effect in the N400 time window such that a smaller N400 was elicited by a related prime and target pair as compared to an unrelated prime and target pair when they used unmasked prime words. But when they used masked prime words they did not observe any difference in the N400 components between the related versus the unrelated pairs, indicating that the N400 effect does not reflect automatic spreading activation, but instead reflects ease of integration of the meaning. Kutas & Hillyard (1984) also found a similar effect in the N400 time window using a sentential context instead of a single word context.

However, more recent ERP studies support a different view of the role of semantic congruence (DeLong, Urbach, Groppe, & Kutas, 2011; DeLong, Urbach, & Kutas, 2005; Kutas, Van Patten, & Kluender, 2006). Contextual information automatically pre-activates a certain target word based on top-down information, rather than only activating a discourse (or semantic) level of representation. For example, DeLong et al. (2005) utilized a phonological rule of English to examine the characteristics of context-based prediction. Sentences were constructed varying in cloze probability ranging from 10% to 90%, and half of the sentence-final nouns began with a vowel sound and the rest began with a consonant sound. For instance, given 'The day was breezy so the boy went outside to fly…' the most predictable noun phrase was 'a kite;' however, an unpredictable, but plausible, noun phrase could be 'an airplane'. If contextual information leads to the pre-activation (or anticipation) of an upcoming word, N400 modulation could be elicited even when an article is presented as well as when a final word is presented. The result clearly supported the pre-activation view in that a larger N400 amplitude was observed in the 'an' condition when a word with the article 'a' was more expected compared with when a word with the article 'an' was more expected based on the previous context. Note that the N400 difference began to appear when the article appeared on the screen, implying that an upcoming word's phonological features (i.e., whether the onset of the expected word is a vowel or a consonant) was pre-activated on the basis of prior context before the critical word actually appeared. In addition, DeLong et al. (2011) were interested in what kinds of cost would be elicited when pre-activation based on prior context is wrong. Given that readers actively pre-activate a word based on prior context, they should experience a processing cost when an unexpected word follows the context. Supporting this hypothesis, more N400 negativity in an anterior-frontal region was observed when an unexpected word appeared as compared to when an expected one appeared, demonstrating that there is some cost of pre-activation (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007). Given that one can pre-activate an incoming word based on contextual information, interaction between top-down and bottom-up information should occur when the incoming word is processed.

It is noteworthy to mention that most theoretical accounts of the effect of word predictability and semantic congruence have been developed based on ERP studies in which words are generally presented one after another (Rapid Serial Visual Presentation, RSVP). Although ERP studies have provided valuable information on mechanisms of human sentence processing, the RSVP paradigm may not be an optimal tool for measuring predictability during natural human sentence processing. For example, because a sentence is presented in a word by word manner, participants are not able to regress back to a previous region, leading to a substantial load on working memory.

Moreover, participants are not able to use preview from the parafovea, which is where a lot of useful information is extracted during normal reading (Choi & Gordon, in press*a*; in press*b*; Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, 1998). Another problem with the RSVP paradigm is its relatively slow presentation rate. In the RSVP paradigm, the stimulus onset asynchrony (SOA) is normally anywhere from 400ms to 700ms, which is much slower than the normal speed of reading. Thus, although ERP studies have shed light on how top-down contextual information affects word recognition, these results should be interpreted with caution when generalizing to normal reading behavior.

The effect of word predictability on word recognition has also been studied in natural reading. Ehrlich and Rayner (1981) first reported the word predictability effect using an eye-tracking paradigm during normal reading. They monitored participants' eye movements while they read through a short paragraph. The target word could appear either in a high constraint context or in a low constraint one. The results showed that a highly predictable context, compared to a less predictable context, led to more skipping and shorter first-pass fixation durations on the target word. Since Ehrlich and Rayner (1981), many studies have observed similar effects of contextual predictability (Altarriba, Kroll, Sholl, & Rayner, 1996; Binder, Pollatsek, & Rayner, 1999; Frisson, Rayner, & Pickering, 2005; Rayner, Ashby, Pollatsek, & Reichle, 2004; Staub, 2011). Although these studies have consistently observed that sentential context can facilitate the process of word recognition, a specific mechanism remains unclear.

In sum, previous studies have provided different views on the influence of sentential context on word recognition with respect to the scope of pre-activation of the upcoming word(s). In particular, while there have been substantial debates on how contextual information affects word recognition in the ERP literature, there has been relatively little discussion in the eye tracking during reading literature. The current project employs eye tracking during reading to provide a better understanding of this issue.

## Contextual effects on word recognition

As discussed above, the current state of word processing is influenced both by word-intrinsic and contextual information. How these two sources of information jointly affect the processing of word recognition during sentence reading is a very important question. In this section, I review some of the empirical studies addressing the issue of the interaction between sentential contexts (e.g., word repetition, sentential constraints) and word-internal factors (e.g., word frequency, orthographic neighborhood.

**Word repetition and word frequency.** The repetition effect in word recognition is robust and has been replicated in a range of different methods such as response times (e.g., Forster & Davis, 1984), fixation durations in reading (e.g., Choi & Gordon, in press*a*), ERP waveforms (e.g., Ledoux et al., 2007), and hemodynamic responses in the brain (e.g., Henson, 2003). However, the possibility of an interaction between word repetition and word frequency has yielded inconsistent results, leading to substantial theoretical debates (Bowers, 2003; Forster, Mohan, & Hector, 2003; Masson & Bodner, 2003). Scarborough, Cortese, & Scarborough (1977) reported that the repetition effect was modulated by word frequency such that the repetition effect was smaller for high-frequency words as compared to low-frequency words, which can be referred to as a *frequency-attenuation* effect. In their experiments, an isolated word was presented for 1 second, followed by a word-nonword decision. The results that Scarborough et al. found contradicted search models of word recognition that assume that lexical entries are organized by word frequency in a stable way that is not easily changed by only a one-time exposure (Becker, 1979; Forster, 1976). Forster & Davis (1984) argued that the frequency-attenuation effect reflects strategic use of episodic memory traces, a strategy that is more advantageous for low-frequency than high-frequency words. In support of this idea, they found no frequency-attenuation effect when they used a masked priming paradigm in which the repeated prime word was presented too briefly for participants to notice. Exactly the same results were observed in French (Segui & Grainger, 1990). Forster and Davis (1984) reasoned that the episodic influence of the frequency attenuation effect could occur at a decision stage in which the increased familiarity of a word combined with repetition causes people to execute decisions more quickly. The results of an intra-sentential priming paradigm, however, differ from those obtained by masked priming studies. Lowder et al. (in press) observed the frequency-attenuation effect in an eye-tracking experiment such that there was greater repetition priming for low-frequency proper names as compared to high-frequency ones. This interaction effect cannot be explained by an increase in familiarity leading to rapid processing in a decision stage because there is no overt decision stage in normal reading. It is still unclear why this discrepancy between an intra-sentential priming study and a masked priming study occurs. Further research should investigate how the repetition effect occurs during natural sentence reading, which can provide insight into how words are recognized when people read sentences. Research on the interaction between intra-sentential repetition priming and processing of word related factors has been focused on the effects of word frequency, which occurs at the level of lexical form. There has been little inquiry into the interaction between repetition priming and other types of word related factors.

**Word predictability and word frequency.** Word predictability and word frequency are the strongest factors affecting word recognition during reading. As described above, there is no doubt that each affects some aspects of word recognition. However, with respect to the joint effects of predictability and frequency, investigations have not arrived at the same conclusion. Early behavioral reaction-time studies mostly reported interactions between the two factors (Stanovich & West, 1983; West & Stanovich, 1982). For example, Stanovich and West (1983) examined how the effects of sentential context are modulated by the frequency of target words. They had participants read a sentence fragment (e.g., *The skier was buried in the*…versus *They said that it was the*…), followed by a target word (e.g., snow). Participants were asked to perform a word-nonword decision or to name the target word. They found a significant interaction such that the predictability effect was larger for low- versus high-frequency words. Recent ERP studies have also reported an interaction effect between predictability and word frequency (Dambacher, Kliegl, Hofmann, & Jacobs, 2006; Sereno, Brewer, & O'Donnell, 2003). In the ERP literature, the effect of word predictability and word frequency is typically captured by the N400 waveform, which peaks around 400ms after the onset of a stimulus (Dambacher et al., 2006; DeLong et al., 2005; Federmeier & Kutas, 1999; Kutas & Federmeier, 2011; Kutas & Hilliyard, 1984, cf. Dambacher, Rolfs, Göllner, Kliegl, & Jacobs, 2009; Hauk & Pulvermüller, 2004; Sereno et al., 2003). Dambacher et al. (2006) found a greater N400 effect elicited by word predictability in a low-frequency word condition relative to a high-frequency word condition, which is consistent with the findings of behavioral studies done by Stanovich and West. The observed interaction effect would imply that these two factors jointly influence the same processing stage of word recognition, or suggest, at least, that word recognition should be accomplished by joint cooperation of more than one factor.

In contrast, eye-movement studies of reading have shown additive effects of word predictability and frequency (Altaribba et al., 1996; Ashby, Rayner, & Clifton, 2005; Lavigne, Vitu, & d'Ydewalle, 2000; Rayner, Binder, Ashby, & Pollatsek, 2001; Rayner et al., 2004). For example, Rayner et al. (2004) directly investigated the interaction of word predictability and word frequency. For first-pass reading time measures, they didn't observe any significant interaction effects, whereas for skipping rates, they did observe a significant interaction effect such that there were higher skipping rates in the high-frequency predictable word condition as compared to in the other three conditions (which were not different from each other). However, the pattern of this interaction effect was different from what would usually be expected. Specifically, while the interaction in behavioral and ERP studies has demonstrated that the effect of predictability is generally larger in the low-frequency word condition than in the high-frequency word condition, the skipping result in Rayner et al. (2004) showed larger effects of predictability in the high-frequency word condition as compared to in the low-frequency one. Ashby et al. (2005), using the same materials as Rayner et al. (2004), did not observe an interaction effect for the first-pass fixation durations, and, unfortunately, did not report skipping rates. Recently, Hand, Miellet, O'Donnell, & Sereno (2010) reported that the predictability by frequency interaction effect is modulated by the saccade launch site. In an overall analysis, Hand et al. found no interaction effect for first-pass fixation duration on the target word, but they reported a significant interaction effect in cases in which the saccade into the target was executed from a position near the target (within 3 characters of the target) and from a position moderately close to the target (3-6 characters from the target), indicating that it is crucial to include the launch site information in analyzing fixation durations on target words. However, Slattery, Staub, & Rayner (2012) refuted Hand et al. (2010)'s argument by showing counterevidence that there is no effect of launch site on the predictability by frequency interaction. Slattery et al. (2012) used linear mixed-effects models to demonstrate that launch site does not modulate the interaction between predictability and frequency. As indicated above, the studies on the interaction between sentential context and word-intrinsic factors have focused extensively on word frequency (cf. Laszlo & Federmeier, 2009).

## Current study

Four eye-tracking during reading experiments were conducted to examine how contextual information and word-intrinsic linguistic information word recognition during reading. Experiment 1 used *cost-benefit* reasoning to address whether predictability leads to pre-activation of specific upcoming word(s) during sentence reading. Previous eye-tracking during reading studies have attempted to investigate how constrained preceding contexts affects word recognition (Ehrlich & Rayner 1981; Frisson et al., 2005; Hand et al., 2010; Rayner & Well, 1996; Rayner, Ashby et al., 2004; Rayner, Slattery, Drieghe, & Liversedge, 2011; Slattery et al., 2012; Staub, 2011). Although these eye-tracking during reading studies consistently support the idea that constraining as compared to neutral contexts facilitate processing of words, there is no clear evidence about whether this facilitation occurs because of prediction of upcoming words. Experiment 1 tested the hypothesis that constraining context is actively used by readers to pre-activate upcoming word forms by manipulating the predictability of upcoming words. Experiment 2 examined the interaction of repetition and neighborhood size in order to assess the level of processing at which lexical activation affects recognition during reading. As described above, previous studies have focused on the interaction between sentential contexts and word frequency (Hand et al., 2010; Lowder et al., in press; Rayner et al., 2004). In Experiment 2, word neighborhood was manipulated to understand whether lexical activation by repetition priming influences word recognition at the level of word form. Some of the results of Experiment 2 were surprising with respect to the kinds of neighborhood size effects that were observed. Therefore Experiments 3 and 4 were designed to seek further understanding of how the inherent lexical characteristic of neighborhood size affects word recognition during reading.

## Experiment 1

The question of the extent to which linguistic aspects of an upcoming word can be pre-activated based on sentential context is one of the most important issues in establishing a better understanding of human language comprehension. As described in the introduction section, one extreme argues that sentential context only provides benefit to integrating a given target word into discourse processing, but the other extreme contends that sentential contexts can rapidly and actively pre-activate semantic (Fedemeier & Kutas, 1999), phonological (Delong et al., 2005), and orthographic features (Laszlo & Fedemeier, 2009) of an upcoming word based on the preceding context. Whereas early psycholinguistic studies using behavioral and neural methods supported the integration view (e.g., Stanovich & West, 1981; Kutas & Hillyard, 1984), recent ERP studies have been interpreted as supporting the pre-activation view (for a review, see Kutas et al., 2006). This experiment attempted to answer this question by employing an eye-tracking method by which more natural reading processes are reflected as opposed to the RSVP paradigm that has been used in ERP studies. To address this issue, I used unexpected, but plausible target words, preceded by a strongly constrained sentential context (Federmeier et al., 2007; Schwanenflugel & LaCount, 1988).

1a. The humps on the back of the tall **camel** made it hard to ride, even with a saddle.

1b. The humps on the back of the tall **horse** made it hard to ride, even with a saddle.

For example, the word *camel* in sentence 1a is highly predictable based on the preceding context, while the word *horse* in sentence 1b is a plausible ending, but not strongly predicted. If readers pre-activate the likely upcoming word based on the preceding context before they see the actual word, a processing cost would be generated when they see the word *horse* (not *camel*). On the other hand, if readers only activate broad level of semantic features based on the sentential context, or if they only use the "processed" word to integrate into the discourse representation that is currently activated, there should be no processing cost when readers actually see the unexpected, but plausible word (e.g. *horse*).

*Methods*

Participants

Thirty two college students at the University of North Carolina at Chapel Hill were tested in the experiment, receiving course credit for their participation. All participants had normal or corrected-to-normal vision and were native English speakers.

Apparatus

Eye movements were recorded with an Eyelink 1000 model (SR Research, Ontario, Canada) interfaced with a Pentium computer. A headrest was used to minimize readers' head movements. Eye movements were recorded from the reader's dominant eye at a sampling rate of 1000 Hz. Sentences were presented in black color on a white background, with characters presented in Courier font (a mono-spaced font). The distance between the participant and the display monitor was 61cm; 3.8 characters subtended $1^{\circ}$ of visual angle.

Materials and Design

Fifty-six words were used as targets with each embedded in a sentence. Fifty-six sentence frames were generated, half with strongly constraining context and half with unconstraining context. Each sentence frame in the constraining condition was followed by either the most expected target word or an unexpected, but plausible target word. The same target words were also embedded in an unconstraining context, leading to four conditions: (1) expected targets in strongly constraining sentence frames, (2) unexpected plausible targets in strongly constraining sentence frames, (3) the same words as (1) in unconstraining sentence frames, and (4) the same words as (2) in unconstraining sentences frames. Table 1 shows an example sentence set of Experiment 1 (See Appendix 1 for entire sentences).

A cloze-type sentence completion task was implemented to determine the probability of the target words based on the initial sentence fragments. Sixteen native English speakers participated in a task in which they were asked to write the first word that came to mind for each sentence fragment. As expected, the average cloze probability of expected target words in the strongly constraining condition was 89% and that of unexpected plausible targets in the same frames was only 2%. The probabilities of same words (expected versus unexpected) in unconstraining sentence frames were relatively low and didn’t differ from each other (4% vs. 0%, respectively). The orthographic characteristics of the target words were also controlled between expected versus unexpected words. Word frequency was calculated using the SUBTLEX corpus (Brysbaert & New, 2009). Expected words had a mean word frequency of 28.5 counts per million and unexpected words had a mean word frequency of 32.6 per million, $t(54) < 1$, ns. Orthographic neighborhood size was calculated by Coltheart' N metric (Coltheart et al., 1977), and there was no difference in the number of orthographic neighbor words between expected and unexpected word sets (5.6 versus 6.3, respectively, $t(54) < 1$, ns).

Procedure

Participants read 56 sentences. On half of the trials a strongly constraining context was presented, whereas on the other half the unconstraining context was presented. Moreover, for each participant, half of the target words were expected and half were unexpected. As a result of each sentence frame being used only once for each participant, the predictability of the target word in a given sentence frame was counterbalanced across participants. The sentences were presented in a different random order to each participant.

**Table 1. An Example Sentence from Experiment 1 with each of the Four Conditions**

| ***Condition*** | ***Sentence*** |
| --- | --- |
| SC, Expected | The humps on the back of the tall **camel** made it hard to ride, even with a saddle. |
| SC, Unexpected | The humps on the back of the tall **horse** made it hard to ride, even with a saddle. |
| UC, Ctrl 1 | I was afraid of the tall **camel** until I went for a slow, bumpy ride on its back. |
| UC, Ctrl 2 | I was afraid of the tall **horse** until I went for a slow, bumpy ride on its back. |

Note. The words in bold are the target stimuli. SC = Strongly constraining, UC = Unconstraining, Ctrl 1 = Control for the expected condition, Ctrl 2 = Control for the unexpected condition.

After the initial calibration and validation were completed, participants were asked to read sentences on the monitor naturally. Sentences were presented at the center of the screen in a random order. Eye movements were measured when participants started to fixate the first word of the sentence. A yes-no comprehension question followed each stimulus sentences in order to encourage careful reading.

*Results*

*Analysis of eye movements*. All trials in which the subject blinked during first-pass reading of the critical region consisting of the pre-target word, the target word and the word after the target were excluded from the analysis, as were trials in which individual fixation duration was shorter than 80 ms and longer than 800ms. For the final analysis 10.3% of trials were excluded by these criteria. First-pass skipping rates on the target word were calculated as the proportion of trials in which the target word was not fixated at all or only fixated after a subsequent word had been fixated. First-pass fixations were those after the eyes fixated on a word until they moved off the word, given that they had not progressed beyond that word before the first fixation. S*ingle-fixation duration* was the average of the duration of the initial, first-pass fixation on a word given that the word received only one first-pass fixation. *First-fixation duration* was the average of the duration of the initial, first-pass fixation on a word regardless of whether there were subsequent first-pass fixations on the word. G*aze duration* was the average of the sum of all first-pass fixation durations on a word. In addition to the first-pass fixations, two kinds of fixation measures that may reflect late stages of word processing were also considered in the analyses. *Regression-path duration* (RPD, sometimes called *go-past time*) was the sum of all fixations beginning with the initial fixation on a region and ending when the gaze is directed away from the region to the right. *Total time* (TTime) is the sum of all fixations on a word. Two levels of contextual constraint and those of expectancy of target word were analyzed by a two-way analysis of variance (ANOVA). Error variance was calculated by participants ($F_1$) and by items ($F_2$).

*Dependent measures on target words*. Table 2 shows the means and standard deviations of all the dependent measures on the target word, and Table 3 shows the inferential statistics on each dependent measure for each variables. Because both descriptive and inferential statistics are presented in Tables 2 and 3, I describe only those results that were interesting with respect to the specific questions addressed by this experiment. As can be seen in Tables 2 and 3, significant interaction effects were observed on gaze duration in both subject and item analyses such that the gaze duration on the expected target (e.g., camel) was shorter in the strongly constraining condition as compared to the neutral condition, whereas the gaze duration on the unexpected target (e.g., horse) was longer in the strongly constraining condition than the unconstraining condition. Contrast analyses were conducted to clarify the source of the crossover interaction between two variables. The contrast analyses confirmed the benefit of the expected target and the cost of the unexpected target in the strongly constraining context and were statistically significant, $F(1,31) = 5.19$, $p < .05$ for the benefit; $F(1.31) = 4.93$, $p < .05$for the cost. Another interesting result was the number of first-pass fixations (NFPFix). This measure also showed a significant interaction between the sentential constraint and the expectancy of the target in that the expected target had fewer first-pass fixations in the strongly constraining condition as compared to the neutral condition, but the unexpected target had more first-pass fixations in the strongly constraining condition than in the neutral condition.

There were no significant interaction effects on regression-path duration, indicating that the processing cost elicited by the unexpected word in the strongly constraining context was generated by the unexpectedness of the target, not by the difficulty of integrating the meaning of the target into the contextual information. Note that both the unexpected and expected target words in the strongly constraining condition are plausible in the preceding sentential context.

Whereas no interaction effect was observed for regression-path duration, a significant strong interaction effect was observed on the total time. This interaction could be due to the difficulty in the integration of the unexpected word in the strongly constraining condition, which is not consistent with the conclusion from the pattern of regression-path durations. However, the result of total time could be due to the spill-over effect of gaze duration. In order to confirm the idea that the interaction effect on the total time reflects the spill-over effect of gaze duration, the rereading time obtained by subtracting gaze duration from total time was analyzed. There was no main effect of sentential contexts, $F_1(1,31) = 1.21$, ns; $F_2(1,54) = .41$, ns. In addition, there was no main effect of expectancy of target, $F_1(1,31) = .36$, ns; $F_2(1,54) = 1.71$, ns. More importantly, there was no interaction effect between the two variables, $F_1(1,31) = 4.13$, $p = .051$; $F_2(1,54) = 2.88$, $p = .096$. The follow-up contrast analysis showed that the marginal trend of the interaction effect was solely due to the benefit from the expected word in the strongly constraining condition, not by the cost from the unexpected word in the same context, $F(1,31) = 4.2$, $p < .05$; $F(1,31) = .63$, ns, respectively. Accordingly, the result of rereading time confirmed that the interaction effect on total time was mainly due to the effect of gaze duration since there was no indication of inhibition caused by the unexpected word in the strongly constraining condition on the subsequent analysis of the rereading measure.

*Discussion*

The results of Experiment 1 were straightforward. A significant interaction effect was observed in gaze duration on the target word, indicating that readers fixated longer on the unexpected target word when the preceding context was highly constraining as compared to when it was not constraining, as well as fixated a shorter time on the expected word in the constraining context than in the neutral condition. The inhibitory effect of the unexpected word did not appear in late measures such as regression-path duration or rereading time, implying that the inhibition caused by the unexpected word in the constraining context does not continue to later processing of comprehension.

The current results support the view that preceding sentential contexts allow readers to actively pre-activate upcoming words (DeLong et al., 2005; 2011; Federmeier et al., 2007). Recent ERP study by DeLong et al. showed that a smaller N400 amplitude in the central-posterior region of brain was observed when the expected word was preceded by a strongly constraining context as compared to by an unconstraining context, and, more importantly, they showed a larger N400 amplitude in the frontal region when the unexpected target was preceded by the strongly constraining context as compared to by the unconstraining context. In highly constraining contexts, readers can easily pre-activate the next word, so that the reading time (or the neural activity) on the word is shorter (or smaller) when the next word is actually predicted relative to when it is not predicted. However, when the prediction on the upcoming word by the constraining context was wrong, such that the next word was not the predicted word, readers should have processing cost to inhibit the activation of the predicted word. In Experiment 1, the processing cost from wrong prediction did not continue to later stages of sentence processing because the unexpected word was very plausible in the sentential context even if it was not actually predicted.

In contrast to the pre-activation account, the integration account has difficulty in explaining the current results. The integration account posits that the facilitation of word processing by constraining contextual information occurs because the meaning of the target can be easily integrated into the sentential context. According to the integration account, both the expected word and the unexpected word should be facilitated by the constraining context because both words can be easily integrated based on the sentential context. The current results were not consistent with the prediction by the integration account in that there was no hint of facilitation of the unexpected word in the constraining context[1]. While ease of integration into the sentence meaning undoubtedly affects the processes of word recognition during sentence reading in some instances, this process does not explain the pattern of results obtained for the highly constraining contexts used in the present studies.

[1] An alternative explanation would be that the unexpected word is less plausible in the highly constraining condition than in the unconstraining condition. However, these words were semantically plausible in both contexts.

**Table 2. Results for the target word in Experiment 1**

| | Fixation duration | | | | | Probability | |
|---|---|---|---|---|---|---|---|
| Conditions | FFD | SFD | GZD | RPD | TTime | Skipping | NFPFix. |
| Constrained, target | 215 (24) | 212 (24) | 220 (27) | 252 (55) | 265 (63) | .26 (.11) | 1.03 (.06) |
| Unconstrained, target | 224 (30) | 218 (29) | 237 (41) | 296 (56) | 309 (86) | .24 (.16) | 1.07 (.09) |
| Constrained, control | 230 (27) | 226 (27) | 256 (43) | 290 (59) | 323 (103) | .25 (.14) | 1.12 (.12) |
| Unconstrained, control | 224 (28) | 225 (27) | 239 (36) | 299 (92) | 297 (54) | .23 (.15) | 1.07 (.09) |



**Table 3. Inferential statistics from ANOVA on the target word in Experiment 1**

| | Constraint | | | | | | Expectancy of target | | | | | | Interaction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 (1,31) | | | $F_2$ (1,54) | | | $F_1$ (1,31) | | | $F_2$ (1,54) | | | $F_1$ (1,31) | | | $F_2$ (1,54) | | |
| | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p |
| FFD | .20 | 561 | .654 | .30 | 492 | .589 | 4.67 | 363 | **.038** | 3.74 | 400 | .058 | 4.15 | 397 | .05 | 4.84 | 400 | **.032** |
| SFD | .35 | 500 | .561 | .07 | 535 | .798 | 10.6 | 338 | **.003** | 10.22 | 319 | **.002** | 1.11 | 517 | .3 | 2.12 | 319 | .151 |
| GZD | 0 | 1095 | 994 | .11 | 1119 | .774 | 18.2 | 655 | **.001** | 8.25 | 1006 | **.006** | 12.6 | 724 | **.001** | 10.5 | 1006 | **.002** |
| RPD | 10.0 | 2275 | **.003** | 6.76 | 4173 | **.012** | 3.53 | 3874 | .07 | 4.28 | 3100 | **.043** | 2.75 | 3605 | .107 | 2.68 | 3100 | .108 |
| TT | .97 | 2867 | .334 | .49 | 3909 | .486 | 8.68 | 1986 | **.006** | 7.53 | 2698 | **.008** | 10.9 | 3579 | **.002** | 10.7 | 2698 | **.002** |
| Skip | 1.82 | .01 | .118 | .51 | .02 | .478 | .39 | .01 | .54 | .12 | .03 | .731 | .001 | .01 | .996 | .002 | .03 | .961 |
| NFix | .15 | .009 | .698 | .034 | .009 | .855 | 8.60 | .007 | **.006** | 5.26 | .007 | **.026** | 9.05 | .007 | **.005** | 9.60 | .007 | **.003** |

## Experiment 2

The results of Experiment 1 showed that the linguistic information elicited by sentential contexts leads to pre-activation of specific words. Given that the contextual information influences the current state of word processing, the important question would be to what extent the sentential context interacts with linguistic characteristics of the current word. However, as described in the introduction, the evidence has been elusive on the interaction between sentential contexts and word-form level factors in eye-tracking during reading studies (e.g., word frequency) (Rayner et al., 2004; Slattery et al., 2012; cf. Lowder et al., in press)[2].

The second experiment examines the interaction of sentential context and word-intrinsic factors by manipulating word repetition and the number of neighbors for the target word. Previous studies have shown that word repetition causes has robust facilitation of word recognition in the intra-sentential repetition-priming paradigm (Choi & Gordon, in press*a*; Gordon et al., 2013; Liversedge et al., 2003; Lowder et al., in press; Traxler et al., 2000). In particular, as discussed earlier, Lowder et al. reported that word frequency effects were significantly modulated by word repetition such that no frequency effect was observed when the

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[2] In our lab, an eye-tracking during reading study was conducted to examine how the effect of neighborhood size on the process of word recognition is modulated by the degree of sentential constraint. The gaze duration on a target word was shorter in the strongly constraining condition as compared to that in the neutral condition, $F_1(1,39) = 10.21$, $p < .005$; $F_2\ (1,58) = 9.71$, $p < .005$. However, there was no interaction between effects of the neighborhood size and sentential constraint such that the facilitative effect of sentential constraint was not modulated by neighborhood size, $Fs < 1$. More interestingly, there were null effects of neighborhood size in that first-pass reading time measures such as gaze duration, first fixation duration, or single fixation duration that didn't differ between the two neighborhood conditions, $Fs < 1$. The absence of neighborhood size effects in this experiment is not consistent with the results in previous studies (Andrews, 1997; Pollatsek et al., 1999; cf. Grainger & Jacobs, 1996). One possible reason for the null effect of neighborhood size might be due to not using exactly the same sentences across the two neighborhood conditions. This issue is to be discussed in later sections.

target word appeared in an earlier region within the same sentence. Given the interaction between word repetition and word frequency, word repetition may modulate other types of word intrinsic factors such as the effect of the number of orthographic neighbors. As reviewed in the introduction, the number of orthographic neighbors has been extensively studied using a variety of isolated word recognition paradigms which show shorter reaction times for words with many neighbors than for those with few neighbors (See Andrews, 1997 for a review). If the effect of word repetition interacts with orthographic neighborhood size, we would expect that the neighborhood size effect should be decreased in the repetition condition relative to the unrepeated condition.

Recent research has calculated orthographic neighborhood size using Orthographic Levenstein Distance (hereafter referred to as OLD; Yarkoni, Balota, & Yap, 2008) rather than Coltheart's N. OLD is defined as the number of insertions, deletions, and substitutions needed to generate one word from another word. For example, the OLD from *CAMEL* to *CAMELS* is 1, reflecting one insertion (S), and the OLD from *CAMEL* to *CARAMEL* is 2, reflecting two insertions (R and A). Although OLD has only recently been used in the psychological literature, it has proven to be very good in capturing the effects of orthographically similar words on lexical access of target words in visual word recognition (Yarkoni et al., 2008; Yap, Balota, Sibley, & Ratcliff, 2012). In the current study, OLD20, the mean Levenstein Distance from a word to its 20 closest orthographic neighbors was used to manipulate degree of orthographic similarity (Yarkoni et al., 2008). Note that as the value of OLD20 is smaller, a word has more orthographically similar neighbor words.

*Methods*

Participants

Fifty two college students at the University of North Carolina at Chapel Hill were tested in the experiment and received course credit for their participation. All participants had normal or corrected-to-normal vision and were native English speakers.

Apparatus

The apparatus was the same as that used in Experiment 1.

Materials and Design

Sixty words were used as targets with each embedded in a sentence. Target words were selected from the CELEX corpus (Baayen, Piepenbrock, & Gulikers, 1995). Thirty target words had many neighbor words (small value of OLD20) and the other thirty words had few neighbor words (large value of OLD20). Table 4 showed orthographic characteristics of target words, which were extracted from the English Lexicon Project website (http://elexicon.wustl.edu). As can be seen in Table 4, the words in the many neighbor condition have smaller OLD20 values than the words in the few neighbor condition, $t\ (58) = 10.02$, $p < .001$. The word frequency was calculated by the SUBTLEX corpus (Brysbaert & New, 2009). Words in the many neighbor condition had a mean word frequency of 7.01 counts per million and words in the few neighbor condition had a mean word frequency word of 5.58 per million, $t\ (58) < 1$, ns. Note that target words that have relatively low word frequencies were selected in this experiment because previous studies reported that lexical access of high-frequency words is not likely to be influenced by the number of neighbor words (Andrews, 1997). The mean word frequency of the closest 20 OLD neighbors was also controlled across the two conditions because the word frequency of orthographic neighbors can affect the processes of target words, t (58) < 1, ns (Grainger & Jacobs, 1996; Pollatsek et al., 1999). Two sub-lexical orthographic characteristics were also considered: Summed bigram frequency (BG_Sum) and summed bigram frequency by position (BG_Freq_ByPos). The BG_Sum is the sum of the frequency of each bigram in a specific word. For example, a word DOG has two bigrams, DO and OG. If DO has a frequency of 10 and OG has a frequency of 5, the BG_Sum is 15. The BG_Freq_ByPos is calculated based on bigram frequencies that are sensitive to positions within words. Position-sensitive bigram counts only consider the letter positions where a bigram occurs. For example, the bigram frequency for DO in DOG counts DO bigrams only when they appear in the first two positions of a word. These two measures in the many neighbor condition were slightly greater than those in the few neighbor condition, but they did not differ statistically, t (58) = 1.74; t (58) = 1.70, respectively. In addition, the latencies of a lexical decision task (LDT) for each word were compared between words in the many versus the few neighborhood conditions. The English Lexicon Project website provides mean reaction times of LDT for 40,481 words. The mean latency of words in the many neighbor condition was 640ms, and that in the few neighbor condition was 689ms, t (58) = 3.86, p < .001. This result indicates that a similar pattern of the facilitative neighborhood effect was observed even when the metric of the orthographic neighborhood was chosen by the OLD20, not by the Coltheart's N.

**Table 4. Orthographic characteristics of target words used in Experiment 2**

| | OLD20 | Freq | OLDF | BG_Sum | BG_Freq_ByPos |
|---|---|---|---|---|---|
| **Many N** | 1.47 | 7.01 | 7.81 | 15578 | 2807 |
| **Few N** | 1.99 | 5.58 | 7.87 | 12707 | 2105 |

Two repetition conditions were employed for target words. Prime words were located early in the stimulus sentence, but were not the first or second word. The discourse contexts in the two conditions were similar even if the prime words in the new condition and those in the repeated condition were different. Table 5 shows an example sentence set of Experiment 2 (See Appendix 2 for entire sentences).

Participants read all 60 sentences, but on half of the trials a repeated target word was presented for a given sentence, whereas on the other half an unrepeated target word was presented. Moreover, for each participant, half of the target words had many orthographic neighbors and other half had few orthographic neighbors. Because each sentence frame was only used once for each participant, the repetition of the target word in a given sentence frame was counterbalanced across participants. The sentences were presented in a different random order to each participant.

**Table 5. An Example Sentence From Experiment 2 with Each of the Four Conditions**

| ***Condition*** | ***Sentence*** |
|---|---|
| Rept, ManyN | We always *spice* our pasta with basil rather than **spice** it with oregano. |
| New, ManyN | We always *flavor* our pasta with basil rather than **spice** it with oregano. |
| Rept, FewN | I wore my mom's *scarf* because I couldn't find the **scarf** I normally wear. |
| New, FewN | I wore my mom's *shawl* because I couldn't find the **scarf** I normally wear. |

Note. The words in italics are prime words, and the words in bold are target stimuli. Rept = Repeated condition, New = unrepeated condition, ManyN = many orthographic neighbors, FewN = few orthographic neighbors.

## Procedure

The procedure was the same as that followed in Experiment 1.

## Results

*Analysis of eye movements*. All restrictions that were applied to the analysis of the Experiment 1 were also considered in Experiment 2. For the final analysis 5.9% of data points were excluded by these restrictions. Four participants were excluded in the final data analysis because they had severe trouble with calibration. First-pass and late reading-time measures were the same as in Experiment 1. The two levels of word repetition and orthographic neighborhood were analyzed by a two-way analysis of variance (ANOVA). Error variance was calculated by participants ($F_1$) and by items ($F_2$).

*Dependent measures on target words*. Table 6 shows the means and standard deviations of all the dependent measures on the target word, and Table 7 shows the inferential statistics on each dependent measure for each variable. Because both descriptive and inferential statistics were reported in Tables 6 and 7, I describe only those results that were interesting with respect to the hypotheses leading to the current experiment. As can be seen in Tables 6 and 7, the main effect of repetition was observed in the subject analysis of gaze duration in that the gaze duration on the repeated target word was shorter than that on the unrepeated target. The repetition effect on the gaze duration was marginally significant in the item analysis. More importantly, the repetition effect was qualified by a significant repetition X neighborhood interaction on the gaze duration in subject analysis and marginal effects in item analysis such that gaze duration on a word with many neighbors was shorter than that on a word with few neighbors in the repetition condition. In the unrepeated condition, gaze durations did not differ between the two neighborhood conditions. This pattern of interaction was also observed in first fixation duration, but the effects were only marginally significant. Although the interaction effect was not in the expected direction, this effect is evidence that word repetition modulates the effect of neighborhood size.

*Discussion*

The most interesting result of Experiment 2 was the interaction between word repetition and orthographic neighborhood size. However, the pattern of interaction was not what had been expected. As described earlier, I assumed that if a word had many neighbors, reading times would be shorter as has been shown in isolated word recognition studies, and accordingly, the neighborhood size effect would be decreased in the repetition condition relative to the unrepeated condition. However, the actual results showed that neighborhood size had a null effect in the unrepeated condition and a facilitative effect in the repetition condition. One possible explanation for the results is that the effect of orthographic neighborhood size during sentence reading is very elusive. Unlike in results obtained by isolated word recognition paradigms, orthographic neighborhood size may not be effective in influencing lexical access during sentence reading. But in the specific case of intra-sentential priming in which a target word has already been accessed immediately before, orthographic neighbors of the pre-accessed word could help with recognizing it. For example, in a sentence like “We always *spice* our pasta with basil rather than **spice** it with oregano”, the word *spice* was primed earlier in the sentence, and when readers saw the target word, spice, its orthographic neighbor words such as *spices, slice, peace,* and *spite* might have helped the process of word recognition. This explanation, however, is counter-intuitive in some ways. For example, most word recognition studies have shown that the information generated by sentential contexts affects processing of the current word in the opposite direction (Lowder et al., in press; Stanovich & West, 1983) in that any word-intrinsic effect such as word frequency in neutral sentential contexts tends to be decreased when biased sentential contexts are given. Another possible explanation for this result involves assigning a different (opposite) role to orthographic neighbor words in the process of word recognition: they may actually inhibit target word processing rather than facilitate it. In normal reading, readers should rapidly and correctly recognize the right word to comprehend the meaning of a sentence. In the above example, the word, *spice*, has many orthographic neighbors, all of which may be candidates for identification. It has been claimed that readers have to inhibit activation of other candidates during reading, and that the amount of inhibition might be greater as the number of orthographic neighbor words increases. But in a priming situation in which a target word was primed in an earlier region, readers do not have to inhibit candidates because they can easily access the target word. In this case, orthographic neighbor words can aid recognition of the target, rather than inhibit it. However, this account is not supported by the current results as there was no inhibitory effect of orthographic neighbor words in the unrepeated condition. If this account were correct, inhibitory effects of neighbor words should have been observed in this experiment.

With regards to specifying the fundamental role of orthographic neighbors during sentence reading, the current experiment has one critical drawback. Words from two neighborhood conditions (many vs. few) were presented in different sentential contexts, with variation occurring in the number of letters of the preceding word, frequency of the preceding word, and meaning of the sentential context. For example, *slice* (a word with many neighbors) versus *scarf* (a word with few neighbors) is not only different in terms of the number of orthographic neighbor words, but also different with respect to the preceding context. In the following experiments, the effect of neighborhood size is evaluated in a more controlled way, so as to provide insight into how neighborhood size affects word recognition during sentence reading.

**Table 6. Means (SDs) on the target word in Experiment 2**

| | Fixation duration | | | | | Probability | |
|---|---|---|---|---|---|---|---|
| Conditions | FFD | SFD | GZD | RPD | TTime | Skipping | NFPFix. |
| Rept, ManyN | 212 (27) | 207 (28) | 231 (38) | 318 (105) | 308 (67) | .22 (.13) | 1.11 (.13) |
| New, ManyN | 224 (34) | 216 (33) | 248 (42) | 343 (135) | 324 (79) | .21 (.16) | 1.13 (.11) |
| Rept, FewN | 222 (32) | 216 (31) | 246 (42) | 330 (107) | 327 (89) | .20 (.13) | 1.13 (.12) |
| New, FewN | 222 (32) | 217 (33) | 246 (38) | 317 (97) | 340 (81) | .20 (.13) | 1.13 (.11) |



**Table 7. Inferential statistics from ANOVA on the target word in Experiment 2**

| | Repetition | | | | | | Neighborhood | | | | | | Interaction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F_1$ (1,51) | | | $F_2$ (1,58) | | | $F_1$ (1,51) | | | $F_2$ (1,58) | | | $F_1$ (1,51) | | | $F_2$ (1,58) | | |
| | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p |
| FFD | 3.60 | 542 | .064 | 2.56 | 350 | .12 | 3.38 | 292 | .072 | .97 | 488 | .33 | 3.62 | 513 | .06 | 2.37 | 350 | .13 |
| SFD | 2.89 | 571 | .095 | 2.82 | 322 | .01 | 2.75 | 422 | .104 | 1.35 | 478 | .25 | 1.15 | 627 | .29 | .71 | 322 | .40 |
| GZD | 4.72 | 820 | **.034** | 2.95 | 654 | .09 | 2.98 | 732 | .09 | .69 | 1299 | .41 | 4.26 | 861 | **.04** | 3.23 | 654 | .08 |
| RPD | .34 | 5293 | .563 | .13 | 10389 | .72 | .33 | 7826 | .569 | .14 | 16451 | .71 | 2.03 | 9672 | .16 | 1.61 | 10389 | .21 |
| TT | 3.09 | 3812 | .085 | 2.81 | 2666 | .01 | 5.63 | 2872 | **.021** | 1.62 | 4530 | .21 | .066 | 2669 | .8 | .11 | 2666 | .74 |
| Skip | .06 | .01 | .801 | .04 | .01 | .85 | 1.12 | .01 | .294 | .51 | .01 | .48 | .14 | .01 | .71 | .13 | .01 | .72 |
| NFix | .85 | .01 | .362 | .62 | .01 | .44 | .36 | .01 | .55 | .09 | .01 | .77 | 1.67 | .01 | .20 | 2.08 | .01 | .16 |

## Experiment 3

The purpose of Experiment 3 was to examine the role of orthographic neighbor words in recognizing a specific target word during sentence reading. The current experiment was motivated by the result of Experiment 2 in which the effect of orthographic neighbors on target words was not facilitative as observed in previous isolated word-recognition tasks (Andrews, 1989; 1992; Forster & Shen, 1996; Peereman & Content, 1995; Sears, Hino, & Lupker, 1995) and in one eye-tracking study of reading (Pollatsek et al., 1999). Two types of theoretical explanations have been offered for the facilitative effect of orthographic neighbors. The first is that the facilitation of word recognition by neighbor words is due to word-to-letter feedback as found in interactive-activation model (hereafter, IAM, McClelland & Rumelhart, 1981). The IAM consists of series of levels corresponding to feature, letter, and word units in which lexical access occurs based on bidirectional facilitation between levels and bidirectional inhibition within levels. According to this model, feedback from the word units to the letter units can provide additional excitation to the shared letter units which facilitate processing of the target word, a process called the GANG effect (McClelland & Rumelhart, 1981). For example, if readers see the word, *slice*, then word units for neighbors like *spice*, *lice*, *slide*, *slices*, *slick*, *slime*, *life*, *like*, etc. are also activated. These activated word units send feedback to their constituent letter units, including those shared by the target word, and this activation speeds recognition of the target word.

The second explanation of the facilitative neighborhood effect is the multiple read-out model (hereafter, MROM) proposed by Grainger and Jacobs (1996). In the MROM, word recognition can be influenced by three different decision criteria: local lexical activity (M component), global lexical activity (Σ component), and time limitation (T component). The local lexical activity reflects lexical access for a specific word, while the other two components can be shaped by task-specific goals. Accordingly, in a lexical decision task, these three components can be dramatically changed by the characteristics of the nonwords that are used in the task or by the instructions given to participants. For example, the facilitative neighborhood effect was larger when the nonwords in the task were very word-like (e.g., when they were pseudohomophones) as compared to when the nonwords were not word-like (e.g., when they were random consonant strings). Grainger and Jacobs argued that the facilitative effect of the number of neighbors in a lexical decision task was dependent upon how the task (e.g., composition of stimuli over trials) caused readers to adjust the threshold of the Σ component. Therefore, according to the MROM, the facilitative neighborhood effect should be eliminated in tasks such as identification of briefly presented words rather than judgment of lexical status (Snodgrass & Minzer, 1993). The fundamental difference with regard to the neighborhood size effect between the IAM and the MROM is whether the effect is driven by the mechanism of lexical selection in the mental lexicon or by the global lexical activities that are strongly shaped by task-specific goals.

One shortcoming of all single-word recognition paradigms using response time is that they require a secondary meta-linguistic task, which can influence reaction times (Balota & Chumbley, 1984; 1985). Unlike the single word recognition paradigms, sentence reading does not require a secondary task and therefore provides evidence about how neighbor words affect lexical access under more natural task conditions. Experiment 2 did not show a main effect of the number of neighbor words on first-pass reading time, but words with many neighbors and those with few neighbors were presented in different sentential contexts. In the current experiment, each target word (a word with many neighbor words versus a word with few neighbors) was preceded by the exact same sentence context thereby minimizing variability in reading time due to differences in preceding contexts. If the facilitative effect of neighborhood size occurs based on the letter-to-word facilitation by neighbor words, as proposed by the IAM, then the facilitative effect should be also observed in a sentence reading experiment. Alternatively, if the neighborhood effect occurs due to the strategy of increasing global lexical activation in a lexical decision task as suggested by the MROM, the facilitative effect would not appear because global lexical activation is not relevant in any obvious way to word recognition during sentence reading.

Additionally, as described earlier, using Levenshtein distance (OLD20) instead of Coltheart' N allows examination of neighborhood effects in longer words. Because use of OLD20 in studies of neighbor size is relatively recent, most studies have used very short words (4 or 5 letters) for which Coltheart' N provides a reasonable metric; Cotheart's N has less value in characterizing the neighborhood sizes of longer words because the number of neighbors differing by one letter in one position decreases rapidly as words get longer. Recent studies have shown that the OLD20 metric based on Levenshtein distance can predict neighborhood size effects in lexical decision tasks (Yakoni et al., 2008; Yap et al., 2012). The current experiment will assess whether that is also true for neighborhood size effects in normal reading. In addition, the use of seven letter words should reduce the rate at which words are skipped and therefore provide a better measure of neighborhood effects on first-pass reading time measures such as gaze duration.

*Methods*

Participants

Forty college students at the University of North Carolina at Chapel Hill were tested in the experiment and received course credit for their participation. All participants had normal or corrected-to-normal vision and were native English speakers.

Apparatus

The apparatus was the same as that used in previous experiments.

Materials and Design

Sixty seven-letter words (30 with many neighbors and 30 with few neighbors) were selected as target words and were embedded in a set of 30 sentences (See Appendix 3). As can be seen in Table 8, the words in the many neighborhood condition have a lower OLD20 value than the words in the few neighborhood condition, $t(58) = 11.11$, $p < .001$. The word frequency was calculated by the SUBTLEX corpus (Brysbaert & New, 2009). Words in the many-neighbors condition had a mean word frequency of 7.34 counts per million, and words in the few-neighbors condition had a mean word frequency word of 7.49 per million, $t(58) < 1$, ns. Note that the target words were again very low frequency words. The mean word frequency of the closest 20 OLD neighbors was controlled across the two conditions because the word frequency of orthographic neighbors can affect the processes of target words, t (58) < 1, ns (Grainger & Jacobs, 1996; Pollatsek et al., 1999). Two sub-lexical orthographic characteristics were also considered: Summed bigram frequency (BG_Sum) and summed bigram frequency by position (BG_Freq_ByPos). These two measures were not statistically different between the two neighborhood-size conditions, ts (58) < 1, ns. As in Experiment 2, reaction times of LDT were compared between the two neighborhood conditions. The results showed the facilitative trend of neighborhood size such that words with many neighbor words had shorter reaction times as compared to words with few neighbor words (674ms vs. 697ms, t (58) = 1.31, p = .19).

A pair of words (one with many neighbors versus one with few neighbors) was embedded in the exact same sentential context (See an example in Table 9). Participants read 30 sentences in which half of the target words were words with many neighbors and half were words with few neighbors. As a result of each sentence frame being used only once for each participant, the number of neighbors for the target word in a given sentence frame was counterbalanced across participants. The sentences were presented in a different random order to each participant.

**Table 8. Orthographic characteristics of target words used in Experiment 3**

| | **OLD20** | **Freq** | **OLDF** | **BG_Sum** | **BG_Freq_ByPos** |
|---|---|---|---|---|---|
| **Many N** | 1.93 | 7.34 | 7.10 | 25219 | 4575 |
| **Few N** | 2.61 | 7.49 | 6.89 | 25520 | 4348 |

**Table 9. An Example Sentence From Experiment 3**

| ***Condition*** | ***Sentence*** |
|---|---|
| Many N | The ancient text mentioned a **drought** that affected the villagers' lives. |
| Few N | The ancient text mentioned a **prophet** that affected the villagers' lives. |

Note. The words in bold are target stimuli. Many N = many orthographic neighbors, Few N = few orthographic neighbors.

Procedure

The procedure was the same as that followed in the previous experiments.

*Results*

*Analysis of eye movements*. All restrictions that were applied to the analysis of the previous experiments were also considered in Experiment 3. For the final analysis, 6.05% of data points were excluded by these restrictions. First-pass and late reading-time measures were the same as in the previous experiments. The two levels of orthographic neighborhood size were analyzed by a one-way analysis of variance (ANOVA). Error variance was calculated by participants ($F_1$) and by items ($F_2$).

*Dependent measures on pretarget words*. Table 10 shows the means and standard deviations of all the dependent measures on the pretarget words, and Table 11 shows the inferential statistics on each dependent measure for each variable. As can be seen in Tables 10 and 11, there was no difference between the many and few neighborhood conditions in any dependent measures for the pre-target word.

*Dependent measures on target words*. Table 10 shows the means and standard deviations of all the dependent measures on the target words, and Table 11 shows the inferential statistics on each dependent measure for each variable. A main effect of neighborhood size was observed such that gaze duration was longer for words in the many neighborhood condition than in the few neighborhood condition. Skipping rates did not differ between the two neighborhood-size conditions.

*Dependent measures on posttarget words*. Table 10 shows the means and standard deviations of all the dependent measures on the posttarget words, and Table 11 shows the inferential statistics on each dependent measure for each variable. As can be seen in Tables 10 and 11, the main effect of neighborhood size was also significant in subject analyses of the first-pass reading time measures on the posttarget region, but was not significant in the item analyses.

*Discussion*

The result of this experiment showed that words with many neighbor words are likely to be fixated longer than words with few neighbor words.

The inhibitory effect of neighborhood size is consistent with the idea from the MROM model (Grainger & Jacobs, 1996) that word recognition tasks assess the target word on multiple dimensions that are influenced by the specifics of the task. According to the MROM, the facilitative effect of neighborhood size in the lexical-decision task occurs because words with many neighbors cause a high level of lexical activation (the importance of which may be moderated by additional task factors). Global lexical activation is unlikely to be useful during sentence reading where the reader is most likely attempting to recognize the specific words in the text. In the present study, words with many neighbors showed elevated reading times as compared to words with few neighbors, a pattern that could be explained in different ways. For example, inhibitory processes could slow down word recognition when a target activates multiple candidates, or words with indistinct codes could be recognized more slowly than words with distinct codes. In contrast, the current result cannot be explained by the GANG effect in the IAM which involves feedback from word units to letter units (McClleland & Rumelhart, 1981). The IAM does include mechanisms for intra-lexical inhibition that could explain the slower processing time for words with many neighbors. However, the inclusion in the IAM of mechanisms that allow neighborhood size to influence word recognition in both facilitative and inhibitory ways complicates evaluation of the model.

**Table 10. Means (SDs) on the target word in Experiment 3**

| | | Fixation duration | | | | | Probability | |
|---|---|---|---|---|---|---|---|---|
| Region | Conditions | FFD | SFD | GZD | RPD | TTime | Skipping | NFPFix. |
| Pre Target | Many N | 229 (39) | 216 (35) | 251 (58) | 310 (94) | 365 (109) | .36 (.13) | 1.13 (.13) |
| | Few N | 232 (46) | 225 (36) | 259 (59) | 308 (87) | 370 (104) | .36 (.15) | 1.15 (.16) |
| Target | Many N | 228 (26) | 221 (24) | 278 (53) | 347 (80) | 408 (100) | .093 (.09) | 1.24 (.19) |
| | Few N | 225 (27) | 215 (28) | 260 (39) | 326 (79) | 392 (71) | .096 (.09) | 1.18 (.16) |
| Post Target | Many N | 246 (38) | 240 (38) | 280 (59) | 407 (161) | 353 (88) | .44 (.20) | 1.17 (.17) |
| | Few N | 223 (41) | 220 (43) | 251 (54) | 336 (107) | 328 (89) | .47 (.14) | 1.15 (.16) |



**Table 11. Inferential statistics from ANOVA on the target word in Experiment 3**

| | PreTarget | | | | | | Target | | | | | | PostTarget | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F_1$ (1,39) | | | $F_2$ (1,29) | | | $F_1$ (1,39) | | | $F_2$ (1,29) | | | $F_1$ (1,39) | | | $F_2$ (1,29) | | |
| | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p |
| FFD | .135 | 1364 | .72 | .341 | 913 | .56 | .296 | 550 | .589 | .379 | 443 | .543 | 8.43 | 1173 | **.006** | .937 | 1982 | .341 |
| SFD | 1.81 | 820 | .19 | .001 | 751 | .97 | 1.81 | 378 | .187 | 1.11 | 514 | .3 | 6.97 | 1218 | **.012** | .640 | 1949 | .430 |
| GZD | .518 | 2100 | .48 | .005 | 1420 | .94 | 6.13 | 1161 | **.018** | 4.34 | 1313 | **.046** | 9.13 | 1774 | **.004** | 1.71 | 2413 | .201 |
| RPD | .028 | 4552 | .87 | .04 | 5264 | .84 | 2.81 | 2953 | .102 | 1.34 | 4130 | .257 | 6.89 | 14507 | **.012** | 4.03 | 16983 | .054 |
| TT | .069 | 7039 | .8 | .057 | 3113 | .81 | 1.64 | 3263 | .208 | .249 | 10434 | .622 | 2.6 | 4746 | .115 | .213 | 3327 | .648 |
| Skip | .058 | .015 | .81 | .051 | .013 | .82 | .062 | .004 | .805 | .014 | .006 | .905 | 1.14 | .014 | .293 | 1.69 | .007 | .204 |
| NFix | .638 | .019 | .43 | .397 | .015 | .53 | 6.14 | .011 | **.018** | 3.3 | .016 | .08 | .391 | .019 | .536 | .695 | .011 | .411 |

## Experiment 4

The purpose of Experiment 4 was to assess the generality of the surprising results found in Experiment 3. It followed the design of that experiment but used target words with five letters rather than seven. If the inhibition from many neighbor words in Experiment 3 occurred because of the difficulty of selecting the correct target word out of many indistinctive orthographic candidates, the same results should be observed in Experiment 4 in which five-letter words were used as target words. Additionally, Experiment 4 tests the important question of whether neighborhood size affects word skipping. Substantial studies have examined what kinds of linguistic features affect word skipping during reading. For example, word frequency (e.g., Choi & Gordon, in press*a*), word repetition (e.g., Lowder et al., in press), word predictability (e.g., Rayner et al., 2011), number of syllables (Fitzsimmon & Drieghe, 2011), and lexical status (e.g., Gordon et al., 2013) have been known as critical factors that influence word skipping during reading. However, neighborhood size has not been studied yet pertaining to word skipping during reading. The current experiment attempts to investigate whether neighborhood size affects word skipping, and if so, how it influences skipping behavior. If neighborhood size affects word skipping similarly to how it affects fixation durations, higher skipping rates would be expected in the few neighborhood condition as compared to in the many neighborhood condition. Alternatively, if word skipping occurs because neighbors of the target word cause an increase in global lexical activity and in this way increase the sense that the target is indeed a word, then higher skipping rates would be observed in the many neighborhood condition relative to in the few neighborhood condition.

*Methods*

Participants

Forty-eight college students at the University of North Carolina at Chapel Hill were tested in the experiment and received course credit for their participation. All participants had normal or corrected-to-normal vision and were native English speakers.

Apparatus

The apparatus was the same as that used in previous experiments.

Materials and Design

Sixty five-letter words, 30 with few neighbors and 30 with many neighbors, were selected as target words and were embedded in a set of 30 sentences (See Appendix 4). As can be seen in Table 12, the words in the many neighborhood condition had a lower OLD20 value than the words in the few neighbor condition, $t\ (58) = 11.58$, $p < .001$. Word frequency was calculated using the SUBTLEX corpus (Brysbaert & New, 2009). Words in the many neighbor condition had a mean word frequency of 13.53 counts per million and words in the few neighbor condition had a mean word frequency word of 6.22 per million, $t\ (58) = 1.94$, $p > .05$. Note that all target words were low frequency. The mean word frequency of the closest 20 OLD neighbors was also controlled across the two conditions because the word frequency of orthographic neighbors can affect the processes of target words, $t\ (58) < 1$, ns (Grainger & Jacobs, 1996; Pollatsek et al., 1999). Two sub-lexical orthographic characteristics were also considered: Summed bigram frequency (BG_Sum) and summed bigram frequency by position (BG_Freq_ByPos). These two measures in the many neighbor condition were slightly greater than those in the few neighbor condition. The BG_Sum did not differ statistically, t (58) = 1.24, ns, but the BG_Freq_ByPos was greater in the many neighbor condition relative to the few neighbor condition, t (58) = 2.97, p < .01. As in previous experiments, reaction times of LDT were compared between the two neighborhood size conditions. The results showed a statistically significant facilitative effect of neighborhood size such that words with many neighbor words had shorter reaction times as compared to words with few neighbor words (623ms vs. 696ms, t (58) = 4.58, p < .001).

A pair of words (one with many neighbors versus one with few neighbors) was embedded in the exact same sentential context (See an example in Table 13). Participants read 30 sentences in which half of the target words were many neighbor words and half were few neighbor words. As a result of each sentence frame being used only once for each participant, the predictability of the target word in a given sentence frame was counterbalanced across participants. The sentences were presented in a different random order to each participant.

**Table 12. Orthographic characteristics of target words used in Experiment 4**

| | OLD20 | Freq | OLDF | BG_Sum | BG_Freq_ByPos |
|---|---|---|---|---|---|
| **Many N** | 1.54 | 13.53 | 7.81 | 13322 | 2580 |
| **Few N** | 2.06 | 6.22 | 7.78 | 12080 | 1961 |

**Table 13. An Example Sentence From Experiment 4**

| ***Condition*** | ***Sentence*** |
|---|---|
| Many N | Kim's favorite toy is the wooden **crown** her grandfather gave her. |
| Few N | Kim's favorite toy is the wooden **easel** her grandfather gave her. |

Note. The words in bold are target stimuli. Many N = many orthographic neighbors, Few N = few orthographic neighbors.

Procedure

The procedure was the same as that followed in previous experiments.

*Results*

*Analysis of eye movements*. All restrictions that were applied to the analysis of Experiment 1 were also considered in Experiment 4. For the final analysis, 6.3% of data points were excluded by these restrictions. First-pass and late reading-time measures were the same as in Experiment 1. The two levels of orthographic neighborhood size were analyzed by a one-way analysis of variance (ANOVA). Error variance was calculated by participants ($F_1$) and by items ($F_2$).

*Dependent measures on pretarget words*. Table 14 shows the means and standard deviations of all the dependent measures on the pretarget words, and Table 15 shows the inferential statistics on each dependent measure for each variable. As can be seen in Tables 14 and 15, no dependent measure showed a significant difference between the many and the few neighbor conditions.

*Dependent measures on target words*. Table 14 shows the means and standard deviations of all the dependent measures on the target words, and Table 15 shows the inferential statistics on each dependent measure for each variable. The main effect of neighborhood was observed in skipping rates in that words with many neighbor words were more likely to be skipped relative to words with few neighbor words in both subject and item analyses. However, the gaze duration results showed the opposite pattern of neighborhood effects such that gaze duration on the many neighborhood condition was longer than that on the few neighborhood condition. The inhibitory neighborhood effect on the gaze duration was significant in the subject analysis and had strong inhibitory trend in the item analysis. As found in Experiments 3, neighborhood size affected gaze duration on a target such that readers spent more time looking at a target when it had many neighbor words as compared to when it had few neighbors, supporting the idea that the speed of recognition of the correct target is inversely correlated with the number of neighbor words.

The interesting finding of Experiment 4 was the opposite pattern of results of gaze duration and word skipping in relation to the effect of neighborhood size. As described above, an inhibitory effect of neighborhood size was observed in gaze duration, whereas a facilitative effect of neighborhood size was found in word skipping. Further explanation will be considered in later sections.

*Dependent measures on posttarget words*. Table 14 shows the means and standard deviations of all the dependent measures on the post-target words, and Table 15 shows the inferential statistics on each dependent measure for each variable. As can be seen in Tables 14 and 15, there was no difference between the many and the few neighbors condition on any dependent measure.

*Discussion*

The result of this experiment showed that having many neighbors increases the frequency with which a word is skipped, but also increases the duration that it is fixated if it is not skipped. This result is intriguing in two ways.

First, gaze duration showed an inhibitory effect of number of neighbors. Experiment 2 of Pollatsek et al. (1999) also found an inhibitory effect of number of neighbors in an eye-tracking experiment but it was due to the presence of higher-frequency neighbor words. When they controlled the number of higher frequency neighbor words, the inhibitory effect disappeared. The current experiment controlled the frequency of neighbor words across the two neighborhood size conditions and also used a different metric of orthographic neighborhood size. One concern about the gaze duration result was that the item analysis did not show a significant difference between the two neighborhood-size conditions. Examination of the frequency of words in a pair showed that some pairs (e.g., *greed* versus *alibi*) were not well matched. As mentioned before, it is relatively difficult to observe neighborhood effects when high-frequency words are used as target words. Although the word pairs that were used in this experiment contained low-frequency words, some of them had a relatively large frequency difference between the two words. Accordingly, a post hoc analysis was conducted after excluding 7 word pairs in which frequency was not appropriately matched. The gaze duration result showed that the inhibitory effect of the number of neighbor words was observed in both subject and item analysis, $F_1(1,47) = 5.46$, $p < .05$; $F_2(1,22) = 9.40$, $p < .01$. This replicates the finding obtained in Experiment 3 when longer target words were used. The inhibitory effect of neighborhood size was observed in both experiments using short and long words conditions indicating that words with distinctive orthographic codes were processed faster than ones with indistinct orthographic codes.

The second intriguing finding of this experiment was that words with many neighbors had higher skipping rates than matched words with few neighbors. Usually higher skipping rates are associated with shorter gaze durations and both measures are generally considered to reflect ease of word recognition (Choi & Gordon, in press*a*; Gordon et al., 2013; Rayner, 1998). If exactly the same lexical recognition processes are involved in skipping and fixation measures, then a greater number of neighbors should have been associated with lower skipping rates rather than higher ones. Why then was the opposite pattern observed? One answer to this question can be found in recent eye-tracking during reading studies on word skipping (Choi & Gordon, in press*a*; in press*b*; Gordon et al., 2013). These studies showed that skipping rates were higher when the letter string in parafoveal preview just to the right of fixation was a word (e.g., *brain*) as compared to when it was a word-like nonword (e.g., *brane*). They also showed that the skipping rate for previewed non-words was not affected by repetition and frequency manipulations of the base word from which the non-word was derived even though those manipulations did affect skipping rates when the word itself appeared in the parafovea. Further, skipping rates were very similar when the letter strings in parafoveal preview were both words (e.g., *plain* versus *plane*) even when one of the words was not semantically plausible given the preceding context. Choi and Gordon (in press*b*) interpreted these results as indicating that the oculomotor mechanisms underlying skipping are triggered by an implicit lexical decision that the letter string in parafoveal preview is a word. This characterization naturally leads to the view that factors that facilitate explicit lexical decisions, such as number of neighbors, should also cause higher skipping rates. According to Grainger & Jacobs (1996), in a lexical decision task, participants do not have to exactly recognize what the target word is. Instead, they decide its lexical status based on global lexical activation that can be influenced by the number of neighbor words. Operation of a similar mechanism may influence skipping behavior during reading so that seeing a word with many neighbors in parafoveal preview prompts more global lexical activation that results in increased skipping. This issue is revisited in the General Discussion.

**Table 14. Means (SDs) on the target word in Experiment 4**

| | | Fixation duration | | | | | Probability | |
|---|---|---|---|---|---|---|---|---|
| Region | Conditions | FFD | SFD | GZD | RPD | TTime | Skipping | NFPFix. |
| Pre Target | Many N | 210 (31) | 205 (30) | 256 (60) | 337 (134) | 505 (142) | .10 (.10) | 1.22 (.24) |
| | Few N | 213 (35) | 206 (35) | 264 (79) | 335 (107) | 486 (148) | .10 (.11) | 1.26 (.18) |
| Target | Many N | 237 (39) | 232 (39) | 263 (51) | 351 (102) | 412 (94) | .16 (.16) | 1.14 (.12) |
| | Few N | 233 (31) | 228 (33) | 250 (39) | 335 (120) | 391 (104) | .12 (.11) | 1.10 (.10) |
| Post Target | Many N | 225 (45) | 222 (45) | 243 (58) | 322 (105) | 343 (104) | .48 (.13) | 1.09 (.13) |
| | Few N | 229 (51) | 225 (51) | 252 (65) | 332 (109) | 346 (93) | .47 (.15) | 1.11 (.13) |

**Table 15. Inferential statistics from ANOVA on the target word in Experiment 4**

| | PreTarget | | | | | | Target | | | | | | PostTarget | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fsubject (1,47) | | | Fitem (1,29) | | | Fsubject (1,47) | | | Fitem(1,29) | | | Fsubject (1,47) | | | Fitem(1,29) | | |
| | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p | F | MSE | p |
| FFD | .704 | 362 | .41 | 1.62 | 377 | .21 | .84 | 459 | .363 | .67 | 700 | .421 | .304 | 1438 | .58 | .264 | 1220 | .61 |
| SFD | .035 | 480 | .85 | .46 | 486 | .50 | .65 | 493 | .423 | .45 | 809 | .508 | .157 | 1443 | .69 | .398 | 1116 | .53 |
| GZD | 1.08 | 1624 | .31 | .679 | 2247 | .42 | 5.06 | 708 | **.029** | 2.71 | 905 | .111 | .99 | 2019 | .33 | .019 | 1801 | .89 |
| RPD | .032 | 5721 | .86 | .021 | 5330 | .89 | 1.15 | 5038 | .289 | .30 | 6501 | .590 | .366 | 6184 | .55 | .109 | 8705 | .74 |
| TT | 1.22 | 7517 | .27 | .685 | 6880 | .42 | 2.44 | 3874 | .125 | 1.14 | 4436 | .295 | .051 | 3887 | .82 | .062 | 3619 | .81 |
| Skip | .014 | .003 | .91 | .039 | .004 | .85 | 5.12 | .01 | **.028** | 7.24 | .005 | **.012** | .16 | .014 | .69 | .425 | .008 | .52 |
| NFix | 1.49 | .017 | .23 | .56 | .019 | .56 | 6.12 | .006 | **.017** | 2.46 | .008 | .127 | .519 | .015 | .48 | 2.57 | .006 | .12 |

## General Discussion

The overarching goal of the present research was to investigate how the linguistic information activated by preceding sentential contexts and by a currently processed word affect word recognition during sentence reading. Four eye-tracking during reading experiments were conducted and the results can be summarized as follows: 1) In a case in which a highly-constraining context allowed a specific word to be predicted based on the preceding contextual information, readers pre-activated an upcoming word at the level of word form. This pre-activation facilitated the processing of the expected target word. More interestingly, if the pre-activation was wrong, readers spent more time processing the unexpected word than they did when that word was preceded by an unconstraining context. 2) Lexical activation elicited by intra-sentential word repetition modulated the effect of orthographic neighborhood size such that shorter fixation durations were observed for words with many neighbors as compared to those with few neighbors when the target word was repeated from an earlier region in the sentence. No difference between words with many as compared to few neighbors was found when the target word was not repeated. The results were surprising because they implied that neighbor words actually inhibit processing of target words rather than facilitate processing as reported in previous word recognition studies. Accordingly, additional experiments were conducted in which the two types of words were presented with exactly the same preceding sentential contexts. Two results were obtained. Experiments 3 and 4 showed that a word with many orthographic neighbor words was fixated longer relative to a word with few neighbors, supporting the idea that a distinct orthographic code helps readers recognize a word during sentence reading. Additionally, Experiment 4 showed that a word with many orthographic neighbor words was skipped more frequently as compared to a word with few neighbors.

Many studies have shown that preceding context can rapidly influence the process of word recognition. These studies have used many different methods including eye movements during reading (e.g., Rayner & Well, 1996), eye movements during spoken word recognition (e.g., Allopenna, Magnuson, & Tanenhaus, 1998), visual world paradigm (e.g., Kamide, Altmann, & Haywood, 2003), and ERP with rapid serial visual presentation (e.g., DeLong et al., 2011; 2005). For example, recent ERP studies have shown that lexical features of the upcoming word are pre-activated even before the word appears (DeLong et al., 2005; Federmeier et al., 1999; Laszlo & Federmeier, 2009). A specific question of the first experiment was whether this pre-activation of upcoming words actually causes a processing cost when the prediction is wrong. The result of Experiment 1 supported the idea that readers actively pre-activate an upcoming word at the level of word form and that they experienced a processing cost when the actual word was not the expected one. A further issue about pre-activation relates to how generally the pre-activation occurs based on preceding contexts. The current experiment used strongly constraining contexts (89% occurrence of the expected target words based on the preceding context measured by a sentence completion task) to examine if the processing cost occurs during reading. Follow-up research may examine whether this mechanism of pre-activation operates when moderately constraining preceding contexts are used.

In Experiment 2, the influence of sentential contexts on word recognition during reading was studied using intra-sentential repetition priming (i.e., facilitation of the recognition of a word when it has appeared previously in a sentence). The priming effect is a robust finding in eye-tracking studies of reading (Choi & Gordon, in press*a*; Gordon et al., 2013; Ledoux et al., 2007; Liversedge et al., 2003; Lowder et al., in press; Traxler et al., 2000). If repetition priming influences broad semantic/discourse level processing, inherent linguistic features of a target word such as orthographic neighborhood should not be affected by repetition priming. Alternatively, if the repetition priming affects processing of lexical form of an upcoming target, the word-intrinsic linguistic characteristics should be modulated by the repetition priming. The finding obtained in Experiment 2 supported the latter hypothesis in that there was an interaction between word repetition and orthographic neighborhood size. Surprisingly, the pattern of interaction was not consistent with the prediction based on the lexical-decision literature (See Andrews, 1997 for a review) that a word with many orthographic neighbors would be recognized faster than one with few neighbors and that this effect would diminish when the word was repeated within a sentence because facilitation due to repetition would be greater for difficult words (e.g., Lowder et al. in press). Instead the results suggested that orthographic neighbor words inhibit the processing of a target word, rather than facilitate it during sentence reading. Accordingly, the facilitation of target processing attributable to orthographic neighbor words was observed only when the word was repeated from earlier in the sentence. No effect of neighborhood size was found in the unrepeated condition. Thus, although the effect of neighborhood size occurred in an unexpected pattern, this result showed evidence that linguistic information activated by sentential contexts affects processing of the target word at the lexical form level.

The idea that preceding sentential contexts modulate the current state of word recognition has been supported by findings observed in recent studies (Kim & Lai, 2012; Laszlo & Federmeier, 2009; Lowder et al., in press). For example, Laszlo and Federmeier (2009) examined how sentential contexts interact with the processes of the lexical form of a target word. In strongly constraining contexts (e.g., *Before lunch he has to deposit his paycheck at the* ______), the amplitude of N400 was smaller when the target string was a word (e.g., bark) that was orthographically similar to an expected target word (e.g., bank) as compared to when it was a orthographically dissimilar word (e.g., hook). More interestingly, a similar pattern of results was observed in a comparison between an orthographically similar illegal letter string (e.g., bxnk) versus a dissimilar letter string (e.g., tknt). The authors argued that readers pre-activate the lexical form of an upcoming word, which can activate corresponding letter information. In other words, readers can not only activate the word, *bank*, based on the preceding context, but also activate letters *b*, *a*, *n*, and *k* which belong to the word *bank*. Accordingly, when readers saw a letter string, *bark*, that was orthographically similar to the pre-activated target word, *bank*, they obtained additional facilitation from the pre-activated letter information. This explanation is partly consistent with the results observed in Experiments 1 and 2 of the current study with regards to the notion that the strongly constraining contexts led to pre-activation of an upcoming word at the level of orthographic form. However, one concern about the result obtained by Laszlo & Federmeier pertains to the timing of the effect. Their significant effects were in the

N400 differences component, meaning that the effect appeared 400 ms after the onset of the target string. Considering that the mean gaze duration of target words in Experiments 1 and 2 was around 230 ms, the effect occurring in Laszlo & Fedemeier's study seems very late to be an effect on word recognition. With respect to the temporal gap between eye-tracking and ERP, Kim and Lai (2012) reported an interesting result. They too used strongly constraining sentential contexts and compared ERPs elicited by different target string conditions. They compared a letter string such as *cake*, *cede*, *tont*, and *srdt* followed by a strongly constraining sentential context like "*She measured the flour so she could bake a* _______". They found smaller N400 amplitude in the *cede* than in the *tont* condition, which was consistent with the result obtained by Laszlo and Fedemeier. However, more interestingly, greater amplitude of P130 was observed in the *cede* condition as compared to other three conditions, indicating that rapid similarity-based conflict between expected and actual orthographic input occurred during target word recognition. That is, anticipatory processing caused by the preceding context generated an expected target word (e.g., cake), which produced conflict between the expected word, *cake* and actual orthographic input, *cede*. This competition occurred only 130 ms after the onset of the target string, which is more consistent than other ERP studies with the time course observed in eye-tracking during reading studies. These ERP studies have clearly shown evidence that linguistic information elicited by sentential contexts pre-activates upcoming language input at the level of word form. One methodological concern of these ERP studies is that they have mostly used rapid serial visual presentation (RSVP) in which participants read a sentence word by word and the target string is the last word of a sentence. This particular way of presenting stimuli might allow participants to exploit additional strategies, such as consciously generating lexical predictions during the interval between words, which could affect language comprehension. The current experiments, using an eye-tracking during reading methodology which we believe captures more natural sentence processing, found very similar results that sentential contexts activate the lexical form of the upcoming words and modulate the current state of word recognition.

In Experiment 2, facilitation in first-pass reading time was found only in the repetition condition for a word with many neighbor words. This finding gave an interesting perspective on the role of orthographic neighborhood size during sentence reading. The results might imply that the existence of many orthographic neighbor words actually hinders the processing of a target word. Yet Experiment 2 provided only tentative support for this conclusion because it did not control the preceding sentence contexts across the two classes of words. Therefore, Experiments 3 and 4 were designed to assess the role of orthographic neighbor words in word recognition during reading. The results of Experiments 3 and 4 were very straightforward. Fixation duration of a word with many orthographic neighbor words was longer relative to that of a word with few neighbors. The inhibitory effect of orthographic neighborhood size observed in Experiments 3 and 4 cannot be explained by the word-to-letter feedback mechanism proposed by the IAM (Andrews, 1997; McClleland & Rumelhart, 1981). One potential explanation for the inhibitory neighborhood size effect in IAM is that there is intra-level lexical inhibition between word units so that a word with many neighbor words receives more inhibition than one with few neighbors. For example, Pollatsek et al. (1999) reported an inhibitory neighborhood effect when a word had many orthographic neighbors relative to when it had few neighbors. But in that study the inhibition from neighborhood size could also have been due to the difference in the number of higher frequency neighbor words in the two neighborhood-size conditions. Consistent with this, the inhibitory effect disappeared when the number of higher frequency neighbor words was matched across the many versus few neighbor conditions. Furthermore, the inhibitory effect of orthographic neighbors was found in masked priming studies when the prime was a higher-frequency word than the target. Otherwise the inhibition did not occur (Bijeljac-Babic, Biardeau, & Grainger, 1997; DeMoor & Brysbaert, 2000; Nakayama, Sears, & Lupker, 2011; Segui & Grainger, 1990; cf. Davis & Lupker, 2006). According to the IAM, if features of higher frequency neighbors were controlled, the inhibitory effect from neighbor words should be minimized. Therefore, the inhibitory effect of neighborhood size obtained in Experiments 3 and 4 of the current study is not able to be fully accounted for by the lateral inhibition mechanism of the IAM because the mean word frequency of neighbor words was controlled across the two neighborhood conditions.

Given that the IAM has difficulty in explaining the current data, an alternative explanation based on orthographic distinctness should be considered. According to this hypothesis, ease of lexical access increases as a target word has a more distinct orthographic code. On this account the fixation duration for *prophet* would be shorter than that for *drought* because its orthographic code is more distinct. When participants read a word in a sentence, a set of candidates can be activated based on the orthographic similarity to the target word. If the candidate set is relatively large, readers need more time to select the correct target from among the many candidates, whereas if the set is quite small, readers do not experience strong competition among candidates because the orthographic code of the target is distinctive. The concept of orthographic distinctiveness should be further elaborated upon in future research.

Another intriguing result was the difference in skipping rates between the many versus the few neighborhood conditions in Experiment 4. Although Pollatsek et al. (1999) reported a similar finding in their Experiment 3, they argued that the higher skipping rate for the many neighbors condition was due to misperception of the letter string in parafoveal preview. That is, readers would be more likely to misperceive a target word as one of its neighbors if the word had many as compared to few neighbors. Thus, Pollatsek et al. concluded that the difference in skipping rates between the many versus few neighbor conditions resulted from misidentification of the target words. This conclusion was supported by the finding that when readers skipped a word with many neighbors they were more likely to regress back to it as compared to when they skipped a word with few neighbor words (20% vs. 12%, respectively). In contrast, for the current result, there was no difference in the rates of regression back to skipped target words as a function of number of neighbors, a result that is not consistent with misidentification of the target word (See Choi & Gordon, in press*a*, in press*b*). Accordingly, an alternative explanation is needed for the difference in skipping rates found for words with many versus few neighbors.

Models of eye movement control during reading have attempted to explain why words are skipped during reading (Engbert, Nuthmann, Richter, & Kliegl, 2005; Pollatsek, Reichle, & Rayner, 2006). One prominent serial attention shift model (e.g., E-Z Reader, Pollatsek et al., 2006) posits that attention is allocated word by word, and the default saccade target is the next word. Lexical processing proceeds on the fixated letter string until a familiarity check (the L1 stage) is completed, indicating that recognition of that string as a word is imminent. Completion of L1 initiates motor programming of a saccade to the next word while lexical processing of the fixated string continues until it is fully recognized (the L2 stage). Completion of L2 causes an attentional shift to lexical processing of the next word. In most cases, lexical processing is still ongoing when the eyes move to the next word, and the processing during that shift provides parafoveal preview benefit for the next word. In a minority of cases, the familiarity check (L1) on the parafoveal string is completed with sufficient time to cancel the planned saccade to that string and to reprogram a longer saccade that skips it. Therefore, understanding the mechanisms that trigger skipping is the key to understanding the linguistic and perceptual factors that determine the speed of completing the familiarity check (L1). Although some studies have attempted to characterize the familiarity check (Reichle, Tokowicz, Liu, & Perfetti, 2011; Reingold & Rayner, 2006), they have not provided a precise explanation. Recently, Choi and Gordon (in press*a*; in press*b*) characterized the L1 stage as an implicit lexical decision because the rate of language-based skipping for previewed transposed-letter (TL) nonword strings (e.g., *nroth* vs. *bilnk*) did not depend on the ease of recognizing the base word from which the TL nonword was derived (e.g., *north* vs. *blink*). Even though those TL preview strings provided activation for the base words, they impeded word skipping because they were not words. The results of Experiment 4 also support the idea that word skipping occurs based on checking lexical status of the letter string in parafoveal preview. As noted earlier, according to the MROM, lexical decision is affected by the global lexical activity ($\Sigma$ component), which means that a word with many neighbor words would be determined as a word faster than one with few neighbors. Lexical decision data from the English Lexicon Project show this pattern for the words used in Experiment 3. During reading, if the word seen in parafoveal preview has many neighbor words, activation of those neighbor words should increase the global lexical activation which should result in more word skipping. In contrast, parafoveal preview of a word with few neighbors would result in less activation of neighbor words, leading to less skipping. This account of word skipping based on global lexical activity provides a detailed characterization of how words are skipped during reading.

## Conclusion

Examining how words are recognized has been the focus of a great deal of research in cognitive science and cognitive neuroscience because many types of processes play a role in this seemingly simple task. In particular, efforts to understand how word-intrinsic and word-external factors interact to affect word recognition during reading has provided a valuable way to increase theoretical understanding of language processing and of the more general principles by which cognitive processes interact. This dissertation investigated how word-external factors, specifically sentential context and intra-sentential word repetition, interact with the word-intrinsic factor of lexical neighborhood size to affect word recognition during reading. The results reported here have shown that readers pre-activate upcoming word(s) at the level of word form and that this affects recognition of the activated words at the orthographic level and impedes recognition of non-activated words. Further, they have shown that orthographically similar neighbor words in the lexicon interfere with processing of a word during reading. These findings can provide insight into the nature of language comprehension and provide important evidence that must be accounted for in constructing models of language processing.

# Appendices

## Appendix 1

All sentences used in Experiment 1. Target words are in bold and in the brackets; the first word is the expected one, and the second is the unexpected one.

| Conditions | Sentences |
|---|---|
| Constraining Contexts | Our furtive neighbor looks like James Bond, so Jan thinks he's a secret [**agent, spy**] living a double life. |
| | In a dire emergency you can pull a lever to sound the [**alarm, bell**] on any modern train. |
| | When I was little I loved to sail my toy [**boats, ships**] in the tub or the pool. |
| | The humps on the back of the tall [**camel, horse**] made it hard to ride, even with a saddle. |
| | For Halloween I don't feel comfortable with my kids asking for [**candy, treats**] from strangers. |
| | When I put my seat belt on, I never heard the sound of a [**click, buckle**] that let me know it was fastened. |
| | One milestone in history was learning to weave linen or wool to make [**cloth, fabric**] for clothing and shelter. |
| | We had to do 50 pushups every day because of the new basketball [**coach, trainer**] and his fitness regime. |
| | She hated flying and was afraid her plane would [**crash, fail**] every time she flew across the country. |
| | I brought bread to the park's pond to feed the [**ducks, geese**] while my friend read her book. |
| | The story of Noah's ark is that it was built to survive the [**flood, rains**] and carry pairs of animals. |
| | Strawberries are my favorite [**fruit, berry**] in the summer, but I prefer oranges in winter. |
| | She organized the data in a bar [**graph, chart**] to make it easier to see on her poster. |
| | Every year I put flowers on my late husband's [**grave, tomb**] to commemorate his death. |
| | He had a tall glass of fresh-squeezed orange [**juice, nectar**] waiting for him on the counter after his run. |
| | At noon I left the office to meet my friend for [**lunch, tea**], so we could catch up on each other's lives. |
| | Jo's daughter is tall, thin, and very pretty, so she wants to be a [**model, singer**] when she grows up. |
| | I could hear a lot of [**noise, babble**] coming from my next door neighbors' apartment, which was unusual for them. |
| | She held the unconscious man's wrist to check his [**pulse, watch**] and frowned at what she saw. |
| | When my tires run out of air I use one of the free bike [**pumps, stations**] the university provides. |

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|---|---|
| | I hadn't seen the game yet, so I asked Zack not to tell me the final [**score, result**] since he had seen it already. |
| | At the play, my friend saved two [**seats, places**] for us using his jacket and backpack. |
| | The librarian put the book up on the [**shelf, counter**] before leaving for lunch. |
| | He was paralyzed when he fractured his [**spine, neck**] in the awful car crash. |
| | She stirred the soup with a wooden [**spoon, ladle**] before serving it to her family. |
| | I prefer bitter dark chocolate, since milk chocolate is too [**sweet, rich**] for my taste. |
| | Instead of telling us what to write about, my teacher let us pick the [**topic, theme**] for our essays. |
| | The pioneer had four horses hitched to his [**wagon, cart**] for speed and endurance. |
| Unconstraining Contexts | My nephew surprisingly kept a secret [**agent, spy**] toy from his childhood right through college. |
| | I wondered about what sound the [**alarm, bell**] made in that deaf person's home. |
| | When I was little, my brother broke my toy [**boats, ships**] and had to buy me new ones out of his allowance. |
| | I was afraid of the tall [**camel, horse**] until I went for a slow, bumpy ride on its back. |
| | The kid I babysat kept asking for [**candy, treats**] or he'd start crying and screaming. |
| | When I heard the sound of a [**click, buckle**], I knew my son had put his seat belt on and we could leave. |
| | Using cotton instead of linen to make [**cloth, fabric**] was one effect of the Industrial Revolution in England. |
| | We were all really happy with the new basketball [**coach, trainer**] and his approach to teaching. |
| | My flight was delayed because the plane would [**crash, fail**] if it weren't serviced first. |
| | I told my friends not to feed the [**ducks, geese**] or they'd never stop bothering us. |
| | It was unlikely that her house would survive the [**flood, rains**] the heavy storm would bring. |
| | My mom baked my favorite [**fruit, berry**] pie for my graduation in May. |
| | She found out about the pay inequality from a bar [**graph, chart**] printed on a flyer in the lunchroom. |
| | I wanted my husband's [**grave, tomb**] and mine to be next to each other, so I reserved plots in a nearby cemetery. |
| | On the front of his shirt there was an orange [**juice, nectar**] stain left over from breakfast. |
| | I didn't think she would bring a friend to [**lunch, tea**], so the reservation was only for two people. |
| | It takes more work to be a [**model, singer**] than most people realize. |
| | Yesterday morning, there was a lot of [**noise, babble**] coming from the apartment next door. |
| | Jack always remembers to check his [**pulse, watch**] before and after excercising. |
| | The company provided free bike [**pumps, stations**] on the bottom level of the parking deck. |

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|---|---|
| | I didn't want to know the final [**score, result**] until I saw the performance that led up to it. |
| | I was really lucky that my friend had saved two [**seats, places**] for us at the play. |
| | She looked on the [**shelf, counter**] for her missing keys, but they weren't there. |
| | In the car crash, he fractured his [**spine, neck**] and was never able to walk again. |
| | The crotchety neighbor started ranting and waving a wooden [**spoon, ladle**] at the kids across the street. |
| | I'll ask my sister if the food is too [**sweet, rich**] for her neighbor's potluck dinner. |
| | My group decided to come up with our own [**topic, theme**] for a research project instead of choosing from the list. |
| | He didn't want anything hitched to his [**wagon, cart**] until he fixed the back wheel. |

Appendix 2

All sentences used in Experiment 2. Target words are in italics, and the prime words are in bold and in the brackets. The first prime word is the repeated one, and the second is the unrepeated one.

| Conditions | Sentences |
|---|---|
| Many neighbor words | He liked [**pears, fruit**], so he cut up some *pears* for his lunch. |
| | Twinkies never go [**stale, bad**], but fresh bread turns *stale* in a matter of days. |
| | The cruise [**liner, ship**] wasn't huge, but the *liner* still had many amenities. |
| | With the business deal at [**stake, risk**], the company's future was at *stake* as well. |
| | Many people didn't notice the warning [**cones, zone**], though the *cones* were bright orange. |
| | The red [**lever, alarm**] activates the siren, so pull the *lever* if there is danger. |
| | The deer sniffed at the [**tents, camp**], then ran away from the *tents* and into the woods. |
| | If you [**grate, grind**] your teeth during the day, it's no wonder you *grate* them while you sleep. |
| | The big, mean [**bully, child**] picked on Ryan, so the *bully* ended up with a bloody nose. |
| | The [**slate, stone**] countertops were nice because the *slate* was easy to clean. |
| | The new [**clamp, nails**] held the boards together better than the old *clamp* did before. |
| | The queen prefers the simple [**crown, tiara**] because the ornate *crown* is very heavy. |
| | He wouldn't go near the [**shark, ocean**] after hearing about last week's *shark* attack on the news. |
| | We always [**spice, flavor**] our pasta with basil rather than *spice* it with oregano. |
| | The new ads caused a [**spike, jump**] in sales, but the *spike* didn't last long. |
| | She picked out a [**witch, crooked**] hat to go with her *witch* costume for Halloween. |
| | My favorite [**blend, kind**] of coffee is expensive, so I bought a cheaper *blend* to save money. |
| | The coach doesn't want to [**boast, brag**] about his team, but the players *boast* despite his wishes. |
| | He took off the arm [**brace, sling**] because the *brace* was itchy. |
| | I caught a tiny [**flake, bit**] of snow on my tongue, and the *flake* immediately melted. |
| | My brother likes donuts with chocolate [**glaze, icing**], but I prefer the plain *glaze* on mine. |
| | The explorer's [**greed, desire**] led him to steal the gold, and his *greed* made him enemies. |
| | She made a [**peach, banana**] smoothie and added a slice of *peach* as a garnish. |
| | The rain made the road [**slick, wet**], but my tires can handle *slick* surfaces, thankfully. |
| | The wine [**stain, spill**] on the carpet was no match for the *stain* remover Kyle had. |
| | The [**stove, range**] remained hot for a long time after the *stove* was turned off. |
| | A wizard cast a [**curse, spell**] on the town, but no one believes in the *curse* or magic. |
| | The student could [**forge, fake**] his mom's signature but didn't know how to *forge* his |

| | |
|---|---|
| | dad's. |
| | One small [**sheep, lamp**] escaped the herd, but the other *sheep* didn't notice. |
| | I eat a [**snack, meal**] before I exercise and a *snack* after I'm done. |
| Few neighbor words | A cold makes you [**cough, sick**], but allergies may cause you to *cough* in the spring. |
| | People are [**merry, happy**] around the holidays when they see how *merry* others are. |
| | The [**cello, string**] section of the orchestra consisted of four *cello* players this season. |
| | The pianist played a bright [**chord, note**] followed by a somber *chord* during the song. |
| | We tried to [**drift, float**] down the river but quickly decided to *drift* back to shore. |
| | The [**ruler, leader**] of the kingdom sat with a fellow *ruler* at the festival. |
| | I wore my mom's [**scarf, shawl**] because I couldn't find the *scarf* I normally wear. |
| | I imagined rolling fields of [**wheat, grain**] as I ate my *wheat* bread sandwich. |
| | When she fell, she hit her [**ankle, foot**], and her *ankle* was swollen for weeks. |
| | I saw a large [**eagle, bird**] in the tree, but the *eagle* screeched when I got too close. |
| | The wooden [**easel, stand**] Michelle used was the *easel* she got for her birthday. |
| | At the family reunion, Jack's [**niece, child**] played with my *niece* while the adults talked. |
| | In the grocery [**aisle, lane**], the child threw a can into the *aisle* and screamed. |
| | Underneath the tall [**maple, birch**] tree, my friend found a *maple* leaf for her scrapbook. |
| | She waved the [**torch, flame**] wildly after grabbing my *torch* from me. |
| | The [**width, girth**] of the sandwich far exceeded the *width* of my open mouth. |
| | The garden's [**aroma, scent**] reminded me of the *aroma* of grandma's perfume. |
| | She heard of her [**rival's, enemy's**] death and mourned her *rival* despite their past. |
| | We denied knowing the [**rumor, secret**] although we heard the *rumor* last week. |
| | The lone adult [**cobra, snake**] seemed to protect the *cobra* nest for some reason. |
| | I forgot one [**digit, number**] while typing the ten *digit* password in the dark. |
| | While I watched nesting [**geese, robins**], a huge flock of *geese* flew over the horizon. |
| | I relinquished my [**razor, blade**] because security would not allow the *razor* inside the court. |
| | I devoured my [**sushi, shrimp**], but my friend hated his *sushi* and went hungry. |
| | I hid the [**atlas, globe**] since I found dirty fingerprints on the *atlas* last week. |
| | The satellite was in [**orbit, space**] until the meteor knocked it out of *orbit* ten years later. |
| | Our small [**yacht, boat**] was sinking when a passing *yacht* heard our cries for help. |
| | He thought the [**idiom, saying**] was great, and thus overused the *idiom* in his paper. |
| | In the [**zebra, African**] area at the zoo, a brave *zebra* approached the fence near us. |
| | Though the Eskimo's [**igloo, home**] was made of snow, the *igloo* was not cold on the inside. |

## Appendix 3

All sentences used in Experiment 3. Target words are in bold and in the brackets. The first word is the one with few neighbor words, and the second is the one with many neighbor words.

| Sentences |
| --- |
| The ancient text mentioned a [**prophet, drought**] that affected the villagers' lives. |
| The mayor had acquaintances in many [**spheres, sectors**] throughout the city. |
| The dieters hit their ideal [**targets, weights**] and celebrated together. |
| The driver hit [**reverse, traffic**] and slowly rolled to a stop. |
| Annie brought her [**terrier, satchel**] with her to work each day. |
| Climbing the steep [**terrain, boulder**] was too difficult for amateur hikers. |
| Isaac's favorite activity at camp is [**archery, cricket**] as long as the weather is good. |
| In the check-out line the [**cashier, scanner**] was working slowly. |
| Paying for [**therapy, flight**] wouldn't fit into Sarah's tight budget right now. |
| She began to experience [**renewal, rewards**] from her career. |
| She belonged to a [**lineage, faction**] that contained many dangerous criminals. |
| She hated to talk about [**suicide, heights**] on top of the high-rise building. |
| Her new [**liberty, mission**] brought her to New York for the first time. |
| The proposal was rejected because his [**anxiety, conceit**] caused them to lose interest. |
| The television show's amount of [**viewers, savings**] decreased each week. |
| The child cried after receiving an unpleasant [**vaccine, stinger**] in her arm. |
| Jeremy suffered painful [**torture, bruises**] in the interrogation room. |
| The modern sculpture was made from [**durable, diverse**] materials found in everyday life. |
| I was surprised to find a great [**prodigy, plumber**] like John in a small town. |
| Jack was excited to see the fantastic [**drummer, concert**] at the music festival. |
| The city has preserved the 18th century [**cuisine, convent**] that it is famous for. |
| The boy was afraid of the [**dentist, monster**] he thought would hurt him. |
| Sandy bought the fresh [**lettuce, lobster**] that was just delivered to the market. |
| Kim enjoys going to the [**airport, pasture**] every now and then. |
| Jan was tired after searching for the lost [**tourist, slipper**] the whole morning. |
| Maria doesn't want to buy a [**forgery, scooter**] if it's expensive. |
| The dog's tiny [**puppies, whisker**] brushed against my hand and startled me. |
| The predictable [**failure, concept**] of the captain's plan didn't impress the general. |
| The bowling team members have many [**hobbies, strikes**] amongst themselves. |
| The cardiologist examined the [**density, breaths**] of the patient's lungs. |

Appendix 4

All sentences used in Experiment 4. Target words are in bold and in the brackets. The first word is the one with few neighbor words, and the second is the one with many neighbor words.

| Sentences |
|---|
| The baby was frightened by seeing a dangerous [**hound, cobra**] in the movie. |
| Emma received a fluffy [**towel, scarf**] from her aunt as a surprise Christmas gift. |
| Kim's favorite toy is the wooden [**crown, easel**] her grandfather gave her. |
| Jack was not rich enough to buy the expensive [**stove, yacht**] he dreamed about. |
| Jim prefers using a sharpened [**blade, razor**] to shave his mustache. |
| Bill couldn't find any organic [**cream, cocoa**] at the grocery store. |
| Emily planned to buy a fragrant [**spice, cigar**] at the market. |
| The camper brought his favorite [**snare, torch]** on the hunting trip. |
| The cartoon featured a talking [**shark, eagle**] and his animal friends. |
| During the sale, a box of the freshest [**pears, sushi**] costs only six dollars. |
| Laura poured the delicious [**peach, maple**] syrup on her pancakes. |
| The news reported that the endangered [**diver, koala**] was barely saved in time. |
| The traveler saw a herd of wandering [**sheep, zebra**] and took a picture. |
| The team had to be incredibly [**brave, agile**] to get ahead in the game. |
| After walking through the surprisingly [**dusty, humid**] area, I needed to shower. |
| Adam was jealous of his brother's [**snack, viola**] which was better than his. |
| Walking in the narrow [**brace, aisle**] made Jo feel uncomfortable. |
| Deciphering the ancient [**fable, atlas**] proved difficult for the historians. |
| The pleasant [**smell, aroma**] of cinammon filled the bakery. |
| Alan's resentful [**bully, rival**] made his life difficult and frustrating. |
| The newborn [**chick, niece**] I held was so tiny and fragile. |
| A mysterious [**witch, vapor**] appeared in the town one day. |
| We saw numerous [**tents, geese**] as we walked around the lake yesterday. |
| I heard about the terrible [**sleet, theft**] on the news and decided not to go out. |
| The massive [**crane, wharf**] towered over the tiny dock nearby. |
| My task was to carefully [**blend, ladle**] the beverage before serving it. |
| The fair weather led to a plentiful [**grape, wheat**] harvest the next year. |
| The camera's [**handy, extra**] features made it easy to use. |
| At meetings, they always [**glaze, drift**] over important details and focus on the big picture. |
| Her blatant [**greed, alibi**] was unbelievable, so no one took pity on her. |

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