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Phonological And Orthographic Repetition Effects Across Words In Adult Skilled Sentence Reading: An Eye Movement Analysis

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PHONOLOGICAL AND ORTHOGRAPHIC REPETITION EFFECTS ACROSS WORDS IN ADULT SKILLED SENTENCE READING: AN EYE MOVEMENT ANALYSIS

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ABSTRACT

Visual word recognition is central to skilled silent reading. This project investigated the situation in which two words within a sentence share phonological information. Previous eye movement reading studies have made attempts to understand how prior exposure to a word could influence the speed of recognizing another phonologically and/or orthographically similar word. Results have been accounted for by different visual word recognition models which agree on the competition among similar words in the lexicon. However, a closer inspection revealed several concerns. First, there is little direct evidence demonstrating the across-word effect in normal reading. Second, the existing work in English often confounded the phonological repetition patterns and the concurrent orthographic repetition. Finally, conflicts arise between the existing evidence and the lexical competition models employed to account for it. This project consists of three eye movement reading experiments to explore the phonological repetition effects with and without orthographic repetition across words. Results are interpreted from the perspective of the Lexical Quality Hypothesis, which highlights the roles of phonology in different levels of reading processing.

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LIST OF ABBREVIATIONS

IA ....Interactive Activation

LQH ....Lexical Quality Hypothesis

OR...Orthographic Repetition

OR+PR...Orthographic and Phonological Repetition

PR...Phonological Repetition

TTE .... Tongue-Twister Effects

VWR .... Visual Word Recognition

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Visual word recognition (VWR) is central to skilled reading. Each printed word has an orthographic form that represents a phonological form. Phonological information is activated early and used to recognize words (Davis, 2003, 2005; Frost, 1998, Halderman, Ashby & Perfetti, 2012). In daily reading, it is not uncommon to encounter multiple words that share phonological pattern information. For example, in the sentence *I intend to write a letter while I ride the train,* the phonological patterns within the words WRITE and RIDE are largely repeated except one different phoneme (/t/ vs. /d/). Given the two words have distinct spelling forms, this is a phonological repetition alone pattern without concurrent orthographic repetition across words.

There is limited evidence regarding phonological repetition effects on word recognition during reading. Orthographic and phonological repetition are, by definition, confounded in alphabetic writing systems like English. Likewise, English reading studies that were designed to explore either orthographic or phonological repetition effects often confounded the two patterns in their materials. For example, one might set out to study orthographic repetition between a pair of words like BLUE and BLUR (e.g., Paterson, Davis, & Liversedge, 2009) but these words also share phonological repetition. This project contains the experiments that were designed to disentangle the two repetition patterns.

This project investigated a different question from a body of previous work that employed a prime word that stands in for the target for a brief period of time (Davis & Lupker, 2006; De Moor & Brysbaert, 2000; Drews & Zwitserlood, 1995; Grainger, Colé, & Segui, 1991; Grainger & Ferrand, 1994; Segui & Grainger, 1990; Davis & Lupker, 2006; Segui & Grainger, 1990). Instead, the current experiments looked into how prior words have influences on the recognition process of subsequent words in the course of continuous silent reading. All the critical words involved in manipulations were part of an ongoing sentence representation.

Previous researchers have evaluated across-word repetition effects from a connectionist framework. Two connectionist models of VWR, the Dual Route Cascaded model (Coltheart, 2001) and the Triangle model (Plaut, 1996), were presented to address how an individual word's recognition was influenced by the number of words that are orthographically and/or phonologically similar to the word. In particular, these models associate the repetition effects with competition for recognition of a single word, between multiple lexical representations that are similar in orthographic forms. This perspective is consonant with the dominant task paradigm of presenting a brief prime followed by a target word, in which participants are asked to recognize the target word only. A different perspective may be needed to accommodate the effects of prior words in a sentence context on subsequent words in that context. The Lexical Quality Hypothesis (LQH, Perfetti, 2007) provided insights into this issue by suggesting that context processing could modulate lexical competition and that the quality of VWR is associated with the generalized knowledge of orthographic and phonological information.

Readers' eye movements were monitored as they silently read sentences in three experiments that looked at phonological repetition with or without concurrent orthographic repetition across words in a sentence. The first experiment examined the effects of orthographic repetition while controlling phonological overlap. The second experiment examined the effects of phonological repetition while controlling orthographic overlap. The third experiment exploited word frequency as a marker of lexical access and manipulated the word frequency relations between two phonologically related words in a sentence to further investigate the time course of these effects.

1.2 BACKGROUND

This project investigated whether phonological repetition between two words affects word recognition processes in normal silent reading. It has been documented that orthographic and phonological processing are initiated very early and automatically on the way to lexical access (e.g., Folk, 1999, Ashby, Treiman, Kessler & Rayner, 2006, Ashby & Clifton, 2005, Rayner, Sereno, Lesch, & Pollatsek, 1995, Rayner, Pollatsek & Binder, 1998, Lee, H., Rayner, & Pollatsek, 1999, Lee, Y., Binder, Kim, Pollatsek, & Rayner, 1999, Rayner, Liversedge, White, & Vergilino-Perez, 2003, Rayner, 2009, Rayner, Liversedge, & White, 2006, Inhoff & Topolski, 1994, Jared, Levy, & Rayner, 1999). Moreover, verbal working memory (phonological) plays a key role in reading comprehension by maintaining the phonological representations of the words in a serial order and presenting them via subvocal rehearsal for text comprehension. In the course of normal reading, recurring VWR processes yield phonological output of each word that is integrated into the flow of verbal working memory, as the verbal working memory generates information flow to support sentence comprehension. The activated phonological information from prior could be carried over and integrated into the sentence flow which is necessary for sentence comprehension. It is plausible to consider the phonological information from prior words could remain active when readers process the subsequent word. In particular when the later word has repeated phonological information, the exposure to prior words could have across-word effects on subsequent word processing. In alphabetic writing systems the phonological repetition patterns are often represented by repeated orthographic information. Questions remain regarding whether phonological repetition alone can affect recognition of successive words and whether orthographic repetition interacts with phonological repetition effects on word recognition during reading. Limited work has been done to understand these repetition effects.

There is a large body of evidence from a variety of reading related tasks demonstrating that phonological information is activated very early in visual word recognition. For example evidence from eye movement monitoring during silent reading has indicated that phonological codes are activated during a reader's initial look at the critical word (Folk, 1999, Ashby, Treiman, Kessler & Rayner, 2006, Ashby & Clifton, 2005, Rayner, Sereno, Lesch, & Pollatsek, 1995, Rayner, Pollatsek & Binder, 1998, Lee, H., Rayner, & Pollatsek, 1999, Lee, Y., Binder, Kim, Pollatsek, & Rayner, 1999, Rayner, Liversedge, White, & Vergilino-Perez, 2003, Rayner, 2009, Rayner, Liversedge, & White, 2006, Inhoff & Topolski, 1994, Jared, Levy, & Rayner, 1999).

More evidence from eye movement experiments revealed the early-activated phonology affecting lexical access. These studies primarily use two paradigms of eye contingent display change to detect the very earliest activation of phonological representations; fast-priming and parafoveal preview. Both paradigms involve a briefly presented prime word that stands in for the target word. In the fast-priming procedure, participants read a single sentence, in which a consonant string is originally embedded at the position of a target word (Sereno & Rayner, 1992). When the eyes cross an invisible boundary to the left of the target, a display change presents a prime word for the first 20-45ms of the fixation at the target location. The prime is then masked by the target word that appears during fixation (Sereno & Rayner, 1992, Rayner, Sereno, Lesch & Pollatsek, 1995, H. Lee, Rayner & Pollatsek, 1999). Results consistently showed that phonological processing could take place during the first 50 to 100 ms of the initial fixation on a word during reading (Rayner, et al, 1998, Sparrow & Miellet, 2002, Lee, et al, 1999, Slattery, Pollatsek & Rayner, 2006, Rayner, et al, 2003). That is, readers spend less time reading a target word primed with a phonologically related word, than an unrelated control word matched in frequency and length. In addition, fast-priming studies also found that readers process sub-lexical, syllable information during reading (Ashby & Rayner, 2004, Ashby, et al, 2006, Ashby & Clifton, 2005, Ashby, 2006), supporting the early activation of phonology.

The second display change paradigm is the parafoveal preview paradigm. Different from the fast-priming paradigm, the prime in the parafoveal preview was visible to readers on the target position only before readers began to fixate on the target position (Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Liversedge, & White, 2006;

Rayner, 2009). Once readers' eyes moved beyond the middle of the word prior to the target position, the prime was replaced by the target word. Results demonstrated that readers were able to extract phonological information from the preview of a word before fixating on the word during reading (Ashby & Rayner, 2004, Pollatsek, et al, 1992, Rayner, et al, 2006, Rayner, 2009).

Taken together, previous studies using the display change paradigms provided compelling evidence of early activation of phonology in VWR during reading. These studies utilized a pair of words that repeat phonology and/or orthography, and found that presenting one could affect the subsequent recognition of the other one. But in these studies, the prime served as a stand-in for the target word. The current study further examined the across-word influence of phonological and orthographic repetition across multiple word recognition episodes in a sentence during normal silent reading. That is, in a normal sentence without display change, does processing of a word encountered earlier (prime) have consequences on the recognition of a word encountered later (target)?

Some studies have examined the phonological repetition effects across consecutive words in normal sentence reading, which is more relevant to the current research interest. For example, tongue-twister sentences contain multiple words that share repeated word-initial phonemes (e.g. "*The detective discovered the danger and decided to dig for details.*", McCutchen & Perfetti, 1982). A number of tongue-twister studies found that skilled readers were slower and less accurate in reading and comprehending tongue-twister sentences as compared to when they read control sentences without phonological repetition (Hanson, Goodwell, & Perfetti, 1991; Keller, Carpenter, & Just, 2003; Kennison, Sieck, & Briesch, 2003; Kennison, 2004; McCutchen, Bell, France, & Perfetti, 1991; McCutchen & Perfetti, 1982; Acheson & MacDonald, 2011). This phenomenon, referred to as the tongue-twister effect (TTE), suggests that repeated word-initial phonemes across words slow silent reading. However, these studies mainly focus on late stages of sentence processing, i.e. text integration and comprehension rather than early word processing (McCutchen & Perfetti, 1982; McCutchen, Bell, France & Perfetti, 1991; Kennison, 2003, 2004; Acheson & MacDonald, 2009, 2011).

Despite the emphasis on memory-based effects, results from the tongue-twister research suggest the possibility that phonological repetition from prior words interferes with lexical access of the words read later that share the repeated phonemes. Robinson and Katayama (1997) had participants perform a lexical decision task that included a group of tongue-twisting words with repeated initial phonemes and a group of of non-repetition control words. Two groups of words were matched in length and frequency. Reaction time for nonwords was significantly longer in the tongue-twisting group than in the control group. This finding suggests that phonological repetition across words creates interference in lexical access given the lexical decision task does not involve memory or comprehension. Note that this is not a reading task.

In fact, little research has directly examined the possibility of phonological repetition affecting word recognition in normal reading. Previous TTE research primarily focused on memory-based measures such as total sentence reading time or offline reading comprehension tasks (McCutchen & Perfetti, 1982, McCutchen, et al, 1991, Kennison, 2003, 2004). Missing data on early measures in these studies cannot exclude the possibility of earlier phonological repetition effects on lexical processing during reading.

Eye tracking is an ideal tool to fulfill the purpose of exploring phonological repetition effects on word recognition because it provides continuous measure of uninterrupted reading. Recent eye movement experiments from our lab (Yan & Morris, 2012, 2013) have captured early TTE in reading. Specifically, each tongue-twister sentence contained four critical words with repeated word-initial phonemes (e.g. No one would eat *Brad's burned bran buns* at the bake sale.); and the control sentences had the same structure except that two critical words were exchanged for words with different word-initial phonemes (e.g. No one would eat *Dave's burned spice buns* at the bake sale.). Longer gaze durations arose on the third word in the four-word tongue-twister phrase as compared with the counterpart in the control phrase. This was direct evidence demonstrating that phonological repetition could slow early fixations of a word, a time window mainly for lexical access.

The above evidence revealed three paradigms of reading experiments yielding inconsistent effects regarding the phonological repetition manipulation. A fast homophone prime activated early phonological processing of a target word as readers' eyes first fixate on the word. A parafoveal homophone prime activated early phonological processing of a target word prior to readers' initial fixation on the word. Note that in the two paradigms the prime word is neither a part of the context nor a fully processed representation. The prime was only presented briefly in order to activate the phonological information of the upcoming target word. In contrast, when multiple words in the context share repeated word-initial phonemes, prior processing of the word read earlier led to slower recognition of the word read later in normal reading. This across-word phonological repetition in normal reading is of primary interest in this project.

Another issue to consider in evaluating the phonological repetition research regards the extent to which the phonological repetition effects might be attributed to accompanying orthographic repetition. In the English writing system, repeated phonological patterns are often represented with repeated orthographic forms. For example, FATE and FACE are defined as both orthographic and phonological neighbors given they differ by only one letter and one phoneme on the same position. In the example at the beginning, WRITE and RIDE are phonological neighbors but they have distinct orthographic forms. Therefore, phonological repetition between words may or may not come along with proportional orthographic repetition. In order to have a comprehensive understanding about phonological repetition, it is necessary to review previous studies that have looked into orthographic repetition effects in VWR during reading.

Previous fast-priming studies have reported that an orthographic neighbor prime could facilitate the target word processing during reading (H. Lee, Rayner, & Pollatsek, 1999, 2002; Y. Lee, Binder, Kim, Pollatsek, & Rayner, 1999; Rayner, Sereno, Lesch, & Pollatsek, 1995, Nakayama, et al, 2010). For example, Y. Lee et al. (1999) reported that participants fixated for significantly less time on the targets (e.g., There was a *lone* rider on the trail.) when they were primed by its orthographic neighbor (e.g., *line*) than by an unrelated control prime (e.g., *wind*). In their second experiment, they also manipulated the relative frequency between the prime and the target in addition to the orthographic repetition and they found that the facilitative effects held regardless of the frequency relations between primes and targets: a) low-frequency primes and high-frequency targets (e.g., *pare–pain*), (b) high-frequency primes and high- frequency targets (e.g., *seat–sent*), (c) low-frequency primes and low-frequency targets (e.g., *foal–fowl*), and (d) high-frequency primes and low-frequency targets (e.g., *have–hare*). This finding has been supported by a later study by H. Lee et al. (2002) who found the same group of target words were read faster when primed by either higher or lower frequency related primes than by unrelated primes. Note that in the two experiments, those orthographic neighbors had varied phonological repetition. For example, LONE and LINE are also phonological neighbors whereas SEAT and SENT differ by more than one phoneme.

Parafoveal priming studies have also yielded facilitation of orthographic repetition in word recognition during reading. Williams and colleagues (2006) examined how a parafoveal preview of an orthographic neighbor of a target word affects subsequent recognition of the target word. In the experimental sentence “Mary was afraid of *sleet* when she had to drive in the winter,” the prime word (SWEET) was a higher frequency neighbor of the target word (SLEET) and was presented in the original position of the target until readers’ eyes moved across an invisible boundary to fixate on the target word the first time. Inconsistent with the fast-priming studies above (Y.Lee, et al, 1999; H.Lee, et al, 1999), Williams found only those previews of higher frequency orthographic neighbors led to shorter first fixation and single fixation durations on low-frequency target words relative to a control condition that used unrelated nonword previews but not vice versa. Similar to the fast-priming studies above, the orthographic neighbors in this experiment also have mixed phonological repetition patterns.

Only a few studies have looked into orthographic repetition during normal reading without eye contingent display change. A recent eye movement study by Paterson et al. (Paterson, Davis & Liversedge, 2009) observed “an inhibitory orthographic repetition effect” between two words in normal sentence reading. Each experimental sentence contained a pair of words that were or were not orthographic neighbors, e.g. “*There was a **blur/gasp** as the **blue** lights of the police car whizzed down the street.*” Results indicated that prior processing of the prime word increased early processing time of the target when they were orthographic neighbors (BLUR-BLUE) as compared to the unrelated pairs (GASP-BLUE). In the meantime, they manipulated the relative frequency between words by switching the roles of the prime and the target in a different sentence “*In the photograph, the **blue/town** lights were a **blur** against the cold night sky*”. As a result, the processing costs of orthographic neighbors held with longer fixations on the target (BLUR) primed by its neighbor BLUE than the control TOWN. According to the authors (Paterson, et al, 2009), orthographic repetition between words “inhibited” recognition of the later word during continuous sentence reading, opposite to the facilitation in display change paradigms. Moreover, this across-word orthographic repetition effect was not influenced by relative word frequency between the prime and the target. Generally, the orthographic repetition effects in normal reading are largely different from the effects observed in eye contingent display change paradigms.

The experiments conducted by Paterson et al (2009) had a different design from previous studies using display change paradigms. In Paterson’s experiment, both words were part of the sentence, with the first word (BLUR/GASP) acting as the prime and the later one (BLUE) the target. An intervening region was inserted between the two critical words (“as the” and “lights were a”, respectively). Both words were fully fixated and processed as part of the text to proceed normal reading comprehension. In this manner, this study examined if the fully accessed lexical representation of the prior word could influence the subsequent word recognition as reading progresses. Instead, in the display change paradigms, the briefly-presented prime word does not belong to the context and cannot receive full recognition due to the limited visual availability to readers. The role of the prime is to prompt the early activation of partial phonological or orthographic information when the upcoming target is present for full recognition in context. Considering the discrepancy among these paradigms is critical to make difference to the across-word repetition effects, this project adopted the normal reading paradigm for the present experiments.

In sum, this review discusses eye movement reading studies that have looked into orthographic and phonological repetition between words in a sentence. Three remarkable facts are summarized. First, there were processing costs associated with orthographic and phonological repetition across words during normal silent reading. Both orthographic and phonological repetition led to slower recognition processes of the target word read later. Second, in the orthographic repetition research there were often mixed phonological repetition patterns and vice versa, which might lead to mixed repetition effects. Third, as compared with phonological repetition research, orthographic repetition research was more likely to consider the potential influence of relative word frequency.

Word frequency is by far the strongest factor that is known to determine the speed of recognizing an individual word (Whaley, 1978, Grainger, 1990, Rayner & Duffy, 1986). Assuming readers are presented with an unexpected word and initiate orthographic and phonological processing automatically to recognize the word, it is possible that the relationship of word frequency of the prime and the target could exert unique influence on the repetition effects between words in a sentence. However, the relative frequency effect was not consistently observed in previous studies as reviewed above.

The main issue raised by the above literature review is the confounded orthographic and phonological repetition patterns in most of the previous studies. The observed processing costs could be derived from the joint interference from two repetition patterns, the repeated orthographic and phonological information across words, or either of the two. This project attempts to disentangle the independent phonological and orthographic repetition effects across words during reading. Of primary interest is that to what extent readers' exposure to repeated phonological information across words in a single sentence could have independent consequences on subsequent word recognition.

1.3 THEORETICAL FRAMEWORK

This section explores theoretical perspectives that can appropriately address the across-word repetition effects on visual word recognition process during normal reading. Two aspects are critical in terms of selecting the appropriate models. First, although many VWR models have been developed to accommodate various effects in isolated word recognition, few have accounted for the recurring word recognition processes across multiple words during reading. As introduced later, the Lexical Quality Hypothesis is one that focuses on VWR during the reading process. Second, previous work has attempted to employ the Interactive Activation models to understand different scenarios of orthographic or phonological repetition effects between two words, for example, the neighbor priming effect in the priming reading paradigms and the across-word effect in normal reading here. However, questions remain regarding the compatibility between results from the different paradigms. The IA models might not be the best account for the question of primary interest in this project. In this section, the two theories are compared in terms of their different perspectives about how similar orthographic and phonological representations across words would influence VWR in continuous silent reading.

In general, most VWR models consider the word recognition process as an interaction between top-down grapheme-phoneme mapping principles and the contents of the lexicon (Grainger & Jacobs, 1996, McClelland & Rumelhart, 1981, Coltheart, 2001, Norris, 2009, etc). An ideal VWR model should predict behavior outcomes based on the two aspects. The recognition of an individual word could partially depend on the lexical properties shared among the word and the other words in the lexicon.

The existing models of VWR are mostly derived from the efforts to understand the performance patterns in VWR tasks that require different output forms, for example, reading aloud the recognized letter strings (naming), deciding if a letter string is a real word (lexical decision), judging if a word belongs to a semantic category, etc. These tasks focus on a variety of manipulations on different stages of the VWR process and also involve strategic processes to differing degrees. From the above review it is evident that different paradigms of studying VWR reading could lead to contrasting results. In order to understand how the VWR process is influenced by prior word processing in context, the first model to review needs to address the characteristics of word recognition during normal reading comprehension.

A theoretical framework, the Lexical Quality Hypothesis (LQH) by Perfetti and colleagues (Perfetti & Hart, 2001, 2002, Perfetti, 2007), might provide unique insights into the repetition effects on VWR in reading. Different from many prevailing models of VWR that focus on isolated word recognition (Davis & Lupker, 2006; Grainger & Ferrand, 1994; Davis, 2003, etc), the LQH particularly focuses on the VWR process for the purpose of reading comprehension. In their view, it is a dynamic process to recognize a word and to integrate it into the flow of comprehension. Successful reading requires both "bottom-up" decoding (the restricted interactive model, Perfetti, 1992), i.e. to recognize individual words in the context, and "top-down" global comprehension processes. Reading comprehension efficiency heavily depends on the prompt availability of various types of information necessary for creating text meaning. (Frishkoff, Perfetti, & Collins-Thompson, 2011; Perfetti, 2007; Perfetti & Hart, 2002; Perfetti, Yang, & Schmalhofer, 2008).

The "Lexical quality" (LQ), as the central notion of this theory, refers to the extent to which readers are able to retrieve a given word's identity to support comprehension in a given context (Perfetti & Hart, 2002). The source of this ability is the knowledge a reader has about specific lexical representations.

A high quality lexical representation incorporates detailed orthographic, semantic, and phonological information. The stronger and more specific orthographic and phonological information regarding a word representations a reader possesses, the higher quality word representation could be formed and the more efficiently that word can be accessed during reading.

The LQH emphasizes that a critical step to create high quality word representations is the precise mapping of phonological codes with the given orthographic form (Share, 1995). The exact mapping is critical to generate important discriminators among orthographic and phonological information. Otherwise, the process of recognizing a particular word could be vulnerable to the activation of other lexical representations with similar orthographic and/or phonological forms. Poor quality representations are those with orthographic representations that are not fully specified by the corresponding phonological information (some letters are not represented) or phonological representations characterized by variable grapheme-phoneme correspondence. Poor quality word representations have a lower dimensional feature structure due to lack of exact orthography-phonology mapping.

The LQH further indicates that phonological repetition is more detrimental to the VWR processes in reading comprehension than orthographic repetition. The ability to acquire high-dimensional representations is commensurate with the ability to skillfully use linguistic cues during retrieval from the lexicon, i.e. lexical access. Even for skilled readers, the distinctiveness of phonological representations is critical for distinguishing phonologically similar words from each other. Highly similar phonological forms like those of phonological neighbors could cause confusion in retrieval even when the spelling forms are different (Perfetti, 2007). In normal silent reading, phonology serves as a single cue associated with multiple items in memory-based information flow. The phonological form of a word retrieved earlier in the context could remain active when the word's phonological neighbor is encountered subsequently. Repeated phonemes across those items will reduce the discriminability of the phonological cues and create interference in retrieving information to aid in sentence processing.

Prior to the LQH, a series of the Interactive Activation (IA) models have addressed the influence of orthographic similarity on visual word recognition. The traditional viewpoint of VWR has yielded several dual-route theories to differentiate two mechanisms that separately direct orthographic forms to meanings. The Dual-Route Cascaded model by Coltheart and colleagues is representative of the early IA models. (Coltheart, 2001). The DRC model primarily includes two implemented routes for directing the written form of a single word (the orthography) to the pronunciation (the phonology). The two routes differ in whether they rely on word-level representations. The non-lexical route is referred to as the GPC (Grapheme-Phoneme Correspondence) route, through which the orthographic form is transformed into the phoneme without involving lexical processing (i.e. the known lexicon). Instead, the GPC route converts a letter string into a phoneme string by using grapheme-phoneme correspondence rules. The other one, the lexical route, has built-in knowledge of words (mental lexicon) that allows directly mapping the orthographic form of a whole word to their corresponding phonological form. This route operates on the basis of the build-in orthographic lexicon and the corresponding phonological lexicon. That means the VWR process does not necessarily involve phonological processing and phonological information is not always retrieved from the lexicon as the product of identification. Therefore, two orthographically similar words could be categorized into different routes for recognition with or without phonological processing depending on readers' lexical knowledge.

An updated version of the IA model, the Triangle model, emphasizes the computational encoding process during which readers learn to convert the given orthographic forms into phonological output. As compared with the traditional dual-route theories, the Triangle model attempts to use one general principle to characterize the process of mapping representations of the spelling forms of words (orthography) to representations of the corresponding sounds (phonology). The Triangle model does not have the level of a built-in lexicon for whole-word mapping, as recognizing a word does not activate a particular, one-to-one corresponding representation of this word. Given there is no built-in lexicon consisting of whole words, the VWR processes of two similar letter strings are dependent on the activation strength spreading across orthographic and phonological units.

Both the DRC and the Triangle models, as well as those models that were developed later based on the IA framework (e.g. Grainger & Jacobs, 1996; the Self-organizing Lexical Acquisition and Recognition, SOLAR; Davis, 2003; the Spatial Coding Model, SCM, Davis, 2010), incorporate the component of form-based lexical competition when describing the VWR process (Coltheart, et al, 2001; Harm & Seidenberg, 2004; Plaut, et al, 1996, McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). The IA models naturally produce inhibition (Norris, 2013) because one must distinguish the word for recognition from its orthographic neighbors that need to be suppressed. According to this perspective, the VWR process involves a series of competitive activation processes among perceptually similar lexical representations. For example, the DRC and the Triangle predict that words that have more orthographic neighbors should be recognized slower because it receives more competition from other lexical candidates (Davis, 1999, 2003; Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981). In addition, IA models predict a prime frequency effect (Davis & Lupker, 2006; Segui & Grainger, 1990), that is, presenting a higher frequency neighbor should inhibit a lower frequency target's recognition because word frequency impacts the strength of activation of a word representation. High frequency words are supposed to suffer rare competition from their low frequency neighbors because high frequency words have lower threshold or stronger lexical strength for activation. Robust lexical competition could occur on low frequency words that have high frequency neighbors.

Against the original predictions of IA models, data patterns in fast-priming eye movement reading experiments showed opposite effects on the early fixations of the target word, which indicated faster word recognition after prior processing of an orthographic neighboring prime (Williams, et al, 2006; H. Lee, Rayner, & Pollatsek, 1999, 2002; Y. Lee, Binder, Kim, Pollatsek, & Rayner, 1999; Rayner, Sereno, Lesch, & Pollatsek, 1995, Nakayama, et al, 2010). In order to resolve the conflict between the data and the theory, the Triangle model includes a decision process to respond to the overall activation in the lexicon (Grainger, & Jacobs, 1996). For a particular target word, more orthographic neighbors create more over activation and offset the slowed response due to competition. In addition, at least three possible lexical competition explanations have been presented to account for the facilitative orthographic priming effects. First, the large perceptual overlap between the orthographic neighbors may have counteracted the effects of the competition process at the lexical level (Nakayama, et al. 2010). The second possibility is that presenting a particular prime may compete with the target, but simultaneously suppress the activation of other lexical competitors, thereby creating facilitation to some degree for the target (Davis, 2003; Perry, Lupker & Davis, 2008). Thus, the absence of a processing cost in the fast priming task does not necessarily conflict with lexical competition models (e.g., Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981). Third, the lexical competition account was associated with the E-Z Reader model of oculomotor control, which considers that word recognition is the primary determinant of eye movements during reading. The process takes two steps: an initial familiarity check where multiple lexical candidates might be activated, followed by a verification stage when full lexical identification occurs (Reichle, Rayner & Pollatsek, 2003; Reichle, Pollatsek, Fisher, & Rayner, 1998). Williams et al. (2006) argued that brief exposure to a word's neighbor principally affects the familiarity check by activating letter representations that are mostly shared with the target word, including the neighbor prime. The facilitation occurs in the first stage, particularly for high-frequency neighbors because their increased familiarity produces more effective letter activation.

The present project focuses on the normal recognition processes across multiple words in sentences. This is different from display change priming studies where the prime is employed as a tool to activate properties of a target word, and is not a part of the on-going representation. The lexical representation of the prime may compete with that of the target to fit in the single word position in text. But in a normal sentence, prior words have been fully recognized and incorporated into the ongoing text before affecting the subsequent target. The repetition occurs across words in the context rather than during an individual word recognition episode. It is necessary to reconsider the extent to which the processing costs of repetition across words in normal reading can be explained by lexical competition models such as the IA models. The relation of word frequency should be an effective tool to manipulate the extent of lexical competition between two neighbor words in a sentence.

As noted above, the "inhibitory orthographic repetition effect" from Paterson et al. (2009) has been interpreted as a result of lexical competition as well. According to Paterson et al, the activation of the prime's lexical representation was so strong that it did not decay over the intervening region, which continued to interfere with the following activation of a similar lexical representation of the target word. They also implied that during this process, the target was possibly misidentified as another lexical competitor when first fixated, resulting in extra time for correction. In fact, Paterson's data contradicts prominent viewpoints of lexical competition in two respects. The first relates to when lexical competition occurs in the process of word recognition. Paterson's effects were captured on first fixations, gaze durations and later measures such as regression-path durations of the target. Lexical competition is expected to occur very early and disappear quickly. The other issue is if the relative word frequency between the prime and the target modulates the orthographic repetition effect. As indicated above, most of IA models, i.e. the DRC and the triangle, predict a prime frequency effect, namely only high frequency primes interfering with low frequency targets (Davis & Lupker, 2006; Segui & Grainger, 1990) because higher frequency words have stronger activation strength of lexical access than their lower frequency competitors. However, Paterson et al. found that low frequency primes impeded recognition of high frequency targets and vice versa (Paterson, et al, 2009). In other words, low frequency words created interference to high frequency targets as high frequency words did to low frequency targets. The existing evidence has shown the processing costs of orthographic repetition during normal reading is constant regardless of the relative word frequency manipulation, which disagreed with the prediction of lexical competition.

The orthographic and phonological repetition effects have been addressed separately according to the LQH or the IA models. In general, the IA models characterize the word representations as nodes in a network that are connected by inhibitory links and the VWR processing as a series of attempts to activate the most possible nodes at orthographic and phonological levels. They consider lexical competition as a form-based mechanism. In an IA network, word-level representations are connected first by orthographic forms and thus orthographic similar words are more closely connected by the inhibitory links among each other than phonologically similar words. Recognition of a target word could be interfered by the competition from the other orthographically similar lexical candidates in the mental lexicon. In contrast, the LQH points out that the efficient lexical access relies on specific phonological information mapped with the given orthographic form. It also suggests the possibility that repeated phonological information across words could reduce the discriminability between the target word and the other phonologically similar words, which leads to slower recognition process of the target word. The LQH circumvents the prediction about how lexical competition influences the phonological repetition effects (Perfetti & Hart, 2002, Perfetti, 2007), although it indicates that recognizing high frequency words should be less likely activate lower frequency homophones. In the meantime, individual differences exist in the dependence on context to facilitate word recognition across words and readers. Recognition of low frequency words is more likely to be aided by context which would reduce the repetition interference from its high frequency competitor. Lexical competition does not necessarily lead to the orthographic and phonological repetition effects, and the relative frequency between words might not interact with the repetition effects.

CHAPTER 2

EXPERIMENTS

This project provides an investigation of phonological repetition across words in normal reading for two reasons. First, previous studies made very limited efforts to disentangle phonological from orthographic repetition effects. Although English reading research has reported the two effects in different experiments, the property of the English language determines that the manipulations of orthographic and phonological repetition across words are easily confounded. Second, the theoretical models hold disconnected perspectives about orthographic and phonological repetition effects in VWR processes during reading. The LQH model emphasizes activated phonology during reading and attributes the processing costs of phonological repetition to the absence of distinctiveness between the phonological representations of the two words. On the other hand, traditional IA models mainly associate the orthographic repetition processing costs across words in normal reading with lexical competition resolution. However, the normal reading processing is not the problem space described by IA models as analyzed earlier, suggesting that alternative models might be more appropriate for accounting for the repetition effects of interest here.

This project contains three eye movement reading experiments to fulfill the two purposes. Methodologically, the experiment design separated the phonological and orthographic repetition patterns between words in a sentence to inspect their independent effects on individual word recognition process during reading. Second, the new evidence would contribute to re-evaluating the existing theoretical accounts for the across-word repetition effects during normal sentence reading.

2.1 EXPERIMENT 1

2.1.1 Introduction

The goals of Experiment 1 were 1) to examine the extent to which phonological repetition modulates the across-word effects on recognizing a pair of orthographic neighbors during reading and 2) to distinguish the independent orthographic repetition from the combined orthographic and phonological repetition patterns between two words in a sentence.

The current experiment differentiated two types of orthographic neighbor pairs. In one condition, orthographic neighbors are also phonological neighbors (OR+PR) and differ in only one letter and only one phoneme (e.g. FATE-FACE). In the other condition, orthographic neighbors (OR) differ in only one letter but more than one phoneme (e.g. FACT-FACE). The two types of orthographic neighbors served as the prime word in two conditions to precede the same target word, e.g. FATE-FACE in the OR+PR condition and FACT-FACE in the OR condition. An unrelated word that has no repetition with the target word served as the prime in the control condition.

In addition, the orthographic neighbors used in Paterson's experiment did not always have the same word-initial letters. One third of the paired orthographic neighbors differed in word-initial letters (e.g. ROYAL-LOYAL), and the remaining were orthographic neighbors with repeated initial letters (e.g. LADY-LAZY). Considering the impact of word-initial letters is significant on early processing of a word (e.g., White, Johnson, Liversedge & Rayner, 2008), the present experiment exclusively uses the orthographic neighbors with repeated initial letters in order to maximize the likelihood of detecting OR effects. In all cases, the prime and target share the same initial letter. Readers' eye movements were monitored and first fixation and gaze duration on the target word served as the primary dependent variables.

2.1.2 Method

Participants

Forty-eight participants were recruited from the USC psychology department participant pool and from undergraduate linguistics courses. Participants received extra credit for their participation. All participants were native English speakers with normal corrected or uncorrected vision.

Stimuli

Thirty-three words were selected as target words. All target words are nouns 4 or 5 letters long. In three conditions, each target (e.g. FACE) was paired with a prime word that 1) differs by a single letter and a single phoneme (e.g. FATE) in the OR+PR condition; 2) differs by a single letter and by more than one phoneme (e.g. FACT) in the OR condition; or 3) little or no orthographic or phonological repetition (e.g. CALL) in the CTRL condition. The three primes for one target were matched in word length, word frequency, and initial letter.

Each prime-target pair was embedded in a single sentence frame. A given sentence frame had three versions that differed by the prime word, as shown in the example below. The target word was the same across the three versions and the prime always preceded the target. The prime was never the first word and the target was never the last word in a sentence. Two or three short words were inserted between the prime and the target as the intervening region. The region from the prime to the end of sentence was constant across all three versions.

A sentence frame with three versions

OR+PR: Orthographic and Phonological neighbors

e.g. Sue had to accept an unpleasant **fate** when her **face** was badly injured.

OR: Orthographic neighbors only

e.g. Sue had to accept an unpleasant **fact** when her **face** was badly injured.

CTRL: No repetition

e.g. Sue had to accept an unpleasant **call** when her **face** was badly injured.

(The primes and the targets are in bold.)

All versions of all experimental sentences, together with 27 filler sentences, were validated via semantic plausibility norms administered to a separate sample of 48 undergraduates from one undergraduate psychology class. The students voluntarily participated via an online survey for extra credit. Participants were asked to indicate how well they understood each sentence using a four point Likert scale, with 1 indicating " I cannot understand it at all." and 4 indicating " I can understand it very well." Because the three versions of sentences represent the three experimental conditions respectively, the purpose of the norming task was to ensure that sentences from the three conditions had equivalent semantic acceptability.

The USC Blackboard system recorded participants' responses and created item analyses for each sentence. Only sentences that had received a rating of 3 or 4 from more than 75% of respondents were retained for the reading experiment. Six sentences that failed to reach this criterion were modified and rated by another sample of 51 undergraduates from another class. These adapted sentences met the criterion and were added into the formal experimental stimuli. The finalized stimuli consisted of 33 experimental sentence frames and 27 control sentences.

Design

The manipulations were made within participants using a Latin Square design. Each participant read each of the 33 experimental sentence frames only once and only one of the three possible versions, as well as the 27 filler sentences. Materials were presented in a random order to each participant.

Procedure & Apparatus

All participants gave informed consent prior to participating in the experiment. Each participant was instructed to sit in front of a computer screen and silently read sentences shown on that screen for comprehension. They were also informed that some sentences would be followed by a True/False comprehension question. Before presenting sentences, the eye-movement monitoring system was aligned and calibrated by a standard

9-point full screen for each participant; this took approximately five minutes. After calibration, each trial presented one sentence in a single line. As reading proceeded, eye movements were monitored from the right eye using an Eyelink 1000 eye tracker with a sampling rate of 1000 Hz. A center-point-only calibration was used between each trial, and the full 9-point calibration was re-conducted as necessary throughout the experiment. Probe comprehension questions were presented after each filler sentence and required participants to respond by mouse-clicking “YES” or “NO” buttons on the screen. After the presentation of each experiment sentence, the screen showed “Click YES to continue” to instruct participants to proceed by clicking the YES button on the screen. The entire session took less than half an hour and the experimenter was in the room with the participant at all times. All participants performed at 95% or higher on the comprehension questions.

2.1.3 Results

The target word is the primary region of interest in this experiment. The initial analysis on this region consisted of two eye movement measures: a) first fixation durations (FFD, the duration of the first fixation to fall inside of the interest area) ; b) gaze durations (GD, the sum of fixation durations on a word from the first time that a word is fixated upon until the eyes move to another word). The two measures represent the earliest processing of a word and are associated with the initial lexical processing. In addition, the spillover from the target word (the FFD on the next word after the target word) was included as the first run of eye movement measure. The means of the early measures for three conditions are summarized in Table 2.1.

Secondary analyses explored eye movement patterns after the first pass on the target word. Two representative measures were reported: a) regressions out of the target word (the regression(s) being made from the target word to earlier areas of the sentence prior to leaving the current word in a forward direction). b) regression-path durations (the sum of all fixation durations from first entering the target word region during first pass reading until leaving it to the right, including regressive fixations). Additional late measures include regression-in probability on the prime (the percentage of the trials in which there was at least one look back to the prime from later areas of the sentence) and total reading time on the prime (the summed durations of all fixations on the prime word). The means of the late measures are summarized in Table 2.2.

Approximately 1% trials were excluded from analysis due to the absence of fixation on the target words. Individual fixations shorter than 120 ms or longer than 1000 ms were excluded from the analysis.

Linear mixed-effects models (LMM, Baayen, Davidson, & Bates, 2008) assessed each measure in this study. Each LMM had two fixed effects, the OR effect (OR vs. CTRL) and the OR+PR effect (OR+PR vs. CTRL), and two random effects, by-participants and by-items variation (Barr, Levy, Scheepers, & Tily, 2013). In order to examine the PR effect, planned t-tests further compared the OR and OR+PR conditions on each of the measures.

Initial processing on the target word

The FFD and GD are the early measures associated with the initial processing of the target word. As Table 2.1 shows, a 22-ms cost was observed in the FFD for the

OR+PR condition compared with the CTRL condition (β=20.73, SE=5.80, t=3.57, p<.001). GD in the OR+PR condition also showed a 20-ms cost compared to the CTRL condition (β=21.10, SE=7.65, t=2.76, p<.01). There was no evidence of orthographic effects when the phonological repetition between prime and target was reduced. This is evidenced by the negligible differences between the OR and CTRL conditions in FFD (7-ms, β=6.46, SE=5.78, t=1.12, p>.05) and GD (3-ms, β=4.271, SE=7.62, t= .56, p>.05). There were no significant spillover effects. Table 2.3 presents the parameters of LMMs with statistical significance.

The planned comparisons revealed a 15-ms cost in FFD for the OR+PR condition as compared with the OR condition (β=14.26, SE= 5.70, t=2.50, p<.05). The differences in FFDs for the two conditions were beyond what could be accounted for by orthographic repetition. Similar patterns were found in GD, although the effect did not reach significance (17ms, β=16.83, SE= 7.52, t=2.24, p=.06). Results of planned t-tests are summarized in Table 2.4.

Later processing on the target word

The regression-path durations on the target reflect the processes of re-reading and integrating the word before moving on to read the rest of the sentence. Interestingly, there was evidence of a continued processing cost in the OR+PR condition. There was a 53-ms cost in the regression-path duration (β= 53.39, SE=18.17, t=2.94, p<.01) for the OR+PR condition compared with the CTRL condition. Similar to the early measures, regression-path durations showed no OR effect between the OR and the CTRL conditions (15ms, β=15.68, SE=18.12, t=.87, p>.05). The planned t-tests revealed a trend of PR effect between the OR and the OR+PR conditions (38 ms, SE=17.87, t=2.11, p=.08). This result pattern prompted an exploratory analysis of additional re-reading measures.

Other late measures on the target word showed similar patterns by only yielding significant OR+PR effects. There was a 37-ms cost in the total reading time in the OR+PR condition compared to the control (β =39.09, SE =12.04, t =3.25, p<.01), with no significant effect in the OR condition (17-ms, β =19.68, SE=12.01, t=1.64, p>.05). The regression out probability also showed a robust OR+PR effect (8.6%, β=.08, SE=.03, t=3.14, p=.001) and no OR effect (4.9%, β=.04, SE=.03, t=1.72, p>.05).

Table 2.1 First Pass Measures on the Target Word (Experiment 1)

	FFD	GD	Spillover from Target
OR+PR	255	277	239
OR	240	260	235
Control	233	257	235

Table 2.2 Re-reading Measures on the Target Word (Experiment 1)

	Regression-Path Durations on Target	Regressions out of Target	Total reading time on Target
OR+PR	401	25%	373
OR	363	21%	353
Control	348	16%	336

Table 2.3 Parameters of the LMMs for the Measures on the Target Word (Experiment 1)

Model summary for FFD on the target				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	232.8	6.3	36.8	<.001
OR+PR vs. CTRL	20.7	5.8	3.6	<.001***

OR vs. CTRL	6.5	5.8	1.1	>.05

Model summary for GD on the target				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	254.0	8.0	31.8	<.001
OR+PR vs. CTRL	21.1	7.7	2.8	.006**
OR vs. CTRL	4.3	7.6	.6	>.05

Model summary for Regressions out of the target				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	.16	.03	6.0	<.001
OR+PR vs. CTRL	.08	.03	3.1	.001***
OR vs. CTRL	.04	.03	1.7	.08 .

Model summary for Regression-Path Durations on the target				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	344.9	19.2	17.9	<.001
OR+PR vs. CTRL	53.4	18.2	2.9	.003**
OR vs. CTRL	15.7	18.1	.9	>.05

Model summary for Total Reading Time on the target				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	331.5	14.8	22.4	<.001
OR+PR vs. CTRL	39.1	12.0	3.3	.001***
OR vs. CTRL	19.7	12.0	1.6	>.05

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 2.4 Planned Comparisons: OR+PR vs. OR (Experiment 1)

Priori t-tests : OR+PR vs. OR			
Measure	*SE*	*t*	*p*
FFD	5.7	2.5	.033*
GD	7.5	2.2	.06 .
Regression-Path	17.9	2.1	.08 .

Regression-out % on targets	.03	1.5	>.05

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

2.1.4 Discussion

When orthographic and phonological repetitions were maximized (OR+PR) between the two words, there was a robust processing cost as compared with the CTRL condition. The OR+PR primes slowed the recognition processes of the target word as compared with the unrelated control primes that preceded the same target. Early fixations on the target, i.e. FFDs and GDs, were inflated when the target was preceded by its orthographic neighbor than by an unrelated control word. These data replicated Paterson’s primary findings by showing the slowed word recognition processes.

In contrast, when the phonological repetition between prime and target was reduced, the repetition cost described in the previous paragraph went away. That is, there was no cost observed in the OR condition compared to the CTRL. Considering the primes in the OR and the OR+PR conditions only differ by phonological overlap (FACT-FACE vs. FATE-FACE), these results suggest that phonological repetition contributed greatly to the processing costs of reading a pair of orthographic neighbors in a sentence.

The conclusion that phonological repetition accounts for the processing costs across words is reinforced by the evidence of a phonological repetition effect in the FFD (and marginally in GD) between the OR+PR and the OR conditions. As said above, the only difference between the two conditions lies in the extent to which the prime and the target are phonologically repeated, which is supposed to be the dominant source of the robust OR+PR effect on the target word processing. To further examine this hypothesis, Experiment 2 directly looked into the factor of phonological repetition contributing to the OR+PR effect in word recognition during reading.

In addition, there was a robust cost in the late measures on the target for the OR+PR condition, i.e. longer regression-path durations on the target word when preceded by an OR+PR neighbor than when preceded by a control. This is consistent with data reported in Paterson et al (2009) as orthographic repetition. Moreover, the pattern of regressions out of the target word also demonstrated a robust OR+PR effect. There was no OR effect in the two measures.

2.2 EXPERIMENT 2

2.2.1 Introduction

Experiment 1 showed a convincing effect of the combined orthographic and phonological repetition (OR+PR) and no effect of orthographic repetition alone (OR) on the target. That is, recognition of a target word during reading was significantly slowed by its OR+PR prime (i.e. both orthographic and phonological neighbor) but not by its OR prime (orthographic neighbor alone). This result pattern led to the hypothesis that phonological repetition (PR) could account for the OR+PR effect. Experiment 2 sought more direct evidence of a PR effect alone and distinguished it from the OR+PR effect that has been observed in the last experiment.

This experiment focused on the independent phonological repetition effects by differentiating them from the combined repetition effects. A target word was paired with two types of phonological neighbors as well as an unrelated control. The two types of phonological neighbors were separated in the OR+PR and PR conditions, with respect to their orthographic repetition property. Eye movement measures on the target word were compared across three conditions to reveal the OR+PR and the PR effects separately.

2.2.2 Method

Participants

Forty-eight participants were recruited from the USC psychology department participant pool system and classes of psycholinguistics. Participants were undergraduates attending USC and native English speakers with normal corrected or uncorrected vision.

Stimuli

Thirty-three words were selected as target words. All target words are nouns 4 or 5 letters long. In three conditions, each target (e.g. FOAM) was paired with a prime word that 1) differs by a single letter and a single phoneme (e.g. FORM) in the OR+PR condition; 2) differs by a single phoneme and by more than one letter (e.g. PHONE) in the PR condition; or 3) little or no orthographic or phonological repetition (e.g. BOWL) in the CTRL condition. The three primes for one target were matched in word length and word frequency.

Experimental sentences were constructed in a manner similar to last experiment. Each prime - target pair was embedded in a single sentence frame. Thus, each sentence frame had three versions that differed by the prime word on the fixed position, as shown in the example below.

A sentence frame with three versions

OR+PR: Orthographic and Phonological neighbors

e.g. Charlie moved the **form** as the beer **foam** spilled over the glass.

PR: Phonological neighbors only

e.g. Charlie moved the **phone** as the beer **foam** spilled over the glass.

CTRL: No repetition

e.g. Charlie moved the **bowl** as the beer **foam** spilled over the glass.

(The primes and the targets are in bold.)

All versions of experimental sentences and filler sentences were validated via the same semantic plausibility norming task and applying the same selection criteria as used in Experiment 1. The finalized stimuli consisted of 33 experimental sentence frames and 27 control sentences. The manipulations were made within participants using a Latin Square design. Materials were randomly presented to each participant. Each participant read each of the 33 experimental sentence frames only once and only one of the three possible versions, as well as the 27 filler sentences.

Procedure & Apparatus

The procedure and apparatus is the same as in Experiment 1.

2.2.3 Results

The measures and regions of interest for analyses are the same as in Experiment 1. Eye movement data were trimmed according to the same criteria before entering the LMM analyses. Approximately 1.2% data were excluded from further analyses due to too short or too long individual fixation durations. Results are discussed below.

Initial processing on the target word

As in Experiment 1 there was evidence of the combined effect of phonological and orthographic repetition. (FFD: 19 ms, β=18.41, SE=5.22, t=3.53, $p < .001$; GD: 26 ms, β =25.31, SE=6.56, t=3.86, $p<.001$). In contrast to the findings regarding orthographic repetition in Experiment 1, the phonological repetition alone (PR) condition demonstrated a 13-ms cost in the FFD (β=11.15, SE=5.23, t=2.13, $p<.05$) and a 15-ms cost in the GD (β =13.65, SE=6.57, t=2.08, $p<.05$). Consistent with Experiment 1, spillover from the target did not show any effect. The means were reported in Table 2.5 and all these effects were statistically significant as summarized in Table 2.7.

Planned t-tests (Table 2.10) were conducted to compare the OR+PR and the PR conditions in all the measures that had shown significant effects. No significance was found in any of these measures in this experiment. In other words, the OR+PR and the PR effects were generally equivalent.

Later processing on the target word

As in Experiment 1, regression-path durations on the target word continued to demonstrate the OR+PR effect (58 ms, β =56.64, SE=15.84, t=3.58, $p<.001$) and the PR effect (34ms, β=32.36, SE=15.86, t= 2.04, $p<.05$). The total reading time on the target also had the significant OR+PR (45ms, β=44.72, SE=10.91, t=4.10, $p<. 001$) and PR

(21ms, β=44.72, SE=10.91, t=4.10, p<. 001) effects. Regressions out of the target, however, did not show any effect. Those means were reported in Table 2.6.

Re-reading measures on the prime

Re-reading measures on the prime showed similar results with the early and late measures on the target word. Both the OR+PR (41ms, β=40.88, SE=12.62, t=3.24, p=. 001) and the PR (33ms, β=38.16, SE=12.52, t=3.05, p<.01) effects were revealed on the total reading time on the prime. In addition, regression-in probability on the prime had a PR effect (5.2%, β=.07, SE=.04, t=2.09, p<.05) and a trend of OR+PR effect (2.2%, β=.04, SE=.04, t=1.03, p>.05). The means on these measures were reported in Table 2.8.

Table 2.5 First Pass Measures on the Target Word (Experiment 2)

	FFD	GD	Spillover from target
OR+PR	248	272	239
PR	242	261	238
Control	229	246	239

Table 2.6 Re-reading Measures on the Target Word (Experiment 2)

	Regression-Path Durations	Regressions out of the Target	Total Reading Time on Targets
OR+PR	378	21%	355
PR	354	21%	331
Control	320	18%	310

Table 2.7 Parameters of the LMMs for the Measures on the Target Word (Experiment 2)

Model summary for FFD on the target				
Predictor	Estimate	*SE*	*t*	*p*

(Intercept)	228.2	5.9	38.8	<.001
OR+PR vs. CTRL	18.4	5.2	3.5	<.001***
PR vs. CTRL	11.2	5.2	2.1	.03*

Model summary for GD on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	244.7	7.5	32.5	<.001
OR+PR vs. CTRL	25.3	6.6	3.9	<.001***
PR vs. CTRL	13.7	6.6	2.1	.03*

Model summary for Regression-Path Durations on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	316.5	17.9	17.7	<.001
OR+PR vs. CTRL	56.6	15.8	3.6	<.001***
PR vs. CTRL	32.4	15.9	2.0	.03*

Model summary for Total Reading Time on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	306.2	13.1	23.4	<.001
OR+PR vs. CTRL	44.7	10.9	4.1	<.001***
PR vs. CTRL	21.0	10.9	1.9	.05*

Model summary for Regression-out % on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	.17	.03	6.7	<.001
OR+PR vs. CTRL	.03	.03	1.1	>.05
PR vs. CTRL	.03	.03	1.3	>.05

Table 2.8 Re-reading Measures on the Prime Word (Experiment 2)

	Total reading time on Prime	Regressions in the Prime
OR+PR	361	23%
PR	353	26%
Control	320	21%

Table 2.9 Parameters of the LMMs for the Measures on the Prime Word (Experiment 2)

Model summary for Regression-in % on the prime				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	2.0	.04	51.2	<.001
OR+PR vs. CTRL	.04	.04	1.0	>.05
PR vs. CTRL	.07	.04	2.1	.04*

Model summary for Total Reading Time on the prime				
Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	248.8	16.0	15.6	<.001
OR+PR vs. CTRL	40.9	12.6	3.3	001***
PR vs. CTRL	38.2	12.5	3.1	.002**

Table 2.10 Planned Comparisons: OR+PR vs. PR (Experiment 2)

Priori t-tests: OR+PR vs. PR			
Measure	*SE*	*t*	*p*
FFD	5.3	-1.4	>.05
GD	6.6	-1.8	>.05
Regression-Path on targets	16.0	-1.5	>.05
Regression-in % on primes	.03	1.0	>.05
Total reading on targets	11.0	-2.2	.07 .
Total reading on primes	12.6	-.2	>.05

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

2.2.4 Discussion

Experiment 2 investigated phonological repetition effects between a pair of phonological neighbors during reading. Two types of phonological neighbors were employed in the

OR+PR and the PR conditions with respect to their orthographic repetition properties. This manipulation elicited significant PR and OR+PR effects respectively. Results were highly consistent across early and late measures. Data from the first two experiments converged on the finding of OR+PR effects and the primary role of PR.

In contrast to the absent OR effect in Experiment 1, the PR primes here slowed the recognition of the target word significantly, evidenced by inflated FFDs and GDs in the PR condition. Given the PR prime had little orthographic overlap with the paired phonological neighbor target, this processing cost could only be attributed to the PR manipulation. Moreover, both experiments have observed very similar OR+PR effects, whereas only PR primes led to difficulty in word recognition between words. This data pattern suggested that PR is a primary source of the processing costs of recognizing a pair of words in a sentence, probably accounting for the OR+PR effect to a large degree.

The OR+PR and the PR conditions yielded equivalent interference in recognition of the target word. Planned t-tests revealed no difference in the two effects in two early measures. The phonological neighbors used in the two conditions differ by the extent to which the words have orthographic overlap with each other. Therefore the factor of OR seems not to be the primary source of this effect.

In sum, the first two experiments consistently observed significantly longer fixations of the target word in the OR+PR condition than those in the CTRL condition. These effects were constrained within the regions of the prime and the target, which were convincingly associated with the lexical processing of the target word. The contrasting result patterns of the independent orthographic repetition and phonological repetition effects indicated that the interference on the early processing of the subsequent word could be mainly attributed to phonological repetition.

2.3 EXPERIMENT 3

2.3.1 Introduction

Experiment 1 was designed to differentiate the independent OR effect and the compound OR+PR effect between orthographic neighbors in reading. Experiment 2 was to identify the independent PR effect between phonological neighbors in the same way. Results from the two experiments consistently revealed the combined OR+PR effects on both early and late measures of the target words. Interestingly, Experiment 1 found negligible OR effects when the PR property was reduced between the prime and the target, whereas Experiment 2 observed robust PR effects when the OR property was reduced. Taken together, data from the first two experiments indicated that the repetition factor that leads to interference in VWR during reading is primarily phonological. Experiment 3 was to further explore the mechanism of this phonological repetition interference in VWR by examining the possibility of the lexical competition account.

The DRC and the triangle models consider that multiple similar lexical candidates result in competition and recognition of a lower frequency word could be slowed by the existence of its higher frequency competitors. In Paterson's study, the relation of word frequency between a pair of orthographic neighbors was manipulated to impact the extent of lexical competition when both words are present as a prime and a target during reading (Paterson, et al, 2009; Williams, et al, 2006). In contrast to their prediction, no relative frequency effect was observed in the eye movement measures of the target word. The present experiment was to examine if the phonological repetition alone effect could be immune to the modulation of relative frequency. In the meantime, the Lexical Quality Hypothesis suggested that lexical competition is not necessarily determined by the relative frequency. If the phonological repetition effect is constant under different relative frequency conditions, the specific lexical competition hypothesis from the first two models seems to be at stake.

The experiment employed pairs of pure phonological neighbors with rare orthographic repetition and differ in word frequency, e.g. ROCK-WRECK. Each word pair was embedded into two versions of sentences in which their orders were switched. An unrelated word matched for length and frequency was in place of the neighbor prime in each version, creating a control sentence without phonological or orthographic repetition.

2.3.2 Method

Participants

Sixty-one undergraduate participants were recruited and screened in the same manner as in prior experiments.

Design and Stimuli

Forty-four pairs of words were selected as the neighbor primes and targets. Each pair consisted of two phonological neighbors with rare orthographic repetition, with one higher in frequency than the other, e.g. ROCK-WRECK. Each of the two words was paired with an unrelated word matched for the frequency and length without any repetition with the other neighbor, e.g. TREE-ROCK and CRASH-WRECK. This unrelated word served as a control prime in contrast to the neighbor prime for its paired target. For example, a target word ROCK was primed by its neighbor WRECK or a non-neighbor substitute TREE.

Each trial was a single sentence containing a prime and a target in the same manner as in prior experiments. The regions between primes and targets were identical for sentences containing the same target and did not differ significantly for sentences containing different targets. In repetition conditions, either the lower frequency neighbor preceded the higher frequency neighbor (e.g., WRECK–ROCK) or vice versa (e.g., ROCK-WRECK), creating two different versions of sentences. Correspondingly, the non-repetition conditions substituted the control words for neighbor primes (e.g., CRASH-ROCK or TREE-WRECK). Thus, each set contained four versions of sentences by crossing the two factors: word frequency of the target word (Frequency: Low vs. High) and Repetition (PR vs. CTRL) as shown below.

Example sentences

Low frequency prime – High frequency target condition (High)

1. Joey knew that the **wreck** was caused by the **rock** on the highway. (PR)
2. Joey knew that the **crash** was caused by the **rock** on the highway. (CTRL)

High frequency prime – Low frequency target condition (Low)

3. Joey knew that the **rock** caused the **wreck** on the highway. (PR)
4. Joey knew that the **tree** caused the **wreck** on the highway. (CTRL)

(The primes and target are in bold.)

All versions of experimental sentences and filler sentences were validated via the same semantic plausibility norming task and applying the same selection criteria as used in Experiment 1 and 2. The finalized stimuli consisted of 44 experimental sentence frames and 26 control sentences. The manipulations were made within participants using a Latin Square design. Materials were randomly presented to each participant.

Each participant read 60 sentences. Forty-four of those sentences were experimental sentences from counterbalanced conditions. Each participant read one of the four conditions in each set. The other 26 items were filler sentences, which were constructed similarly to the experimental sentences in terms of length and structure. Materials were randomly presented to each participant.

Procedure & Apparatus

The procedure and apparatus is the same as in Experiment 1 and 2.

2.3.3 Results

The measures and regions of interest for analyses are the same as in last two experiments. Eye movement data were trimmed according to the same criteria before entering the LMM analyses. Approximately 1.7 % data were excluded from further analyses due to too short or too long individual fixation durations.

Linear mixed-effect models were constructed to primarily analyze three fixed effects of my interest, Frequency of the target (Low vs. High) and Repetition (PR vs. CTRL) and their interaction. The variations across subjects and items were included as random effects. The LMM results are summarized in Table 2.14.

Initial processing on the target word

Two early measures on the target word demonstrated robust phonological repetition effects as expected. There was a 10-ms cost in the FFD for the means between the two repetition conditions against the means between two control conditions (β =10.92, SE=4.55, t=2.40, p<.05). Similarly, the GD measure had a 20-ms cost for the repetition conditions (β =13.80, SE=5.54, t=2.49, p=.01). Comparisons between low and high frequency conditions showed a significant frequency effect in the GD (β=-15.82, SE=5.51, t=-2.87, p<.01), but no significant effect in the FFD (β=-4.31, SE=4.52, t=-.95, p>.05). Of more interest here the interaction between the two factors was not significant in either of the early measures (FFD: β= 3.25, SE=6.39, t=.51, p>.05; GD: β=9.77, SE=7.79, t=1.25, p>.05). The spillover from the target words had no effects. The means were summarized in Table 2.11.

Later processing on the target word

Two late measures, the regression-path durations and the total reading time, yielded significant repetition and frequency effects on the target word (Table 2.12). In the regression-path durations on the target word, there was an 18-ms cost for the means from repetition conditions against the control conditions (β =21.21, SE=8.39, t=2.53, p=.01), and a 39-ms cost for the means from low frequency targets against the high frequency targets (β =-23.17, SE=8.35, t=-2.78, p<.01). The total reading time showed the same pattern: a 46-ms repetition effect (β =45.85, SE=20.58, t=2.23, p<.05) and a 62-ms frequency effect (β =-89.04, SE=20.47, t=-4.35, p<.001). Again, interactions between the two factors were not significant.

The regression-out probability on the target showed a significant frequency effect (β =-.10, SE=.03, t=-3.59, p<.001) but no repetition effects (β=.02, SE=.03, t=.65, p>.05) or interaction (β=.05, SE=.04, t=1.17, p>.05).

Re-reading the prime word

The results from re-reading measures on the prime did not show any significant effects (Table 2.13).

The word-initial bigram frequency

In the first set of LMMs, the word-initial bigram frequency on each target word was included in the models as a fixed effect. In this experiment, phonological neighbors in each pair differ by more than one letter. Repetition patterns of the word-initial letters were mixed: some pairs repeat word-initial letters and some other pairs do not. Since previous evidence suggested that word-initial letters might have a very transient effect on early fixations of the subsequent word, and moreover, it was the frequency of word-initial letter combination that might lead to the effect (White, Johnson, Liversedge & Rayner, 2008). However, bigram frequency did not show significant effects and the LMMs failed to converge due to this fixed effect. In order to maximize the effects of interest, the final LMMs only retained the three primary fixed effects, i.e. Repetition, Frequency and their interaction, and the two random effects, subjects and items.

Table 2.11 First Pass Measures on the Target Word (Experiment 3)

	FFD	GD	Spillover from target
Low-Repetition	250	285	230
Low- Control	241	272	238
High-Repetition	254	284	230
High-Control	243	258	230

Table 2.12 Re-reading Measures on the Target Word (Experiment 3)

	Regression-Path Durations	Regression-out %	Total Reading Time
Low-Repetition	396	21%	781
Low- Control	389	23%	746
High-Repetition	368	16%	730
High-Control	339	16%	673

Table 2.13 Re-reading Measures on the Prime Word (Experiment 3)

	Regression-in %	Total Reading Time
Low-Repetition	23%	751
Low- Control	25%	784
High-Repetition	26%	796
High-Control	24%	787

Table 2.14 Parameters of the LMMs for the Measures on the Target Word (Experiment 3)

Model summary for FFD on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	98.3	7.4	13.4	<.001
Frequency	-4.3	4.5	-1.0	>.05
Repetition	10.9	4.6	2.4	.02*
Interaction	3.3	6.4	.5	>.05

Model summary for GD on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	119.5	9.0	13.3	<.001
Frequency	-15.8	5.5	-2.9	.004**
Repetition	13.8	5.5	2.5	.01**
Interaction	9.8	7.8	1.3	>.05

Model summary for Regression-Path Durations on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	192.8	13.5	14.3	<.001
Frequency	-23.2	8.4	-2.8	.005**
Repetition	21.2	8.4	2.5	.01**
Interaction	8.0	11.8	.7	>.05

Model summary for Total Reading Time on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	534.7	36.6	14.6	<.001
Frequency	-89.0	20.5	-4.4	<.001***
Repetition	45.9	20.6	2.2	.03*
Interaction	35.7	28.9	1.2	>.05

Model summary for Regression-out % on the target

Predictor	Estimate	*SE*	*t*	*p*
(Intercept)	1.89	.05	35.3	<.001
Frequency	-.10	.03	-3.6	<.001***
Repetition	.02	.03	.7	>.05

Interaction	.05	.04	1.2	>.05

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

2.3.4 Discussion

Experiment 3 clearly demonstrated two non-interacting effects, the phonological repetition and the frequency effects, on the early and late measures on the target word. That is, the phonological repetition effect was not modulated by the frequency manipulation. A robust phonological repetition effect was evidenced by inflated early fixations of the target word following its phonological neighbor. In the meantime, a basic frequency effect was shown by longer fixations on low frequency target words than high frequency target words.

A cost was observed very early on the FFDs of the target word in the repetition conditions, indicating that pure phonological interference could rise without orthographic repetition. This result replicated the findings from Experiment 2, since the phonological neighbors used in this experiment had reduced orthographic repetition like those in the PR condition in Experiment 2. Taken together, the three experiments in this project established the phonological repetition effects between two non-consecutive words in a sentence. Early fixations of a target word were prolonged by prior processing of its phonological neighbor, which could be convincingly attributed to the repeated phonological information.

The frequency effects arose since the GD measure of the target word and continued on the late measures. This finding is consistent with previous eye movement studies which consistently captured basic frequency effects on the GD measure (e.g., Inhoff & Rayner, 1986; Rayner & Duffy, 1986).

No interaction was observed between the frequency and the repetition effects, suggesting that the primary phonological repetition effect was not affected by the relative frequency relationship between the two words. In general, the third experiment's results are against the DRC and triangle models regarding their interpretation of the across-word repetition interference. The relative frequency is considered by these models to determine the direction of lexical competition. According to the lexical competition account, high frequency words should not experience competition from low frequency neighbors. However, in the present experiment there was a robust cost of recognizing a high frequency target in the repetition condition. The repetition effect in the high frequency condition was even larger than that in the low frequency condition. These results replicated Paterson's finding as the repetition effects held when the prime and the target switched their roles in a new sentence, and also contradicted the predictions of the IA-based lexical competition account.

CHAPTER 3

SUMMARY AND GENERAL DISCUSSION

Three silent reading experiments were done to investigate how prior processing of a word affected the recognition process of a subsequent word in a sentence when the two words repeat phonological and/or orthographic information. The gaze durations and first fixation durations on the target word were consistently inflated when the target word was preceded by a prior word that differed by only one phoneme during normal sentence reading. These across-word processing costs disappeared when the phonological repetition was reduced between the two words. In contrast to the significant role of phonological repetition, the influence of repeated orthographic information was negligible in the across-word interference on lexical access. The underlying mechanism of phonological repetition effects was further explored by manipulating the word frequency relationship within the word pairs.

In Experiment 1, readers spent longer initial processing time on the target word (FACE) when it was preceded by an orthographic neighbor word differing by only one phoneme (FATE) than when it was preceded by its orthographic neighbor differing by more than one phoneme (FACT) or a dissimilar word (CALL). The orthographic neighbor with less phonological repetition and the dissimilar control word did not differ from each other in terms of their impacts on the target word. This data pattern suggested that orthographic neighbors only produced interference when there was significant phonological repetition involved. No remarkable effects were revealed that could be attributed to the repeated orthographic information. When the component of phonological repetition was reduced between a pair of orthographic neighbors (e.g. FACT-FACE), the repetition processing costs disappeared on the recognition process of the word read later in the sentence.

In Experiment 2, there were similar differences in initial processing time on the target word when it was preceded by a phonological neighbor with or without corresponding orthographic repetition. Both types of phonological neighbors yielded longer early fixations of the target word than the dissimilar control word did. As compared with previous studies in which repeated phonemes were often confounded with repeated spelling forms, the prominent finding here is the independent phonological repetition effect across words when the orthographic repetition was absent. Consistent with Experiment 1, the presence or absence of orthographic repetition did not have any significant impact on the processing costs of phonological repetition on the lexical access of the target word. The phonological representation of the prior word consistently influenced the subsequent word recognition, regardless of the degree of orthographic repetition.

Experiment 3 examined whether the relative frequency between two pure phonological neighbors (with distinct spelling forms) could modulate the phonological repetition effects across words during reading. Results did not yield an interaction between relative word frequency and the pure phonological repetition effects were manifested by inflated initial processing time of the target word. Readers experienced equivalent difficulty recognizing the word read later when it was preceded by phonological neighbor of a higher or lower word frequency during reading.

The above results could be reconciled with the existing evidence from previous studies that looked into orthographic and/or phonological repetition effects across words during normal reading. For example, a recent eye movement study by Frisson and colleagues (Frisson, Olson & Wheeldon, 2014) demonstrated the processing costs across words only when two words had proportional phonological repetition with the orthographic repetition pattern. In Experiment 1, the orthographic repetition alone could not lead to inflated gaze durations of the target word. Moreover, Experiment 2 and 3 successfully evoked the independent phonological repetition effects between words with distinct orthographic forms.

In an earlier study, Paterson and colleagues' work (2009) reported inflated early fixations on a target word preceded by its orthographic neighbor. Note that in their study most of the paired orthographic neighbors were also phonological neighbors by differing only one phoneme (e.g. LADY – LAZY). Similarly, the current Experiment 1 and 2 revealed the processing costs across two words that repeated phonological and orthographic information to a large degree. In addition, Paterson et al. manipulated the relative word frequency between the two words in two different sentence frames and found that the processing cost was unaffected. Consistent with the previous data in their study, there was no evidence that relative word frequency could modulate these repetition effects in Experiment 3.

Although the data patterns across these studies are generally consistent and compatible with each other, evidence accumulates to contradict the theoretical framework that has been used to account for these repetition effects. As discussed in earlier sections, the processing cost effects on recognition processes were attributed to the form-based lexical competition occurring between orthographically similar words, which is a critical component in the context of the Interactive Activation (IA) models. In contrast, the present data identified that the major of the repetition effects were derived from phonological repetition. Furthermore, the IA models predicted that the relative frequency between words should constrain the lexical competition effects only from lexical candidates with higher frequency on those with lower frequency for an individual word. However, the empirical evidence consistently revealed that processing costs of repetition were unaffected by the relative word frequency between two words as in Experiment 3 and Paterson et al. (2009).

In fact, the across-word repetition effects in normal reading raised questions that are beyond the conceptual problem space defined by the IA models. Originally, those models (e.g. Grainger & Jacobs, 1996; the Self-organizing Lexical Acquisition and Recognition, SOLAR; Davis, 2003; the Spatial Coding Model, SCM, Davis, 2010) employed the account of lexical competition to characterize how the identification of a target word could be affected by competing lexical candidates activated by a prime word. In the priming case, the lexical processing of the prime word probably does not reach the full lexical access, as the prime is only presented for a brief time in the same word position as the target word. Therefore the lexical candidates activated by the prime word might not be as strong as the full lexical representation of the target word. Instead, the across-word effects of interest here necessarily involve at least two fully-recognized words in the normal reading process, with the first word's full, active representation influencing lexical processing of the next word on the way to successful recognition. Since the first word has been fully recognized before it has impacts later, the relative word frequency between the two words should not contribute to the competing activation between the two words. The new evidence from the current study is implausible to accommodate in the existing IA-based competition models.

Paterson et al. provided an alternative account to associate the across-word effects with the episodic memory priming model (e.g. Tenpenny, 1995). According to this approach, when prime and target words are read separately as in the present experiment and when these words are orthographically similar, the processing of the target word evokes an episodic memory trace encoded during the processing of the prime word. The main aim of this type of account has been to explain long-term priming effects (Jacoby, 1983; Kolers, 1976; Tenpenny, 1995), with effects being found weeks, months, or even more than a year later. Frisson and colleagues (Frisson, et al, 2014) examined this explanation by manipulating the distance between the prime and target words in normal reading. In their experiments, the resulting processing cost only occurs between the two words when they also share phonological repetition and their distance did not exceed three words in the same sentence. In other words, the active lexical representation of the prime word decayed so quickly that the across-word phonological repetition no longer interfered with the target word at a greater distance. Their results indicated that the phonological repetition effects between two words should not be derived from the long-lasting episodic memory.

The analysis thus far calls for an alternative theoretical perspective other than the lexical competition or the episodic memory accounts. Considering that the processing costs across words have been convincingly associated with phonological repetition, it is plausible to seek the valid explanation from the existing models that focus on 1) visual word recognition during reading and 2) the role of phonological representations in reading. The Lexical Quality Hypothesis mentioned in the Introduction section has provided novel insights into these two issues.

In the LQH framework, phonology, as a constituent of word perception, provides early sources of constraint in word identification (Tan & Perfetti, 1997). The serial processes of phonological information across words could have both local (within a single word) and contextual (across multiple words) influences on visual word recognition during normal reading. Locally, a high quality lexical representation would have combined orthographic, phonological and semantic features that allow the reader to precisely access the exact word that is printed rather than parts of it that may also be parts of other words (Perfetti & Hart, 2002). Beyond the single word situation, repeated phonological information across words reduces the advantage of phonological codes registering word information in working memory. As reading proceeds, phonological representations of prior words are carried over to interfere the subsequent word's phonological processing.

The LQH could yield important implications about how prior words' phonological information could slow subsequent word recognition during reading. First, words that largely repeat both orthographic and phonological information might have lower probability of precise mapping as compared with the words with distinct orthography-phonology mapping. Second, fine-grained phonological information is required to ensure high quality word representations. Presenting a word that has a highly similar sound (phonological neighbors) with the target word could reduce the probability of generating the exact phonological outcome of the target word. Thus when two phonologically similar words are in the same sentence, the phonological features of the first word could interfere the assembling of the lexical characteristics of the second word. Previous studies have well documented the phonological repetition effects impairing reading comprehension speed, e.g. the tongue-twister effect (Acheson & MacDonald, 2009, 2011, McCutchen & Perfetti, 1982, McCutchen, et al, 1991). In these studies, the phonological repetition could elicit interference with or without the corresponding orthographic repetition (McCutchen & Perfetti, 1982, etc).

In the current experiments, when two words in a sentence have repeated phonological constituents as in the present experiments, readers re-encounter a large portion of phonological codes from the first word in the process of recognizing the second word, i.e. the target word. According to the LQH, this is a situation when the lexical quality of the target word is hampered by the phonological information in common with that in the prior word. That is properties of the prior word lowered the lexical quality of the target word in this instance. The normal reading process consists of the unaffected, efficient word identification processes that allowed processing resources to be devoted to comprehension. Under the circumstance of phonological repetition, a low quality word identification retrieved with effort would jeopardize comprehension processes that depend on a high quality representation. The resulting early processing time of the target word was inflated as compared with that in the non-repetition context, as shown in the three experiments.

Frisson and colleagues' study (Frisson, et al, 2014) lent additional support to the

LQH-based explanation for the phonological repetition effects, by revealing that reading comprehension abilities could influence the extent to which readers experienced difficulty in processing sentences containing repeated phonological information. In their second experiment, skilled readers with better comprehension scores were more negatively affected by phonological repetition manipulation than less skilled readers with poorer comprehension performance. This finding is compatible with the LQH that characterizes skilled readers as more proficient in keeping active phonological forms of lexical representations and utilizing phonological cues to retrieve the items for comprehension. Previous studies also found readers were not able to suppress the automatic phonological processing during word recognition even if it causes interference (Folk, 1999). Taken together, there is accumulating evidence indicating the processing costs across words on word recognition processes resulted from repeated phonological information.

In addition to the inflated early fixations, the current data indicated that the robust phonological repetition effects continued to show on late measures. The late interference reflects the well-established tongue-twister effects associated with late stages of sentence processing, i.e. text integration and comprehension (McCutchen & Perfetti, 1982; McCutchen, Bell, France & Perfetti, 1991; Kennison, 2003, 2004; Acheson & MacDonald, 2009, 2011). This is primarily because the phonological repetition effects were typically captured in off line tasks designed to assess working memory effects (McCutchen & Perfetti, 1982; McCutchen, Bell, France & Perfetti, 1991; Acheson & MacDonald, 2009) or at the end of a sentence where the global comprehension takes place (Kennison, 2003, 2004; Acheson & MacDonald, 2011). For example, McCutchen et al. (1991) found longer sentence acceptability judgment times for sentences with phonological repetition words than in semantically matched controls. Similarly, Kennison et al. (2003, 2004) conducted two self-paced reading experiments using the phrase-by-phrase paradigm, and captured more time spent in the ending regions following the tongue-twister region than those following the control region. Based on these findings, the late TTE was interpreted as the phonological repetition interference impeding verbal working memory processes during sentence comprehension. Similarly, the late effects of phonological repetition in the current study might have different mechanisms from that in early word processing stages.

Future work needs to seek more direct evidence to associate the across-word repetition effects with the Lexical Quality Hypothesis. It remains unclear how phonological repetition influences early and late processing of word reading within a sentence. More specifically, the early processing costs on word recognition process might not have a mechanism in common with the late, memory-based interference in reading comprehension, although both early and late effects could be evoked by repeated phonemes across words. In order to distinguish the two possibly different mechanisms in the context of LQH, individual differences in the components of reading abilities might be an effective approach. For example, if readers with better performance on the phonological working memory test experience similar sizes of phonological repetition interference on early measures of target words as those with poorer performance, such phonological repetition effects should not be elicited by the difficulty in memory-related processing, e.g. higher level contextual representations from prior words.

In conclusion, the present three experiments directly demonstrate the across-word repetition effects on early stages of visual word recognition processes within a sentence. More specifically, these processing costs were primarily driven by repeated phonological information from prior words and could not be modulated by the relationship of word frequencies between two words. In contrast, repetition in orthographic forms alone between words in a sentence could not lead to remarkable processing costs on either early or late processing stages of the word read later. These findings challenge the Interactive Activation account, i.e. lexical competition between priming candidates for a single word recognition, for the processing costs between words in context during normal reading. Instead, a reading-focused model, the Lexical Quality Hypothesis, might provide insights into understanding how phonological repetition has influences on early visual word recognition and later processing of comprehending multiple words within a sentence.

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APPENDIX A – STIMULI IN EXPERIMENT 1

*All the prime and target words are in bold. Primes always precede targets.

*OR+PR = Differ by only one letter and one phoneme (**O**rthographic and **P**honological **R**epetition)

OR = Differ by only one letter and more than one phoneme (**O**rthographic **R**epetition only)

CTRL = Different in phonemes and letters (**C**on**tr**o**l**)

101 The dogs were never **born** in the **barn** for many reasons. OR+PR

101 The workers' hands were never **bare** in the **barn** for many reasons. OR

101 The cows were never **held** in the **barn** for many reasons. CTRL

102 The audience was frightened by the **bell** of the **bull** at the rodeo. OR+PR

102 The audience was frightened by the **bulk** of the **bull** at the rodeo. OR

102 The audience was frightened by the **eyes** of the **bull** at the rodeo. CTRL

103 The **cave** contained the **cage** that they were looking for. OR+PR

103 The **cafe** contained the **cage** that they were looking for. OR

103 The **hall** contained the **cage** that they were looking for. CTRL

104 Alice brushed the **coat** of the **colt** at the auction. OR+PR

104 Alice set up the **cost** of the **colt** at the auction. OR

104 Alice forgot the **name** of the **colt** at the auction. CTRL

105 Josh put the fee for the golf **cart** on his **card** before telling his wife. OR+PR

105 Josh put the fee for the medical **care** on his **card** before telling his wife. OR

105 Josh put the fee for the extra **room** on his **card** before telling his wife. CTRL

106 The rioters set on their **cots** with the **cops** in the park. OR+PR

106 The rioters had to **cope** with the **cops** in the park. OR

106 The rioters left the **guns** with the **cops** in the park. CTRL

107 The manager used the **cord** to pull the **cork** out of the bottle. OR+PR

107 The manager asked the **cook** to pull the **cork** out of the bottle. OR

107 The manager needed a **hand** to pull the **cork** out of the bottle. CTRL

108 Priscilla completely blamed the **cats** for the **cuts** on her arm. OR+PR

108 Priscilla found band-aids that were **cute** for the **cuts** on her arm. OR

108 Priscilla found a kind of wild **herb** for the **cuts** on her arm. CTRL

109 The students made a **deal** before the **dean** arrived on the scene. OR+PR

109 The student was **dead** before the **dean** arrived on the scene. OR

109 The students hid the **bird** before the **dean** arrived on the scene. CTRL

110 Sheila has to accept the unpleasant **fate** that her **face** was burnt badly. OR+PR

110 Sheila has to accept the unpleasant **fact** that her **face** was burnt badly. OR

110 Sheila has to accept the unpleasant **news** that her **face** was burnt badly. CTRL

111 The farmer found that adding **feed** makes the cows **feel** warmer. OR+PR

111 The farmer found that adding **fuel** makes the cows **feel** warmer. OR

111 The farmer found that adding **wood** makes the cows **feel** warmer. CTRL

112 The police found five **cases** in the **file** that nobody remembered. OR+PR

112 The police found film **cases** in the **file** that nobody remembered. OR

112 The police found many **cases** in the **file** that nobody remembered. CTRL

113 The pet store attendant grabbed the mouse **fast** with her **fist** to put it in a container. OR+PR

113 The pet store attendant grabbed the **fish** with her **fist** to put it in a container. OR

113 The pet store attendant grabbed the **crab** with her **fist** to put it in a container. CTRL

114 Gregg felt **glee** when the **glue** stuck in May's hair. OR+PR

114 Gregg felt **glum** when the **glue** stuck in May's hair. OR

114 Gregg felt **smug** when the **glue** stuck in May's hair. CTRL

115 Bob warned me that boxing too **hard** may do **harm** to our friendship. OR+PR

115 Bob warned me that killing this **hare** may do **harm** to our friendship. OR

115 Bob warned me that lending **money** may do **harm** to our friendship. CTRL

116 The DJ recorded the old **tale** for the **tape** in the studio. OR+PR

116 The soldier played **taps** for the **tape** in the studio. OR

116 The DJ selected the old **disk** for the **tape** in the studio. CTRL

117 Ted can feel the **heat** on the **heap** of sand on the beach. OR+PR

117 Ted needed **help** on the **heap** of sand on the beach. OR

117 Ted put a **pail** on the **heap** of sand on the beach. CTRL

118 Bill took this **hint** to begin his **hunt** for a new job. OR+PR

118 Bill was too **hurt** to begin his **hunt** for a new job. OR

118 Bill was too **late** to begin his **hunt** for a new job. CTRL

119 The man with a **limp** took the **lamp** from the shop. OR+PR

119 The man who was **lame** took the **lamp** from the shop. OR

119 The man with a **goat** took the **lamp** from the shop. CTRL

120 Sue wanted to buy the **lake** near the **lane** where her mother lived. OR+PR

120 Sue wanted to buy the **land** near the **lane** where her mother lived. OR

120 Sue wanted to buy the **park** near the **lane** where her mother lived. CTRL

121 Tom did the **maze** with his **mate** just for fun. OR+PR

121 Tom did the **math** with his **mate** just for fun. OR

121 Tom did the **quiz** with his **mate** just for fun. CTRL

122 Doug carried his box of **mice** over a **mile** to get it home. OR+PR

122 Doug carried his box of **milk** over a **mile** to get it home. OR

122 Doug carried his box of **eggs** over a **mile** to get it home. CTRL

123 We drink mostly **milk** at the **mill** during lunch hour. OR+PR

123 Tempers are usually **mild** at the **mill** during lunch hour. OR

123 Meg wants to **work** at the **mill** during lunch hour. CTRL

124 Nat asked Joe to **mist** the fresh **mint** in the garden. OR+PR

124 Nat asked Joe to **mind** the fresh **mint** in the garden. OR

124 Nat asked Joe to **grow** the fresh **mint** in the garden. CTRL

125 Roy had **nuts** in the **nets** to share with everyone. OR+PR

125 Roy had **news** on the **nets** to share with everyone. OR

125 Roy had **food** in the **nets** to share with everyone. CTRL

126 Kim looked at the **page** that set the **pace** for the contest. OR+PR

126 Kim was in the **pack** that set the **pace** for the contest. OR

126 Kim looked at the **book** that set the **pace** for the contest. CTRL

127 Jeff loved the **part** that described the **port** where they lived. OR+PR

127 Jeff loved the **poet** that described the **port** where they lived. OR

127 Jeff loved the **song** that described the **port** where they lived. CTRL

128 Kyle checked his heart **rate** before the **race** last Saturday. OR+PR

128 Kyle checked his shoe **rack** before the **race** last Saturday. OR

128 Kyle checked his gym **bags** before the **race** last Saturday. CTRL

129 Billy was too poor to afford even one **shot** at the **shop** in his hometown. OR+PR

129 Billy was too poor to afford even one **shoe** at the **shop** in his hometown. OR

129 Billy was too poor to afford even one **meal** at the **shop** in his hometown. CTRL

130 Derek did not **soak** the bar of **soap** before he used it. OR+PR

130 Derek did not **swap** the bar of **soap** before he used it. OR

130 Derek did not **drop** the bar of **soap** before he used it. CTRL

131 The cook promised to **spice** the only **space** left on the pizza.

OR+PR

131 The cook promised to **spare** the only **space** left on the pizza. OR

131 The cook promised to **cover** the only **space** left on the pizza. CTRL

132 Rachel put the **stem** on the **step** to pick up later. OR+PR

132 Rachel put the **stew** on the **step** to pick up later. OR

132 Rachel put the **tray** on the **step** to pick up later. CTRL

133 Jake dodged the **storm** by the **store** last night. OR+PR

133 Jake dodged the **stone** by the **store** last night. OR

133 Jake dodged the **attack** by the **store** last night. CTRL

APPENDIX B – STIMULI IN EXPERIMENT 2

*All the prime and target words are in bold. Primes always precede targets.

* OR+PR = Differ by only one letter and one phoneme (**O**rthographic and **P**honological **R**epetition)

PR = Differ by only one phoneme and more than one letter (Phonological **R**epetition only)

CTRL = Different in phonemes and letters (**C**on**tr**o**l**)

201 Sue chased after the **cat** while the **cab** waited by the curb. OR+PR

201 Sue came out of the **court** while the **cab** waited by the curb. PR

201 Sue chased after the **dog** while the **cab** waited by the curb. CTRL

202 Kate left her business **card** on all the **cars** in the parking lot. OR+PR

202 Kate tried her mother's **keys** on all the **cars** in the parking lot. PR

202 Kate left a personal **note** on all the **cars** in the parking lot. CTRL

203 The job applicant would remain **calm** for the **call** from her prospective employer. OR+PR

203 The job applicant would **kill** for the **call** from her prospective employer. PR

203 The job applicant would **wait** for the **call** from her prospective employer. CTRL

204 The child put the **cage** near the **cake** at the party. OR+PR

204 The child was told not to **kick** near the **cake** at the party. PR

204 The child put down his **ball** near the **cake** at the party. CTRL

205 Irene hid the **coal** in her **coat** when nobody was looking. OR+PR

205 Irene hid the **kite** in her **coat** when nobody was looking. PR

205 Irene hid the **sock** in her **coat** when nobody was looking. CTRL

206 Lauren threw a fresh **carp** into her **cart** at the store. OR+PR

206 Lauren threw a sewing **kit** into her **cart** at the store. PR

206 Lauren threw a box of **soda** into her **cart** at the store. CTRL

207 Bill was **cheap** and would often **cheat** his employees. OR+PR

207 Bill was the **chief** and would often **cheat** his employees. PR

207 Bill liked **lying** and would often **cheat** his employees. CTRL

208 The magician pulled the **cord** when the **card** appeared on the table.OR+PR

208 The musician played the **chord** when the **card** appeared on the table. PR

208 The audience made a **noise** when the **card** appeared on the table. CTRL

209 The farmer used a **cross** to keep **crows** away from his garden. OR+PR

209 The farmer had frogs **croak** to keep **crows** away from his garden. PR

209 The farmer used the **smoke** to keep **crows** away from his garden. CTRL

210 Marilou put something **fancy** on her **fanny** to attract attention. OR+PR

210 Marilou put something **phony** on her **fanny** to attract attention. PR

210 Marilou put something **weird** on her **fanny** to attract attention. CTRL

211 The experience of Helen's tragic **fate** would never **fade** from her memory. OR+PR

211 What Helen saw in the first **phase** would never **fade** from her memory. PR

211 The days when they were in the **camp** would never **fade** from her memory. CTRL

212 It was a twist of **fate** that the patient's **face** was not healing properly. OR+PR

212 It was in the first **phase** that the patient's **face** was not healing properly. PR

212 It was so sad to **know** that the patient's **face** was not healing properly. CTRL

213 Charlie moved the **form** as the beer's **foam** spilled over the table. OR+PR

213 Charlie moved the **phone** as the beer's **foam** spilled over the table. PR

213 Charlie moved the **watch** as the beer's **foam** spilled over the table. CTRL

214 Steve sold his expensive **gels** to buy the **gems** for his girlfriend. OR+PR

214 Steve sold his expensive **jets** to buy the **gems** for his girlfriend. PR

214 Steve sold his expensive **boat** to buy the **gems** for his girlfriend. CTRL

215 Pamela tried to contain her **ire** while the **ice** melted all over the floor. OR+PR

215 Pamela waited in the **aisle** while the **ice** melted all over the floor. PR

215 Pamela was in a **hurry** while the **ice** melted all over the floor. CTRL

216 Timmy filled a **jar** with some **jam** to eat after practice. OR+PR

216 Timmy went to the **gym** with some **jam** to eat after practice. PR

216 Timmy prepared the **bun** with some **jam** to eat after practice. CTRL

217 Sammy thought it would be **neat** to be **near** the baby on the blanket. OR+PR

217 Sammy decided to **kneel** to be **near** the baby on the blanket. PR

217 Sammy had to move her **chair** to be **near** the baby on the blanket. CTRL

218 Laura felt a mosquito **nick** her on the **neck** at the outdoor party. OR+PR

218 Laura felt a tree limb **knock** her on the **neck** at the outdoor party. PR

218 Laura felt a cold finger **poke** her on the **neck** at the outdoor party. CTRL

219 Kevin threw a **nut** by the **net** to try to catch some fish. OR+PR

219 Kevin spent the **night** by the **net** to try to catch some fish. PR

219 All of the folks got **ready** by the **net** to try to catch some fish. CTRL

220 It was important for all **nine** to be **nice** at the tournament. OR+PR

220 It was important for the **knight** to be **nice** at the tournament. PR

220 It was important for the **judge** to be **nice** at the tournament. CTRL

221 Robert wrote about his **nose** in the **note** to his mother. OR+PR

221 Robert wrote about the **gnome** in the **note** to his mother. PR

221 Robert wrote about the **plant** in the **note** to his mother. CTRL

222 The history class acted out the **raid** in the **rain** as a part of their fieldwork. OR+PR

222 The biology class observed the **wren** in the **rain** as a part of their fieldwork. PR

222 The art class sketched the **swan** in the **rain** as a part of their fieldwork. CTRL

223 The breeders sold the **runt** to pay the **rent** before the end of month. OR+PR

223 The plumber sold the **wrench** to pay the **rent** before the end of month. PR

223 The breeders sold their **goats** to pay the **rent** before the end of month. CTRL

224 Our family loves to **roam** on the **road** between Alabama and Mississippi. OR+PR

224 Our family loves the song Dad **wrote** on the **road** between Alabama and Mississippi. PR

224 Our family loves to watch this **movie** on the **road** between Alabama and Mississippi. CTRL

225 The singer let his eyes **roam** about the **room** last night. OR+PR

225 The singer wrote a **rhyme** about the **room** last night. PR

225 The singer wrote the **lyrics** about the **room** last night. CTRL

226 Karen tightened the **robe** with the **rope** she found in the closet. OR+PR

226 Karen completed the gift **wrap** with the **rope** she found in the closet. PR

226 The murderer strangled the **girl** with the **rope** he found in the closet. CTRL

227 Kyle found some **weed** late last **week** when he mowed the field. OR+PR

227 Kyle found some **wheat** late last **week** when he mowed the field. PR

227 Kyle found some **holes** late last **week** when he mowed the field. CTRL

228 The explorers **seem** to look for the **seed** at the end of the growing season. OR+PR

228 The explorers **cease** to look for the **seed** at the end of the growing season. PR

228 The explorers **want** to look for the **seed** at the end of the growing season. CTRL

229 The fashion model went to the **shows** to find **shoes** for this winter. OR+PR

229 The homeless woman looked in the **chute** to find **shoes** for this winter. PR

229 The poor family searched donation **centers** to find **shoes** for this winter. CTRL

230 Fred went to the **shore** in order to **share** his results with the marine biology class. OR+PR

230 Fred had to feel pretty **sure** in order to **share** his results with the marine biology class. PR

230 Fred worked on a **poster** in order to **share** his results with the marine biology class. CTRL

231 The debate team needed some **wit** for the **win** against the other team. OR+PR

231 The debate team needed a smart **one** for the **win** against the other team. PR

231 The debate team prepared a funny **pun** for the **win** against the other team. CTRL

232 Paul let his arm **rest** on the **rust** and suddenly felt concerned about tetanus. OR+PR

232 Paul scratched his **wrist** on the **rust** and suddenly felt concerned about tetanus. PR

232 Paul took a **seat** on the **rust** and suddenly felt concerned about tetanus. CTRL

233 Kay will **knit** around the **knot** to fix the problem. OR+PR

233 The mouse will **gnaw** around the **knot** to fix the problem. PR

233 Kay will **work** around the **knot** to fix the problem. CTRL

APPENDIX C – STIMULI IN EXPERIMENT 3

*All the prime and target words are in bold. Primes always precede targets.

*hilore = **Hi**gh Frequency Prime and **Lo**w Frequency Target with Phonological **Re**petition

hiloc = **Hi**gh Frequency Prime and **Lo**w Frequency Target as **C**ontrol

lohire = **L**ow Frequency Prime and **H**igh Frequency Target with Phonological **Re**petition

lohic = **L**ow Frequency Prime and **H**igh Frequency Target as **C**ontrol

101 Pamela watched as the **ice** melted in the **aisle** of the grocery store. hilore

101 Pamela watched as the **cream** melted in the **aisle** of the grocery store. hiloc

101 Pamela waited in the **aisle** while the **ice** melted all over the floor. lohire

101 Pamela waited in the **attic** while the **ice** melted all over the floor. lohic

102 The biology class went out in the **rain** to see the **wren** as part of their field work. hilore

102 The biology class went out in the **snow** to see the **wren** as part of their field work. hiloc

102 The biology class observed the **wren** in the **rain** as part of their fieldwork. lohire

102 The biology class observed the **swan** in the **rain** as part of their fieldwork. lohic

103 Irene took off her **coat** to fly the **kite** in the park. hilore

103 Irene took off her **robe** to fly the **kite** in the park. hiloc

103 Irene hid the **kite** in her **coat** when nobody was looking. lohire

103 Irene hid the **bird** in her **coat** when nobody was looking. lohic

104 Jack gave the puppy the **shoe** to **chew** on last night. hilore

104 Jack gave the puppy the **bone** to **chew** on last night. hiloc

104 Jack told the puppy not to **chew** the **shoe** last night. lohire

104 Jack told the puppy not to **bite** the **shoe** last night. lohic

105 Kyle was in town last **week** to see the **wheat** growing in his field. hilore

105 Kyle was in town last **month** to see the **wheat** growing in his field. hiloc

105 Kyle found some **wheat** late last **week** when he mowed the field. lohire

105 Kyle found some **seeds** late last **week** when he mowed the field. lohic

106 The beavers **know** how to **gnaw** through those birch trees. hilore

106 The beavers **wonder** how to **gnaw** through those birch trees. hiloc

106 The beavers **gnaw** in order to **know** what kind of wood it is. lohire

106 The beavers **gnaw** in order to **learn** what kind of wood it is. lohic

107 I had just gotten to **school** when my **skull** started to pound. hilore

107 I had just gotten to **work** when my **skull** started to pound. hiloc

107 We looked at a human **skull** today at **school** for examples of head injuries. lohire

107 We looked at a human **brain** today at **school** for examples of head injuries. lohic

108 The maids **hope** to finish the **heap** of laundry in an hour. hilore

108 The maids **wish** to finish the **heap** of laundry in an hour. hiloc

108 The maids pile the laundry on a **heap** and **hope** to finish it in an hour. lohire

108 The maids place the laundry on a **pile** and **hope** to finish it in an hour. lohic

109 The vet needed an extra **hand** for the **hound** that needed attention. hilore

109 The vet needed more **help** for the **hound** that needed attention. hiloc

109 The vet was upset that the **hound** bit her **hand** during the examination. lohire

109 The vet was upset that the snake **bit** her **hand** during the examination. lohic

110 The doctor told her to **rest** her left **wrist** before playing basketball again. hilore

110 The doctor told her to **check** her left **wrist** before playing basketball again. hiloc

110 The doctor told her to give her **wrist** a long **rest** before playing basketball again. Lohire

110 The doctor told her to give her **knees** a long **rest** before playing basketball again. Lohic

111 Joey knew that the **rock** caused the **wreck** on the highway. hilore

111 Joey knew that the **tree** caused the **wreck** on the highway. hiloc

111 Joey knew that the **wreck** was caused by the **rock** on the highway. lohire

111 Joey knew that the **crash** was caused by the **rock** on the highway. lohic

112 The designer marked one **board** with a **bead** to make it different. hilore

112 The designer marked one **sleeve** with a **bead** to make it different. hiloc

112 Maria put the **bead** on the **board** so she would be sure to remember it. lohire

112 Maria put the **chart** on the **board** so she would be sure to remember it. lohic

113 Carol's **laugh** blew the **leaf** off of the tree. hilore

113 Carol's **shout** blew the **leaf** off of the tree. hiloc

113 I was surprised that the **leaf** made Carol **laugh** as it fell from the tree. lohire

113 I was surprised that the **nest** made Carol **laugh** as it fell from the tree. lohic

114 Mom threw my ripped **shirt** down the **chute** last week. hilore

114 Mom threw my ripped **pants** down the **chute** last week. hiloc

114 Mom looked in the **chute** to find my old **shirt** last week. lohire

114 Mom looked in the **drawer** to find my old **shirt** last week. lohic

115 The ocean was **rough** at the **reef** over spring break. hilore

115 The ocean was **calm** at the **reef** over spring break. hiloc

115 The water at the **reef** was too **rough** for swimming or boating. lohire

115 The water at the **shore** was too **rough** for swimming or boating. lohic

116 Robert wrote a **note** about a **gnome** to his mother. hilore

116 Robert wrote a **song** about a **gnome** to his mother. hiloc

116 Robert wrote about the **gnome** in the **note** to his mother. lohire

116 Robert wrote about the **dwarf** in the **note** to his mother. lohic

117 Sue will definitely **need** my **niece** to babysit the kids. hilore

117 Sue will definitely **ask** my **niece** to babysit the kids. hiloc

117 Sue said that my **niece** will **need** to babysit the kids. lohire

117 Sue said that my **nephew** will **need** to babysit the kids. lohic

118 No one should swim in this **type** of **tide** after a storm. hilore

118 No one should swim in this **kind** of **tide** after a storm. hiloc

118 No one should swim in a **tide** of this **type** after a storm. lohire

118 No one should swim in a **pool** of this **type** after a storm. lohic

119 Off to the **side** there were **sighs** of relief when the athlete stood up. hilore

119 From the **bench** there were **sighs** of relief when the athlete stood up. hiloc

119 There were **sighs** heard from the **side** when the athlete stood up. lohire

119 There were **cheers** heard from the **side** when the athlete stood up. lohic

120 Do not put that turtle in the **pool** or the **pail** while I am gone. hilore

120 Do not put that turtle in the **sink** or the **pail** while I am gone. hiloc

120 Do not put that turtle in the **pail** or the **pool** while I am gone. lohire

120 Do not put that turtle in the **sink** or the **pool** while I am gone. lohic

121 I don't know why this **post** is covered with **paste** and glitter. hilore

121 I don't know why this **wall** is covered with **paste** and glitter. hiloc

121 I don't know why Kim used **paste** to cover the **post** with glitter. lohire

121 I don't know why Kim used **glue** to cover the **post** with glitter. lohic

122 Carol saw her horse under the full **moon** and her **mane** was shining. hilore

122 Carol saw her horse on the large **farm** and her **mane** was shining. hiloc

122 Carol saw her horse's **mane** as the full **moon** was shining. lohire

122 Carol saw her horse's **coat** as the full **moon** was shining. lohic

123 It wouldn't **hurt** to know the **height** in the competition. hilore

123 It wouldn't **help** to know the **height** in the competition. hiloc

123 Cheryl knew that her **height** would **hurt** her in the competition. lohire

123 Cheryl knew that her **weight** would **hurt** her in the competition. lohic

124 My choice was number **eight** on the **ale** list in the menu. hilore

124 My choice was number **seven** on the **ale** list in the menu. hiloc

124 My favorite **ale** was **eight** on the list in the menu. lohire

124 My favorite **beer** was **eight** on the list in the menu. lohic

125 Lee enjoyed the **sound** and the **sand** on the beach. hilore

125 Lee enjoyed the **breeze** and the **sand** on the beach. hiloc

125 Lee enjoyed the **sand** and the **sound** on the beach. lohire

125 Lee enjoyed the **breeze** and the **sound** on the beach.lohic

126 Mom wants a **piece** of the **peel** of my apple. hilore

126 Mom wants a **slice** of the **peel** of my apple. hiloc

126 Mom wants the **peel** from this **piece** of my apple. lohire

126 Mom wants the **flesh** from this **piece** of my apple. lohic

127 Jim will pay the **rent** and get a **wrench** on his way home. hilore

127 Jim will pay the **bill** and get a **wrench** on his way home. hiloc

127 Jim will get a **wrench** and pay the **rent** on his way home. lohire

127 Jim will get a **package** and pay the **rent** on his way home. lohic

128 Jill could not **reach** the **wreath** over the door. hilore

128 Jill completely **forgot** the **wreath** over the door. hiloc

128 Jill knew that the **wreath** couldn't **reach** over the door. lohire

128 Jill knew that the **broom** couldn't **reach** over the door. lohic

129 We will **dig** a new **ditch** to drain the creek. hilore

129 We will **have** a new **ditch** to drain the creek.hiloc

129 The new **ditch** that we **dig** will drain the creek. lohire

129 The new **trench** that we **dig** will drain the creek. lohic

130 Tom spent the whole **night** to untie the **knot** but gave up finally. hilore

130 Tom spent the whole **hour** to untie the **knot** but gave up finally. hiloc

130 Tom tried to untie the **knot** for the whole **night** but gave up finally.lohire

130 Tom tried to untie the **bow** for the whole **night** but gave up finally. lohic

131 Please open the **lock** and check the **leak** on the shed every day. hilore

131 Please open the **door** and check the **leak** on the shed every day. hiloc

131 Please check the **leak** before you **lock** the shed every day. lohire

131 Please check the **gas** before you **lock** the shed every day. lohic

132 Joe wants to **write** on the **root** of the oak tree. hilore

132 Joe wants to **dance** on the **root** of the oak tree. hiloc

132 Joe sat on the old **root** to **write** about the oak tree. lohire

132 Joe sat on the old **swing** to **write** about the oak tree. lohic

133 The ship's **crew** did not have a **clue** to the treasure's location. hilore

133 The ship's **owner** did not have a **clue** to the treasure's location. hiloc

133 The ship's **clue** did not get the **crew** to the treasure's location. lohire

133 The ship's **hint** did not get the **crew** to the treasure's location. lohic

134 The kid was surprised by the **bird** and heard a **burp** coming from the cage. hilore

134 The kid was surprised by the **dog** and heard a **burp** coming from the cage. hiloc

134 The kid heard a **burp** as the **bird** surprised him at the window. lohire

134 The kid heard a **chirp** as the **bird** surprised him at the window. lohic

135 The doctor did not know the **cause** of the **cough** and discomfort. hilore

135 The doctor did not know the **facts** of the **cough** and discomfort. hiloc

135 The doctor said the **cough** was the **cause** of Jay's discomfort. lohire

135 The doctor said the **heat** was the **cause** of Jay's discomfort. lohic

136 That old **hit** was not a **hymn** for children. hilore

136 That old **song** was not a **hymn** for children. hiloc

136 That old **hymn** was not a **hit** for children. lohire

136 That old **tale** was not a **hit** for children. lohic

137 Larry took a **ride** to see the **reed** by the pond. hilore

137 Larry took a **seat** to see the **reed** by the pond. hiloc

137 Larry saw a green **reed** on his **ride** by the pond. lohire

137 Larry saw a green **boat** on his **ride** by the pond. lohic

138 Mary could not **wait** to see the **whale** to come near the boat. hilore

138 Mary did not **want** to see the **whale** to come near the boat. hiloc

138 Mary knew that the **whale** might **wait** to come near the boat. lohire

138 Mary knew that the **dolphin** might **wait** to come near the boat. lohic

139 There was a big **scene** when the **seed** was genetically altered. hilore

139 There was a big **change** when the **seed** was genetically altered. hiloc

139 We saw the new **seed** on the **scene** of genetically altered plants. lohire

139 We saw the new **crop** on the **scene** of genetically altered plants. lohic

140 Jeff sat in my **room** to sing the **rhyme** last night. hilore

140 Jeff sat in my **office** to sing the **rhyme** last night. hiloc

140 Jeff sang the silly **rhyme** in my **room** last night. lohire

140 Jeff told the silly **story** in my **room** last night. lohic

141 The hairdresser won't **call** me to **curl** your hair for the pictures. hilore

141 The hairdresser won't **let** me to **curl** your hair for the pictures. hiloc

141 The hairdresser decided to **set** the **curl** and then call for her assistant. lohire

141 The hairdresser decided to **set** the **style** and then call for her assistant. lohic

142 The young prince will **race** after his **reign** is completed. hilore

142 The young prince will **speak** after his **reign** is completed. hiloc

142 The young prince will **reign** after the **race** is completed. lohire

142 The young prince will **speak** after the **race** is completed. lohic

143 Mary could not **wait** to see the **whale** to come near the boat. hilore

143 Mary did not **want** to see the **whale** to come near the boat. hiloc

143 Mary knew that the **whale** might **wait** to come near the boat. lohire

143 Mary knew that the **dolphin** might **wait** to come near the boat. lohic

144 The gambler showed the **card** when the final **chord** was played. hilore

144 The clown made a **face** when the final **chord** was played. hiloc

144 The musician played the **chord** when the **card** was shown. lohire

144 The musician played the **strings** when the **card** was shown. lohic