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UNIVERSITY OF CALIFORNIA, SAN DIEGO

The Influence of Contextual Constraint on Word Recognition during Reading

A dissertation submitted in partial satisfaction of the requirements for

Doctor of Philosophy

in

Psychology

by

Patrick Reynard Plummer

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2015

The Dissertation of Patrick Reynard Plummer is approved, and is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

2015

DEDICATION

For Keith Rayner, a mentor who opened the doors for me,
and whose door was always open for me.

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- Rayner, K., Abbott, M. J., **Plummer, P.** (in press). Individual differences in perceptual processing and eye movements in reading. In P. Afflerbach (Ed.), *Handbook of Individual Differences in Reading: Text and Context*. (pp. 348-363). New York: Taylor & Francis/Routledge.
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ABSTRACT OF THE DISSERTATION

The Influence of Contextual Constraint on Word Recognition during Reading

by

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Doctor of Philosophy

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The current study investigated the influence of linguistic context on word recognition and sentence processing during reading. Using high temporal resolution eye-tracking methodologies, four experiments tested the effects of prior sentence context on the earliest stages of word identification: the processing of letter and sound information. The studies also examined contextual effects on word processing throughout the time course of the eye-movement behavioral record. The central goal of the work was to examine the extent to which skilled reader's expectations are expressed at various levels of lexical representation and the extent to which expectations exert an influence on the process of word recognition.

Experiment 1 manipulated the information available about a target word. Prior to fixating the target word, subjects were presented with consistent or inconsistent

information about the target word using the gaze-contingent invisible boundary paradigm (Rayner, 1975). Experiments 2a and 2b performed a similar manipulation while examining the influence of lexical characteristics on word recognition difficulty. Experiment 3 investigated the influence of context on intrinsic properties of word processing difficulty. Findings reveal that skilled reader's expectations for upcoming material modulate the process of word recognition and eye movement control during reading. The results of the joint manipulation of word properties and sentence constraint were interpreted with regard to competing accounts of contextual influences on word recognition and comprehension.

Chapter 1

Introduction

The ability to recognize words is one of the more remarkable human information-processing feats. During normal reading, the task of individual word recognition and higher-level sentence comprehension can seem effortless and instantaneous. In fact, skilled readers of English typically read as many as 200 - 300 words per minute with fixations on words typically lasting for less than one quarter of a second (see Rayner, Abbott, & Plummer, in press, for review of individual differences in reading). An intuitive assumption is that the vast majority of time, word recognition is an exclusively bottom-up process where the perception of letter sequences from the printed text are used to identify each word. However, the sentences we read can routinely guide us to expect what linguistic content should be upcoming. Phenomenologically, often people find some words predictable, even guessable, in a particular context. The central focus of this thesis is the extent to which expectations can directly contribute to the seemingly automatic process of word recognition during skilled reading. More specifically, four studies examine whether readers make predictions about upcoming words, letters, and sounds in the text during sentence comprehension and how these predictions might affect the processing of perceptual input.

Eye movement control

The routine speed and efficiency of skilled reading belies the considerable demands of coordinating the efforts of the various cognitive systems that are involved. Several decades of psycholinguistic research have demonstrated that language comprehension processes, oculomotor constraints, and visual acuity limitations all exert systematic influences on eye movement behavior during reading (Rayner, 1998). Thus, the moment-to-moment decisions that skilled readers make about when to move their eyes and where to go in the text are driven, in part, by word recognition and message-level comprehension. As such, the eye movement behavioral record during reading serves as a robust resource for the assessment of online language comprehension.

The accurate recognition and rapid integration of words is the central task of reading comprehension. However, studies have also demonstrated that restrictions imposed by changes in acuity across the visual field and the time required to program and execute eye movements play a considerable role in eye-movement behavior during reading (Rayner, 1998; 2009 for reviews). Studies have shown that the perceptual span in reading (i.e., the area of the visual field from which readers obtain useful visual information in a written text) can be divided into three distinct regions. The central two degrees of vision where acuity is highest is known as the fovea, where letters and words can be recognized with relative ease. The five degrees of visual angle extending around the fovea in either direction is the parafovea, where letter and word recognition is possible but with far more difficulty and considerably reduced efficiency. Beyond the parafoveal region of the visual field is the periphery, where only word length and boundary information can be extracted effectively. To offset

these limitations, readers periodically execute rapid, ballistic eye movements, called saccades, to bring new (or old) areas of text into the fovea for inspection with each fixation. In fact, skilled readers of English typically make multiple saccades every second. Research has also shown that the perceptual span is asymmetric during reading, extending 3 - 4 characters to the left and 14 - 15 characters to the right of any fixation for skilled readers of English; crucially, the observed asymmetry in the perceptual span is in the direction that English text proceeds (i.e., from left to right). These and other findings indicate that dynamic allocation of attention is a critical factor in reading (McConkie & Rayner, 1975; see Rayner 2014 for a review of the perceptual span during reading).

Research has shown that word recognition and sentence comprehension affect eye movements during reading. Although important details have yet to be resolved, two main findings are evident from the literature. First, decisions about when to initiate saccades to new portions of text are heavily influenced by the linguistic information being processed in the current fixation, such as how difficult the fixated word is to process (Rayner, 1998). Second, once a word is chosen as the saccade target, decisions about where to fixate in the word are made largely on the basis of lower-level visual features, such as word length and word boundary information, with some potential influences from letter sequences (Plummer & Rayner, 2012; White & Livensedge, 2004).

Given the link between eye movement control and language comprehension in reading, there are standard measures of reading behavior that index process of word recognition (i.e., lexical access) and the integration of word meanings into an ongoing

mental representation for the broader message being conveyed (i.e., post-lexical processes). The total amount of time spent fixating a word and the probability that a reader will actually fixate that word (at least once) during “first-pass” reading are widely regarded as measures of word recognition difficulty. The probability of returning to fixate a word after having moved past that word in the text (i.e., the likelihood of making a regression) and the time spent fixating a word on a second-pass are both measures of the difficulty associated with integrating identified words into an ongoing message-level or discourse representation. In general, examining the record of eye movements during reading allows researchers to make inferences about how readers process different characteristics of written language. As such, examining the record of eye movements during reading while manipulating specific characteristics of the text allows researchers to make strong inferences about the underlying processes of comprehension.

Word Recognition

Many studies over several decades have demonstrated that skilled readers routinely extract useful information about words and letters in the parafoveal region of the visual field. These studies use the *gaze-contingent invisible boundary paradigm* (Rayner, 1975), an experimental paradigm that allows for the manipulation of text presentation as subjects read sentences on a computer screen. The boundary paradigm is used to display a *preview* string in the place of a *target word* of interest prior to direct fixation during reading (e.g., a string of X's, nonword letter string, or a different

word as the preview for a target). Once readers initiate a saccade crossing an invisible boundary (typically placed just to the left of the target word position), the preview string is replaced with the target word before the next fixation begins. This technique permits experimental control of the available parafoveal information about upcoming letters and words prior to fixating the target word directly. The reading studies using this paradigm have demonstrated that the information readers obtain about words in the parafovea is used during normal word recognition processes. When target words are replaced with invalid preview strings (i.e., any letter string other than the target word) prior to direct fixation, first-pass reading times increase in duration. When the target word is available for the entire experimental trial (i.e., an identical or full preview), the characteristic decrease in target word first-pass reading time is called the *parafoveal preview benefit*. In other words, reading times for a word increase when a valid parafoveal preview for that word is denied prior to direct fixation. A large body of experimental studies using the boundary paradigm have indicated that skilled readers acquire reliable information about a parafoveal word at several levels of representation, including word length information, abstract letter (orthographic) and sound (phonological) information, as well as word meaning (lexical-semantic) information (see Schotter, Angele, & Rayner, 2012 for full review of parafoveal processing in reading). Importantly, these preview benefits indicate that the earliest stages of word recognition typically begin before readers directly fixate the word directly, when it is still in the reader's parafovea.

Many studies have focused on the task of word recognition itself. Once readers reach proficiency, word recognition becomes obligatory and entirely

automatized (Reicher, 1969; Stroop, 1935). To briefly summarize, across competing theories there are two main positions: one set of theories states (at the extreme) that word recognition is achieved via an independent operational module in the cognitive system that acts on perceptual information exclusively and inflexibly transmits output for further processing (Fodor, 1983; Forster, 1979; Henderson, 1982; Kintsch, 1988; Marslen-Wilson, 1978). The alternative to this modular view posits that word recognition is achieved by interactive use of all available information at any level of representation (McClelland & Rumelhart, 1981; Norris, 2006; Seidenberg, Petersen, McDonald, & Plaut 1996). The models differ in crucial aspects of how underlying linguistic representations are stored and accessed during comprehension. Key differences also involve the extent to which *sublexical features* at distinct levels of representation (e.g., a word's constituent phonology and orthography) might interact with one another during different stages of word identification (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Another important theoretical issue is whether mental representations for the *lexical-semantic* information that corresponds to the meaning of a particular word (and potentially other related word forms) influence word processing stages prior to lexical access. Importantly, all of these accounts and models of visual word recognition posit that full word identification relies on the successful access of stored lexical representations via sublexical features. Word recognition can be thought of as full access to the complete orthographic, phonological, and lexical-semantic representations that correspond to a particular word form (Pollatsek & Rayner, 1990). A critical test of the key distinction between these accounts is the extent to which prior linguistic context can exert an influence on

the processes responsible for lexical access. In broad terms, strictly modular views, where word identification is executed by autonomous processes, assume that any influence of context must act through facilitating post-lexical integration, as the resources responsible for lexical identification cannot be influenced by “external” processes (such as sentence or discourse comprehension). On the other hand, non-modular or interactive views assume that lexical identification interacts with processes of higher-level sentence comprehension. These interactive accounts predict influences of linguistic context on word recognition processes as well as post-lexical integration processes.

It is important to note that there is considerable variability in the time and difficulty associated with recognizing words. As such, differences in processing difficulty across words drive much of the variability in reading time. Words that are more difficult to identify generally receive longer first-pass reading times, lower first-pass skipping rates, and are more likely to be refixated during reading. There are a number of factors that determine word processing difficulty, such as *word frequency*, a measure of how often a word occurs across the language (Inhoff & Rayner, 1986; Henderson & Ferreira, 1990), word length (Just & Carpenter, 1980; Rayner, Sereno, & Raney, 1996), *contextual diversity*, a measure of the number of contexts in which a word is likely to appear (Adelman, Brown, Quesada, 2006; Plummer, Perea, Rayner, 2014), and the typical age of acquisition for a word (Juhasz & Rayner, 2003, 2006). Critically, these factors are all context-independent properties of the lexical item or the specific perceptual stimulus that represents the lexical item. Irrespective of the linguistic context in which a word appears, these intrinsic characteristics exert an

influence on word processing difficulty. Accounting for these context-independent influences on word processing is crucial for any examination of context-dependent effects.

Contextual constraint and word predictability

A number of other factors that influence word processing difficulty are based on the linguistic context in which a given word appears. Constructing an interpretation of the message being conveyed by a sentence or text requires the recruitment of knowledge about the world and the language being used. In fact, a central aspect of human cognition involves the combination of bottom-up (perceptual) and top-down (internally represented) resources to construct meaningful interpretations about the current state of circumstances. In an effort to ease the general difficulty of a processing task, individuals (unconsciously) generate expectations regarding what is yet to come in any dynamic situation (Bar, Kassam, Ghuman, Boshyan, Schmid, 2006). Thus, across a wide range of circumstances, the cognitive system makes use of prior experience and relevant context to inform expectations regarding a wide range of potential outcomes. Likewise, skilled readers maintain at least one interpretation of the message being conveyed as they read (Frazier & Rayner, 1982; Levy, 2008; Seidenberg & MacDonald, 1999). Any interpretation must be updated from moment-to-moment as each new word or phrase is recognized. One natural intuition is that the task of sentence comprehension might influence processes at subordinate levels of a reading task, such as word recognition. This possibility has

spawned a growing field of inquiry within psycholinguistics and reading research.

The majority of work in this branch of reading research has been focused on two related questions. First, how rapidly do the effects of message-level sentence comprehension unfold in the eye-movements record, and second to what extent does the sentence comprehension process influence the word recognition process? Many of these studies examined language comprehension by observing the results of sentence context manipulations on eye-movement behavior during reading. Among other influences, the information carried within a particular sentence context can have the effect of constraining possibilities for how the remainder of the sentence or text ought to proceed. Naturally, the strength of linguistic constraints are highly variable across contexts and might be expressed at semantic, syntactic, or pragmatic levels of representation. These forms of *contextual constraint* will, on some occasions, have the effect of rendering a particular lexical item or a small set of words highly predictable. Indeed, the reliable effects of word predictability have been demonstrated across a wide range of empirical studies using behavioral and electrophysiological measures. In the realm of eye movement behavior during reading, contextual constraint has been shown to influence the ease of selecting the appropriate meanings for ambiguous words (Duffy, Morris, & Rayner, 1988; Leininger & Rayner, 2013; Rayner & Duffy, 1986; Sheridan & Reingold 2012), prompt sentence comprehension difficulty as a result of semantically anomalous words (Rayner, Warren, Juhasz, & Liversedge, 2004; Warren & McConnell, 2007; Warren, McConnell, & Rayner, 2008), decrease reading times and fixation probabilities for highly predictable words (Balota, Pollatsek, & Rayner, 1985; Drieghe, Rayner, & Pollatsek, 2005; Ehrlich & Rayner,

1981; Kliegl, Grabner, Rolfs, & Engbert, 2004; McDonald & Shillcock, 2003; Rayner, Binder, Ashby, & Pollatsek, 2001; Rayner, Slattery, Drieghe, & Liversedge, 2011; Rayner & Well, 1996; Smith & Levy, 2013; Zola, 1984), and facilitate processing of words in semantically congruent sentences as measured by eye movement behavior (Camblin, Gordon, & Swaab, 2007; Hess, Foss, & Carroll, 1995; Morris, 1994; Morris & Folk, 1998).

Conventionally, for empirical studies, contextual constraint is operationally defined using the modified *cloze task* (Taylor, 1953), wherein subjects are given a sentence fragment and told to guess the identity of the next word. To measure the predictability of a particular word of interest (the target word) researchers record the proportion of trials in which subjects respond with that word. Typically, words in contexts with cloze proportions of .70 or above are considered high predictability, whereas words with cloze response proportions less than .10 are considered low predictability, although proportions for low predictability words are routinely quite a bit lower than this (Rayner, 1998). The cloze task, as with all operational measures based on subjective ratings and judgments (e.g., familiarity judgments, plausibility ratings), has shortcomings. Typically, the cloze task is performed with no explicit time constraints so participants can take as long as they wish to produce a response. Another potential issue with the cloze task is that it might only be useful for identifying sentence contexts in which one or two words are highly predictable. However, the intuitive and straightforward nature of the task coupled with the fact that it invokes the underlying generative process of interest makes the measure ideally accessible and interpretable as an operational metric. Cloze task responses are most

likely sensitive to a variety of linguistic constraints; however, it is almost certainly the case that subjects bring more than semantic representations to bear on the task of generating a particular cloze response. To the extent that particular continuations are felicitous or, at the very least, grammatical they reflect syntactic constraints imposed by the sentence fragment.

Several more objective alternatives to the cloze task have also been used to assess degrees of contextual constraint and word predictability. These alternatives rely on computational measures of constraint based on linguistic corpus materials.

Transitional probabilities approximating the conditional probability of a word given a particular preceding context (McDonald & Shillcock, 2003a; 2003b; Frisson, Rayner, & Pickering, 2005; Smith & Levy, 2013), formal, information theoretic measures reflecting a word's entropy in context (Boston, Hale, Kliegl, Patil, & Vasishth, 2008; Levy, 2008), conditional co-occurrence probabilities across words (Ong and Kliegl, 2008), and Latent Semantic Analysis (Landauer & Dumais, 1997) measures relating words to a given context (Pynte, New, and Kennedy, 2008; Wang, Chen, Ko, Pomplun, and Rayner, 2010) have all been successfully used to predict the influence of word predictability and contextual constraint on eye-movement behavior during reading.

Smith and Levy (2011) performed an analysis comparing the predictive power of cloze responses and corpus-based measures of word predictability. Their results suggest that the idiosyncrasies apparent in cloze response data are reflective of systematic biases in people's knowledge and beliefs about their native language as compared to true corpus-based computations of the relations between words. Presumably, cloze proportion is an index of the difficulty associated with processing a word in a given

sentence context, or at least is an index of some critical aspects of word processing difficulty during sentence comprehension.

In one of the earliest studies of contextual constraint during normal reading, Zola (1984; but originally reported in McConkie & Zola, 1981) observed modest, yet noteworthy, effects of word predictability. A set of target words were selected and each word was rendered predictable or unpredictable by manipulating the identity of the word immediately preceding the target, or *pretarget word*, in a passage of text, as shown in Example 1.1 taken from Zola (1984) with target words and pretarget words in bold. For this example, the identity of the adjective imposes constraints on the information that has yet to come. Some adjectives will prompt stronger constraints (e.g., things that might be buttered), whereas, others will prompt considerable less constraint (e.g., referents that can be adequate).

Example 1.1

High constraint condition: Since movie theaters must have **buttered popcorn** to serve to their patrons...

Low constraint condition: Since movie theaters must have **adequate popcorn** to serve to their patrons...

The average first-pass reading times for target words were longer in low constraint conditions, where target words were not predictable, when compared to the average first-pass reading times for target words in the high constraint condition. The size of this effect increased when including regressions made from the target word

back into previous words before moving past the target word in the text. The study served to demonstrate that even small changes to a linguistic context can influence the processing difficulty on a word as measured by first-pass reading times (the observed effects were between 15 ms and 25 ms on average). The results of this experiment served as a basis for stronger manipulations of context and more expansive investigation of the corresponding effects on eye movements during reading.

In an eye tracking experiment, Ehrlich and Rayner (1981) manipulated contextual constraint with the use of longer passages where more robust discourse representations and semantic inferences could be generated. In one of the study's experiments, identical target words were presented within a low or high constraint passage. In the second study the passage was held constant while the target word was manipulated to be high or low predictability. The more powerful manipulations of context resulted in considerably larger effects on first-pass reading when compared to Zola's experiment. Target words in predictable contexts were skipped more often during first-pass reading and, when fixated, were read for significantly less time (around 40 ms). The experiments also demonstrated that words in predictable contexts are regressed into less often than words in unconstrained contexts.

Rayner and Well (1996) used the cloze task to examine the influence of word predictability across broader range of contextual constraint. In these materials, target words were presented in sentence contexts that rendered the words high, medium, or low predictability based on cloze response proportions. High predictability words averaged 86% cloze response proportions (range = 73% - 100%), medium predictability words had average cloze proportions of 41% (range = 13% - 68%) and

low predictability words had average cloze proportions of 4% (range = 3% - 5%). They found that high and medium predictability words yielded shorter first-pass reading times when compared to low predictability words, but did not differ from one another. They also found that high predictability target words were skipped significantly more often than low or medium predictability words, which did not differ from one another. In a separate study, Hyona (1993) found no effect of contextual constraint on any of the first-pass reading times and relatively weak and unreliable effects on re-reading (or second pass reading) times. Importantly, the cloze response differences for target words in word predictability conditions were 65.0% and 31.8% respectively. The completion proportions are considerably closer to one another than in previous and subsequent manipulations of contextual constraint. Moreover, the high predictability items were at the lower end of what is generally accepted as sufficient to classify a word as highly predictable in a sentence context. Low predictability items were also much higher in cloze response proportion than what is generally accepted as unpredictable.

In a corpus analysis of reading times, Smith and Levy (2013) demonstrated that word predictability effects can be detected across a wide range of contextual constraint. Their analysis showed that the quantitative effect of word predictability on reading times is consistent across several orders of magnitude. Differences in reading times for words across the low range of constraint, where no items are predictable, were similar to differences observed in reading times for words across more highly constrained contexts. These results indicate that measures of a word's conditional probability reveal distinctions in reading times for words that are at the very low end

of predictability, none of which would be likely cloze responses. This can be taken as evidence that word predictability effects can be observed in reading times even when words are not predictable per se.

Rayner, Binder, Ashby, and Pollatsek (2001) also observed effects of word predictability on first-pass reading times and skipping rates in a separate reading experiment. The predictability effect on target word skipping was also modulated strongly by pretarget fixation location. Target words were skipped increasingly as pretarget fixation locations came closer to the target word. This effect was present under all conditions but was much stronger when words were in highly predictable contexts. They also conducted an analysis of initial word fixation locations (i.e., landing positions) and found that word predictability did not influence the average location of initial fixations on a word. They found that while contextual constraint did influence whether a word received a first-pass fixation, it did not influence where in the word the initial fixation was located. These findings suggest that word predictability influences higher-level comprehension but does not influence saccade targeting, a lower-level aspect of reading.

Balota, Pollatsek, and Rayner (1985) conducted an eye tracking study designed to assess the processing of parafoveal information in reading as a function of contextual constraint. As shown in Example 1.2, target words (in bold) were embedded in a sentence frame where they were rendered highly predictable or less predictable given the prior linguistic context. For this study predictable target words were contrasted with less predictable target words read in the high constraint context.

Example 1.2

High predictability condition: Since the wedding was today, the baker rushed the wedding **cake** to the reception.

Low predictability condition: Since the wedding was today, the baker rushed the wedding **pies** to the reception.

In addition, target words were viewed in one of five parafoveal preview conditions. These preview conditions were classified with respect to the identity of the highly predictable word (i.e., the word that is highly constrained by the context regardless of the target word condition). For the example above the preview conditions included: a full (i.e., identical) preview (cake or pies), a visually similar nonword preview (cahc or pirc), a semantically related preview (pies or cake), a visually dissimilar nonword preview (pirc or cahc), or an anomalous preview (bomb).

The most notable result was an interaction of first-pass target word skipping wherein predictable words presented in the parafovea were skipped more often than unpredictable words. Balota and colleagues considered this to be evidence of enhanced parafoveal information processing in high constraint sentence contexts. Nonword previews that were visually similar to the highly predictable target word (e.g., *cahc* as a preview for *cake*) did not differ in first-pass skipping. There was also an observed main effect of preview whereby visually similar and identical previews reduced gaze durations compared to all other preview conditions. Critically, target word predictability and preview interacted such that the visually similar and identical previews facilitated processing differentially as a function of predictability. The size

of the preview benefit for identical previews and visually similar nonword previews was about twice as large in the high predictability condition compared to the low predictability condition. Critically, the observable processing benefits of word predictability on first-pass skipping rates and reading times were eliminated when parafoveal previews were identical to the predictable word or orthographically consistent with the predictable word. These findings were taken as evidence that contextual constraint improves skilled reader's ability to utilize parafoveal information for word recognition.

Drieghe, Rayner, and Pollatsek (2005) revisited the influence of word predictability on parafoveal preview benefit using Balota et al.'s materials in a replication of the earlier study. They found that highly predictable words were skipped more often than less predictable words and all nonwords irrespective of orthographic or semantic similarity to the target. Interestingly, they found that nonwords visually similar to predictable words were skipped at the same rate as unpredictable or visually dissimilar nonwords. In fact, the discrepancy between skipping rates for predictable words with identical previews was stronger when restricting analyses to cases where the fixation prior to the target word was within 6 characters (i.e., letter spaces) of the target word. Importantly, the two studies observed conflicting parafoveal preview results on target word skipping rates. Drieghe et al. attributed the failure to replicate the pattern of results in the Balota et al. study to increased stimulus display quality, as the two studies were separated by twenty years and vast advances in relevant technologies.

Taken together, these experiments show that word predictability exerts effects

on first-pass reading times and word skipping rates, the earliest possible measures of eye movement behavior that reflect word processing. Previous studies using either cloze proportions or corpus-based word probabilities have demonstrated effects on reading times across a wide range of constraint and predictability values. Despite the observation of reliable word predictability effects on standard measures of word processing during reading it is still unclear whether any stages of word recognition are directly influenced by sentence context. Furthermore, if word recognition is impacted by context it is not clear how whether these influences are driven by expectations for discrete lexical items or expectancies in some other form for upcoming information. Nevertheless, empirical findings have guided the development a number of accounts characterizing the nature of word predictability effects in reading. The remainder of this chapter will summarize those accounts and characterize the broad predictions that fall out of contrasting theories.

Word guessing accounts

The degree to which prior context influences word recognition depends largely on how lexical access is achieved within the language processing system. The most simple and straightforward account for the influence of context on word processing assumes that skilled readers generate predictions or guesses for the identity of every word in a text prior to obtaining perceptual information; readers then engage in a type of hypothesis testing where perceptual input is evaluated with regard to the discrete lexical prediction. If skilled readers generate specific predictions based on sentence

context prior to the initial stages of word recognition, the process would constitute a *prelexical* influence of context on lexical access. The influence would be prelexical to the extent that expectations are formed before readers begin to process the word being predicted. By this account word predictability effects on eye movements during reading are driven by word prediction in an explicit sense.

To maximize the advantage of accuracy, each prediction would need to be expressed as an explicit lexical form with a corresponding orthographic and phonological code exclusive to the specific word. In situations when the upcoming word is accurately predicted, the expectation of a precise lexical form would offer obvious benefits for the stages of word recognition that require processing sublexical features. Presumably, cues provided by the comprehension process guide the selection of candidate words during any prelexical predictive process. Comprehension could also have the effect of spreading activation to lexical-semantic representations that are consistent with any semantic content in the prior context. When accurate, this form of expectation would constitute preactivation of a lexical-semantic representation based solely on contextual constraint. Either a mechanism of prediction would be an automatic component of the comprehension process or there would have to be an independent means of assessing any preceding context with regard to whether there is sufficient constraint to produce a prediction at any given moment. One important question for this account is the process by which such a prediction would be generated. Moreover, if a singular lexical prediction is the result of an explicitly predictive process, the degree to which perceptual input is evaluated with regard to alternative words is also an important consideration. Any word predictions would

need to result from a probabilistic evaluation of a large number of potential lexical candidates.

The typical benefit of such a prediction process in the task of comprehension may largely be contingent on the cost associated with an incorrect guess. If the sole task in prediction is to select one appropriate word among an extremely large number of potential competitors a considerable proportion of the predictions should turn out to be incorrect. The extent to which incorrect predictions could be useful would depend on the specific strategy involved in lexical prediction and how readers are informed by their prior experience with inaccuracy. For instance, if the goals of prediction involve learning general trends about predictive accuracy or learning which cues are the most informative in a prior context, incorrect guesses could be quite useful over the long term. Readers could also increase accuracy and overall processing benefits by learning how incorrect predictions tend to relate to encountered words. However, even if the online consequences associated with an incorrect guess are minimal, it is reasonable to assume an incorrect guess imposes some processing cost or recovery period. There is also no intuitive reason to assume that these kinds of lexical predictions would have high accuracy rates in natural language contexts. Furthermore, high prediction accuracy in the typical cloze task is only observed in contexts of sufficiently high constraint. Readers do well when predicting the next word in a sentence context, even when they are given unlimited time (McConkie & Rayner, 1976). It is also not clear what degree of constraint would be necessary to appreciably increase the likelihood of predictive accuracy.

This kind of strategy was a central component of early cognitive models of

reading (Goodman, 1967; Hochberg, 1978; Smith, 1971). The rationale of these accounts is that word recognition involves a relatively slow visual encoding process and readers can engage in a more rapid prediction process during the encoding period. However, research subsequent to the development of these models revealed that top-down prediction about upcoming words prior to the extraction of useful visual information from the parafovea is unlikely given the size of the perceptual span and the speed of visual encoding during reading (Rayner, Inhoff, Morrison, Slowiaczek, Bertera, 1981; Rayner, Liversedge, White, & Vergilino-Perez, 2003; Rayner, Liversedge, & White, 2006).

Interactive accounts

Taken together, findings have shown that the opportunity to produce a guess about the identity of the upcoming word based on prior context would not precede the availability of visual information about that word. Alternative accounts of word predictability effects have incorporated these findings by assuming that bottom-up visual cues and top-down contextual cues can jointly inform the construction of a guess for the identity of the upcoming word (Balota et al., 1985; Drieghe et al., 2005; McClelland & O'Regan, 1981); in this way a lexical prediction would be a hypothesis for evaluation but one that is established using perceptual information. Drieghe et al. (2005) described this potential process as an “educated guess” informed by contextual and parafoveal input. By this account, the guess for the upcoming word is produced during a stage of processing where readers have access to the word’s constituent

sublexical features (presumably in the parafovea). It is reasonable to assume that the processing of the letters of the upcoming word would not be held off for the purpose of constructing a prediction with contextual cues alone. The use of these expectations would then be a typical aspect of the word recognition process in reading. As such, these accounts of word predictability effects characterize the influence of context as *lexical* (i.e., impacting the process of lexical access) rather than prelexical. Under these accounts contextual constraint might directly modulate the speed and difficulty of word recognition. An important distinction is whether this kind of lexical prediction results in incomplete word processing based on partial visual information and prior context. The resulting influence might decrease the time or effort necessary for typical lexical access. Alternatively, contextual constraint might lower processing thresholds or decision criteria such that readers require less visual evidence before committing to a selection for word identity. This would be tantamount to an “educated guess” based on an incomplete analysis of a letter string (Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998; Drieghe, Brysbaert, Desmet, & De Baecke, 2004). Yet another, alternative interpretation assumes that comprehension of prior context serves to bias the processing system in some way that causes readers to misperceive letter sequences that are visually and orthographically similar to a predictable word form.

The finding that predictable words were skipped more often than less predictable words within the same sentence frame serves as evidence against proposed word guessing strategies wherein lexical predictions precede any substantial processing of the parafoveal word. If the decision to skip is made with little or no regard to the available parafoveal information, then no interactions of preview and

predictability should have been observed. However, this was not the case in either study manipulating orthographic preview information and contextual constraint (Balota et al., 1985; Drieghe et al., 2005). Instead, results were taken as evidence that highly predictable contexts generate circumstances wherein lower-quality parafoveal information is used to verify the identity of the initial letters which provides sufficient evidence to warrant skipping. Importantly, it is still unclear if word predictability effects on skipping are primarily driven by full word recognition.

Recent advances in computational techniques in psycholinguistics have led to the development of sophisticated models and accounts of human language comprehension. Namely, *surprisal theory*, introduced by Hale (2001), assumes that typical humans have a probabilistic model of their native language that is employed during language processing. This language model mediates incremental processing by generating probability distributions over possible interpretations of the current sentence until sentence comprehension is complete. The measure of surprisal for a word is the cost of updating this distribution at the increment when that word is incorporated. The surprisal of a word is equivalent to its relative entropy conditioned on its log-probability given a context (see Levy, 2008 for formal expression of relative entropy); thus, it is the log-ratio of the change in the distribution before and after the word is incorporated. The magnitude of the change in the distribution from one increment to the next represents the processing difficulty of an input (e.g., a word). Crucially, probabilistic expectancies provide a medium through which word predictability (and contextual constraint more broadly) takes effect; in this way many forms of constraint can influence word processing specifically through modulating a

word's predictability in context. Surprisal also offers an elegant solution to an intuitive problem addressed in the literature. According to the assumptions of surprisal, readers would not need to engage in independent word guessing strategies. Instead, readers engage in normal incremental sentence processing and probabilistic expectancies result as a natural and automatic byproduct of comprehension.

In a corpus analysis, Boston, Hale, Kliegl, Patil, and Vasishth, (2008) found that surprisal was a significant predictor of reading times, even when controlling for other predictors (chiefly, cloze proportions). These results suggest that surprisal theory has the potential to serve as a productive measurement of contextual constraint. Moreover, in general practice any probabilistic language model such as n -gram models, probabilistic context free grammar, or transitional probabilities could be used. Work in this domain suggests that readers, at the very least, generate expectancies at abstract levels, such as syntactic class. Moreover, under surprisal theory, skilled language users could have an even more robust probabilistic language model that specifies unique lexical items. In this framework, contextual constraint might restrict expectations to a single word (or small few) which could easily explain observed word predictability effects as a natural by-product of routine comprehension. Furthermore, the means by which a single word or small set of words would receive processing benefits in highly constrained contexts would, presumably, allow expectations to be expressed across a wider distribution of potential words in less constrained contexts. Thus, the surprisal framework can accommodate the findings of Smith and Levy's (2013) analysis demonstrating that the quantitative effect of word predictability on reading times is logarithmic and consistent across several orders of magnitude.

One important question for interactive accounts of word predictability effects in reading is the nature of lexical-semantic representations within the language processing system. Contrasting models of word recognition differ in how exactly lexical entities and their semantic entailments are represented. Word meanings might be internally represented as a pattern of activation across a network of semantic features (McClelland & Rumelhart, 1981; Seidenberg et al., 1996) or as discrete entries within a *lexicon*, a mental inventory of known words complete with constituent sublexical features (Coltheart et al., 2001; Fodor, 1983; Forster, 1979). These aspects of lexical representation will partly determine how lexical access is achieved, how lexical expectations expressed, and how closely predictions would map onto orthographic and phonological representations. Theoretically most models of visual word recognition can accommodate direct influences of linguistic context irrespective of mechanistic details regarding of how lexical items are represented and retrieved. Critically, according to these accounts word predictability effects arise through processing facilitation during word recognition.

Post-lexical accounts

The alternative class of accounts for word predictability effects in reading assume that word recognition processes are not influenced by sentence context. In principle, any strictly modular views of word recognition assume that any influences of sentence context must be post-lexical. This would also be the case if the process of word recognition is too rapid for typical influences from message-level

comprehension processes. It is possible that the automaticity of word recognition processes restricts opportunities for processes at distinct levels of representation to have an influence. This assumption has been a central characteristic for some accounts of word processing (Neely, 1977; Posner & Synder, 1975). These accounts were developed, in part, to characterize priming effects on response times for word naming tasks and lexical decision tasks, where subjects decide whether a string of letters is a word as quickly as possible. Studies demonstrated that response times in these tasks decreased when words were presented following sentence contexts in which the word was highly predictable or even merely semantically congruent when compared to presentation following neutral or incongruent sentence contexts (Fischler & Bloom, 1979; McClelland & O'Regan, 1981; Stanovich & West, 1979; West & Stanovich, 1983). A distinction between automatic and attentional processes with regard to word processing was a central component for these accounts. Lexical access was assumed to be an automatic process insensitive to top-down interference and unavailable for conscious reflection. Subsequent to lexical access, response times in word processing tasks could be affected by attentional processes that are sensitive to interference and make use of shared mental resources (e.g., working memory). These attentional processes are available for conscious reflection in some instances. Critically, interference at this stage was responsible for slowing reaction times on words that were inconsistent with a prior linguistic context. In this framework, contextual cues prompt inhibition and competition that increase the difficulty of processing less predictable words at some point after the word's meaning has been retrieved from long term memory.

There are crucial issues when attempting to apply these accounts to behavior during normal sentence reading where there is no need to prepare for an external motor or articulatory response task. During reading any detectable processing influences can only be observed as influences on eye-movement behavior. Moreover, accounts of word predictability effects that assume that prior context does not influence lexical access must explain the observed word predictability effects in reading exclusively through post-lexical integration and broader comprehension processes. By this account, word predictability mediates the ease of processing at stages subsequent to lexical access, such as reconciling the meaning of the specific word with the ongoing message-level interpretation, or reducing inhibition and competition at lexical-semantic levels of representation. If this is the case, the observed increases in first pass skipping rates as a function of word predictability were driven by post-lexical effects. One possibility is that word predictability increases the speed of post-lexical integration or influences an evaluation of how difficult integration will be after recognition. However, successful completion of post-lexical integration or even a signal of imminent completion both seem unlikely candidates as the criteria for the decision to move beyond a particular word (i.e. deciding to skip over a word during first-pass reading). Given the constraints imposed by the time required to program a saccade this assumption somewhat problematic considering the evident time frame of visual word recognition (Sereno & Rayner, 2000).

Unfortunately, there is no measure of eye movements during reading that constitutes a hard line between word recognition and integration processes. If there are influences of facilitation prior to the completion of lexical access or competition

and inhibition amongst words after lexical access, distinguishing the two potential sources is not a trivial task. As such, care must be taken when drawing inferences about internal processing stages based on behavioral measures of reading as there is no one-to-one correspondence with eye movements and lexical access. However, conflicting accounts of word predictability effects must be expressed as specific predictions for patterns of influence across the combination of first-pass and later reading measures.

Predictions for eye movement behavior

The central focus of the current thesis is the evaluation of word predictability accounts on word recognition. Therefore, the earliest eye-movement measure that is exclusive to a particular word in a sentence (i.e., first-pass skipping rate), will be an important dependent measure for each experiment. At whatever point the influences of contextual constraint arise, corresponding changes must be made to eye movement behavior for any benefits to be maximized. Otherwise, readers are left in a situation where some aspect of language processing is made considerably easier but the extra time or processing resources that result do not enable faster or more efficient reading. In order to avoid wasted effort, skilled readers must be ready to make use of word predictability when the focus of attention is in the parafovea, where the decision to fixate the word or skip the word must be made or in the fovea, where the signal to begin programming a new saccade must be made at some point.

For the purposes of this project, first-pass skipping rate was considered to be

the only reading measure that reflects word recognition and not post-lexical integration, while first-pass reading time was considered as a reflection of both word recognition difficulty and the ease of integration. Furthermore, it was assumed that integrative accounts predict that sizable effects should be observed in first-pass measures, whereas, relatively small effects should be observed in later reading measures. It was also assumed that post-lexical accounts predict that relatively small effects should be observed on first-pass measures, whereas, relatively large effects should be observed in later reading measures. Importantly, the rationale of the experiments assumes that first-pass skipping decisions are made based on the completion of lexical access, the knowledge that word recognition is imminent, or some other evaluation of lexical processing difficulty. The experiments below posit that post-lexical accounts also assume word predictability should not affect first-pass skipping rates. Across the pattern of eye movements, whether a word is skipped and how long readers tend to look at the word when it is fixated must be taken into consideration when examining later measures on the word. In each case, the presence of effects of context on early reading measures will be examined in conjunction with the later measures of regressive eye movements in order to investigate the pattern of effects across the full time-course of word processing.

More specifically, accounts of word predictability effects that posit word guessing or interactive word processing mechanisms assume that predictable words should be skipped more often than less predictable words. These accounts also predict processing facilitation for predictable words as measured by first-pass reading times. These effects might result from confirming explicit lexical predictions, lowering of

processing thresholds for predictable words, or alteration in some decision criterion during parafoveal word processing; in fact, none of these possibilities are mutually exclusive. Moreover, interactive accounts predict that the processing of sublexical features in the parafovea should be influenced directly by contextual constraint and the extent to which parafoveal input corresponds to predictable words. Importantly, these accounts also predict that any effects of contextual constraint are likely to interact statistically with the influences of sublexical and lexical features.

Post-lexical accounts of word predictability effects predict that skipping rates should not be strongly influenced by sentence context. According to these accounts, the decision to skip over a word is made based primarily on context independent factors that affect the completion of lexical-access. Thus, word predictability effects on skipping are less likely to be observed within post-lexical theories as compared to integrative accounts. However, word predictability effects should be observed on first-pass reading times and later measures. First-pass reading times reflect the difficulty associated with word recognition as well as higher-level integration (at least in part). Later measures of reading behavior reflect sentence comprehension processes more so than word recognition processes. In addition, according to post-lexical accounts, word predictability should be less likely to interact statistically with the influences of lexical and sublexical features that affect word recognition. In general, integrative accounts predict larger word predictability effects on first-pass skipping rates and reading times, whereas post-lexical accounts predict larger word predictability effects on first-pass reading times and later reading measures but not skipping rates.

The remainder of the thesis reports four studies of eye movements in reading for the purpose of evaluating two contrasting views of word predictability effects. Each experiment directly manipulated word predictability while controlling for the influences of other important lexical variables. Three of the four experiments used the invisible boundary paradigm to manipulate the information available about a word prior to direct fixation during reading. The boundary paradigm was used to present parafoveal previews that vary in similarity to the target across distinct dimensions (e.g., phonology and orthography). Experimental designs that contrast preview effects across several levels of sublexical consistency (rather than orthographically consistent being compared to orthographically inconsistent) might further illuminate the effects of context on eye movement behavior and adjudicate conflicting accounts of predictability effects in reading. Each experiment investigated the empirical effects of predictability on the processing of various sublexical features for a target word using the eye movement record. The final chapter presents an overview of the findings and considers the implications for theories and accounts of word predictability and sentence comprehension.

Chapter 2

Experiment 1

The task of distinguishing the broad accounts of word predictability effects must begin with focus on the earliest stages of word processing. The extent to which context has an influence on word recognition is a major division between contrasting theories of word predictability effects in reading. The current study examines the interaction of word predictability and the early stages of word recognition, which require processing of orthographic (letter) and phonological (sound) information. One theoretical position posits that word recognition is achieved through an exclusively bottom-up process that cannot be influenced by characteristics of the sentence context, as such, phonological and orthographic processing are unaffected by word predictability. The second theoretical position posits that word recognition can be achieved with the use of bottom-up information about the words' visual features as well as top-down information from long-term memory and the ongoing comprehension process, as such, phonological and orthographic processing can be affected by word predictability.

The earliest stages of word processing during normal reading take place before a word is directly fixated, while it is still in the reader's parafovea- the region of the visual field surrounding the fovea- where acuity is high enough to recognize letters and words, but at considerably reduced efficiency (Rayner, 1998). These initial stages of lexical processing involve the extraction of orthographic and phonological

information from the text as established by studies showing orthographic and phonological preview benefit on first-pass reading measures (Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995; Rayner, Pollatsek, & Binder, 1998).

It is important to note that writing systems are highly variable across languages. The writing system for the English language uses a deep orthography, meaning that there is a close but imperfect correspondence between letter sequences and the sounds they represent, a characteristic that can be exploited experimentally in order to dissociate orthographic and phonological processes. Using the boundary paradigm (Rayner, 1975), studies have shown phonological preview benefits distinct from those of orthographic preview benefits in neutral sentence contexts (Pollatsek et al., 1992; Chace et al., 2005). The findings showed that first-pass reading times were shorter following phonologically or orthographically consistent previews as compared to unrelated-letter previews, with more benefit obtained from phonological preview than from orthographic preview. For instance, reading times for a target word were faster following a phonologically consistent preview (e.g., *paced* as a preview for *paste*) than an orthographically consistent but phonologically distinct preview (e.g., *pared* as a preview for *paste*); moreover, reading times for the target word were faster following either phonological or orthographic previews when compared to unrelated (i.e., visually dissimilar) previews (e.g., *guilt* as a preview for *paste*). These studies show that both orthographic and phonological information are extracted from the parafovea during normal reading.

Studies have also demonstrated that predictability effects can be modulated by

the manipulation of parafoveal information (Balota et al., 1985; Drieghe et al., 2005). The decrease in first-pass reading times typically associated with word predictability was not observed when parafoveal previews were not orthographically consistent with the predictable word. Importantly, there have been inconsistent results in the effects of preview manipulations on predictable words. Balota et al. (1985) found increased skipping for highly predictable target words under full preview and orthographically similar nonword preview conditions when compared to orthographically dissimilar previews. However, using the same materials, Drieghe et al. (2005) found increased skipping only for highly predictable words under full preview conditions but not orthographically similar preview conditions. These conflicting results leave open questions regarding predictability effects on the parafoveal processing of letter strings consistent with predictable words. In addition, the extent to which the phonological preview benefit (independent of orthography) can be modulated by sentence context has yet to be examined directly.

Post-lexical accounts posit that the locus of word predictability effects is after lexical access has been completed. These accounts fall in line with modular word recognition models. Finding that word predictability influences first-pass reading times and later measures but not skipping rates would support post-lexical accounts by suggesting that contextual constraint influences post-lexical integration difficulty but not the difficulty of word recognition. Post-lexical accounts of word predictability effects also predict that parafoveal preview benefit will not be altered by contextual constraint. According to a modular view of word recognition, during the early stages of word recognition, the encoding of sublexical information from the parafovea should

be an inflexible process and not subject to influences from higher-level sentence comprehension processes. Critically, this type of staged architecture assumes that the influence of phonological processing during word recognition should be independent of the influence of word predictability. Post-lexical accounts predict that phonological preview benefit should not be mediated by sentence context in any way and there should be no interactions of word predictability and preview on any reading measure.

In contrast, interactive accounts posit that the process of lexical access is the locus of these effects, in that lexical access is easier for predictable words. Finding that predictable words are skipped more often than less predictable words would provide further evidence in support of integrative accounts by suggesting that sentence context can facilitate word recognition. Interactive accounts also predict that the processing of parafoveal information should be influenced by word predictability. A mechanism or strategy for word guessing would produce predictions that are faithful to the precise orthography of the full word form. If the prediction is selected sufficiently early, it can be used as a hypothesis for evaluating parafoveal information about the upcoming word. If this is the case, word predictability should mediate the processing of parafoveal words. The selection (or activation) of a fully-formed lexical prediction should involve expectation of a specific phonological structure (or a small number of phonological structures). If this is the case, phonological preview benefit would be affected by increasing contextual constraint for a word. However, the manner in which lexical prediction should influence preview benefits is not necessarily clear. Strong expectations for a particular word could reduce or eliminate phonological preview benefit insofar as preview strings do not adhere to the predicted

letter sequence. On the other hand, strong expectations for a fully-formed lexical form could increase the likelihood that any orthographically or phonologically consistent parafoveal input will be associated with the lexical-semantic representation for the predicted word. This would potentially enhance preview benefit of both orthographic and phonological previews. Importantly, given that previously demonstrated preview effects were not in predictable contexts, any facilitation of the recognition process might be obscured by ceiling effects. In general, interactions of word predictability and preview are more likely to be observed according to interactive accounts when compared to post-lexical accounts.

The current experiment systematically assessed the influence of word predictability on parafoveal preview benefits at orthographic and phonological levels of consistency between a given word and its parafoveal preview string. The invisible boundary paradigm (Rayner, 1975) was used to manipulate the phonological and orthographic information available for target words during parafoveal preview (e.g., *paste*, *paced*, or *packs* as potential previews of target word *paste*). When using the boundary paradigm, preview words or letter strings are replaced in the sentence with target words immediately prior to direct fixation on the target, such that the content of the reader's parafovea is restricted to the preview. After the boundary is crossed, the target is presented normally for the remainder of the trial. The letter string available to subjects prior to directly fixating is described as the parafoveal preview. Importantly, these display changes take place during saccades when visual uptake is effectively suppressed, thus, typical subjects are rarely, if ever, aware of the display changes. Critically the boundary paradigm allows for the manipulation of visual input during

earliest stages of word processing. Furthermore, the boundary paradigm makes it possible to influence word recognition processes without having subjects directly fixate nonwords or contextually inappropriate (preview) words. Target words were embedded in a high predictability context, wherein the target word would be easy to guess as a continuation of the sentence and in a low predictability sentence context, wherein the target word would be difficult to guess as a continuation of the sentence in its position (see Example 2.1 with target words in bold).

Example 2.1

High predictability Sentence: The digital file was so large that Ian had to copy and **paste** the text instead of typing it.

Low Predictability Sentence: Late last night, Ian went to the only open store to buy more **paste** for the project.

Three target word parafoveal preview conditions were used. Previews for target words were either identical to the target word (e.g., *paste*), a length-matched heterographic homophone of the target (e.g., *paced*), or a length-matched control word which was orthographically similar yet phonologically distinct from the target (e.g., *packs*). For exactly half of the critical items target words, their heterographic homophones, and orthographic-control words shared, at least, the first two letters (e.g., *paste-paced-packs*). These items were categorized as orthographically similar. For the other half of critical items, targets and homophones shared only one, or neither, of the

initial two letters, while the initial letters of the orthographic-control words were matched to the homophone. These items were categorized as orthographically dissimilar (e.g., *jeans-genes-genre*). Orthographic-control conditions were matched to homophone preview conditions (i.e. sharing at least the two initial letters) in terms of letter overlap, such that for any given item the orthographic-control preview and homophone preview were equally matched in how many letters each shared with the target word. In other words, orthographic similarity for the control preview was assessed with regard to the homophone preview word. This was done in order to control for any independent effects of orthography within the phonological preview effects.

Method

Subjects

Sixty-eight undergraduate students from the University of California, San Diego participated in the study. Subjects received class credit or \$10 per hour for their participation. All subjects were native speakers of English and were naive to the specific research questions and experimental manipulations.

Stimuli

Forty-two target words were used. These words ranged from 3 - 9 characters in length ($M = 4.8$, $SD = 1.2$). Lexical frequency measures were obtained from the HAL corpus (Lund & Burgess, 1996) via the English Lexicon Project (Balota et al. 2007).

Average (log-transformed) word frequency was 9.23 ($SD = 1.35$) for the critical words. This frequency measure is based on per 400 million counts, indicating that these words were high frequency on average. None of the critical items were function words. The mean word frequency for orthographic control preview words was 8.79 ($SD = 1.96$). Phonological preview words had an average frequency of 8.9 ($SD = 2.29$). The difference in the average word frequencies of the phonological preview and orthographic control preview was not significant, $t(82) = 0.24$. Similarly, the frequency of the target word did not differ significantly from either the phonological preview, $t(82) = 0.81$, or the orthographic control preview, $t(82) = 1.21$.

The average cloze proportion for target words in predictable contexts was 0.70 ($SD = 0.28$), while the average cloze proportion for target words in less predictable contexts was 0.01 ($SD = 0.02$). The cloze proportion for these two conditions differed significantly, $t(82) = 16.27$. The average position of the target word for high-word predictability sentences was 11.21 words into the sentence ($SD = 1.66$), and the average position of the target for low word predictability sentences was 10.83 words into the sentence ($SD = 1.66$). There was no significant difference in the position of the target word in the sentence between the two predictability conditions, $t(82) = 1.06$. The average length of the pretarget word in the low word predictability condition was 5.4 ($SD = 1.94$). The average length of the pretarget word in the high word predictability condition was 5.21 ($SD = 1.75$). The difference in the average pretarget word length in the two conditions was not significant, $t(82) = 0.48$.

Apparatus and procedure

Eye movements were recorded using an SR EyeLink 1000 eye-tracker sampling at 1000-Hz. Sentences were presented 60 cm from the subject on a 20-inch HP CRT p1230 monitor with a refresh rate of 150 Hz and display resolution of 1024 x 768 using 14-point Courier New font with one degree of visual angle equaling 2.4 characters. Head and neck movements were minimized via a head-rest and chinrest. Subject viewing was binocular but eye movements were only recorded from the right eye.

Prior to an initial calibration at the start of the experiment, subjects were instructed to read each sentence silently and answer the subsequent true-false comprehension question using a hand-held console. Critical sentences were preceded by 5 initial practice trials and presented in a randomized order mixed with 54 unrelated filler sentences. All 101 sentences were displayed from the left-center of the display screen in a randomized order for each subject (with the exception of initial practice trials). Each trial began with a fixation point at the left-center of the display screen. Once subjects fixated this point the calibration accuracy was validated. If calibration error was above 0.4 degrees of visual angle, the experimenter recalibrated before proceeding with the next trial. Immediately following the end of the experiment, subjects were asked a series of questions to ascertain whether they noticed any display changes. Any subject who reported noticing more than 4 of 28 total display changes during the debriefing was replaced prior to analysis.

Data Analysis

In the current study, measures of reading behavior associated with early word processing were investigated. First-pass reading measures included first-pass skipping rate (the average probability that a word does not receive a first-pass fixation during reading) and gaze duration or first-pass reading time (the sum of all fixations on a word during first-pass reading before moving off of the word to the left or right). Skipping rate captures whether the word was directly fixated during reading and if so, gaze duration reflects for how long. As word recognition for skilled readers is rapid and automatic, it should be noted that gaze duration is an index of both early and relatively late stages of lexical access, whereas first-pass skipping rate is an index of the earliest stages of word processing. Indeed, skipping rates are the earliest available behavioral index of processing for a particular word in a sentence.

Short fixations of 70 ms or below were merged with a fixation within one character distance. Any fixations of 70 ms or below that were not within one character of a longer fixation were eliminated prior to analysis. Long fixations of 700 ms above were eliminated prior to analysis. Trials in which the subjects blinked during first-pass reading for the target word, the word preceding the target word, or the word immediately after the target word were excluded prior to analysis. Trials in which the boundary was triggered at an inappropriate time were also excluded prior to analysis. Display changes took an average of 10 ms to complete from the initial triggering of the boundary to the completion of the display change. Three subjects were replaced after more than 40% of their data were lost due to these exclusions. Four subjects were replaced after reporting having seen more than 4 display changes during the

experiment. After these exclusions 25% of the subjects (15 of 60) reported noticing at least one display change during the experiment. After subject replacement, 8% of the data were lost by these exclusion criteria.

The data were analyzed with generalized linear mixed-effects models (LMM) using the lme4 package (version 1.1-7) (Bates, Maechler, Bolker, & Walker, 2014) within R statistical Computing software (R Development Core Team, 2014). Both subjects and items were entered into analyses as crossed random effects. Models were fit using the maximal random effects structure (Barr, Levy, Scheepers, & Tily, 2013). All continuous (i.e. numerical) variables were centered on their mean prior to analysis. For the analyses of gaze duration and go-past duration, regression coefficients (b) and standard errors (SE) are reported as estimates of effect size and corresponding t values are reported as indications of significance from linear regression models. For the analyses of first-pass skipping and regression rates, logistic regression models were used. For these measures regression coefficients (b) and standard errors (SE) are reported as estimates of effect size with z values as indicators of significance. When using mixed-effects regression models, t and z (absolute) values greater than 1.96 are considered significant at the .05 alpha level.

The effects of categorical predictors (e.g., orthographic similarity) were analyzed with sum coding contrast structures. As preview condition was a three-level factor, analysis of covariance was used for omnibus tests for main effects of preview condition and interactions across preview condition and all other predictors using subjects (F_1) and items (F_2) as random factors. This stage of analysis was included because of the increased likelihood of observing significant differences between factor

levels by chance alone when conducting multiple comparisons for a single factor. Linear mixed-effects models assessed preview effects by contrasting each preview condition to the full preview condition. Specifically, the full preview condition served as a baseline estimate of parafoveal preview benefits for phonological and orthographic control previews.

A recent analysis by Smith and Levy (2013) demonstrated that the effect of word predictability on reading times is logarithmic (meaning that the effect is linear in log-space). In keeping with this finding, log-transformed cloze proportions for target words in their respective sentence contexts were used to examine word predictability in the regression models. For this transformation, cloze proportions of zero were set to .001, which is a considerably lower proportion than having even one subject produce the target word as a response in standard cloze norming datasets. Patterns of significance across dependent measures were essentially identical when using categorical predictability condition or specific (log-transformed) cloze proportion as predictors.

Results

First-pass skipping rates on target word

The analysis of skipping rates revealed a main effect of word predictability such that target words in highly predictable contexts were skipped more often than in less predictable contexts, $b = 0.17$, $SE = 0.06$, $z = 2.77$. The omnibus test of preview condition did not reveal a significant main effect of preview condition. Preview

condition contrasts showed that full previews did not significantly differ from orthographic or phonological previews on skipping rates.

However, there was a marginal interaction of preview condition and target word predictability, $F_1(2, 59) = 2.34, p = .10$; $F_2(2, 40) = 2.39, p = .10$. As shown in Figure 2.1, the interactive pattern of predictability and preview was such that the increase in skipping rates for predictable target words was not observed in orthographic preview conditions, $b = 0.17, SE = 0.10, z = 1.69$.

There was also a marginal interaction of orthographic similarity, preview condition, and word predictability, $F_1(2, 58) = 2.45, p = 0.09$; $F_2(2, 40) = 2.39, p = 0.09$. Figure 2.2 displays skipping rates across target word predictability, preview, and orthographic similarity conditions. The contrast of orthographic control preview and full preview shows that, for orthographically similar items, skipping rates for orthographic control previews under low predictability conditions were higher than skipping rates for full previews under low predictability contexts, $b = -0.17, SE = 0.08, z = -2.11$. No such differences were observed for phonological previews and full previews conditions.

Gaze Duration on target word

Gaze durations across preview and predictability conditions are displayed in Figure 2.3. Word predictability showed a significant effect on gaze durations for the target word wherein words were read faster in highly predictable contexts than in less predictable contexts, $b = -10.07, SE = 1.97, t = -5.10$. The analysis of first-pass

reading time on the target word revealed a main effect of preview, $F_1(2, 58) = 9.43, p < .01$; $F_2(2, 40) = 9.77, p < .01$. Contrasts revealed a phonological preview benefit independent of orthographic preview benefit. Target words received shorter gaze durations following full previews than following orthographic previews, $b = -10.66, SE = 4.05, t = -2.63$. However, there was no significant difference in gaze durations for full previews and phonological previews, $t < -0.08$. There was no significant effect of orthographic similarity or interactions of similarity, all t 's < 1.1 , and preview condition, all F 's < 0.7 .

Supplemental Analysis

The marginal pattern of effects for preview condition on skipping rates was of theoretical interest. In general, interactions of preview condition and word predictability support interactive accounts of word recognition. However, there are no obvious theoretical interpretations that fall out of the marginal effects observed in Experiment 1. The marginal two-way and three-way interactions were characterized by appreciable changes in skipping behavior for orthographic control previews across sentence contexts. Overall, skipping rates for orthographic control previews were higher than expected given that they were chosen to have high letter overlap with phonological previews. If the relatively high skipping rates for orthographic previews (even in low predictability contexts) were driven by letter overlap (and hence confusability) with the target word, then skipping rates should have been near equivalent for phonological and orthographic control previews.

The marginal interactions observed in skipping rates might be driven by high variance in skipping behavior in general. Another possibility is that systematic differences in the intrinsic ease of processing words across the phonological and orthographic preview conditions are responsible for the skipping patterns. While there were no significant differences in mean lexical frequency for the words used as previews, there was more variability in phonological and orthographic preview words when compared to target words. Furthermore, while no target words were function words, some of the preview words were function words (e.g., *witch-which-where*).

In order to more closely examine the effect of preview words on skipping rates and first-pass reading time, a predictor reflecting the numerical difference in target word and preview log frequency was included in the analysis models for skipping rates and gaze durations. When the preview word was lower in frequency than the target word, this value was negative; when the preview word was higher frequency than the target, this value was positive. For full preview conditions this value was always zero.

Importantly, first-pass skipping rates were not significantly influenced by word frequency. Neither the aforementioned word frequency predictor nor a predictor reflecting the preview word's frequency showed significant influences on skipping behavior. While not changing any of the significant preview or predictability effects, the supplemental analysis models revealed a significant effect on gaze durations. As the frequency of the preview word increased relative to the target word, gaze durations increased, $b = 3.91$, $SE = 1.75$, $t = 2.23$. Likewise, when preview words were lower frequency than target words, the resulting gaze durations were shorter than when

preceded by a higher frequency preview. This effect was also observed when replacing the numerical difference between preview and target frequency with the preview word frequency in the analysis models. These findings demonstrate a processing cost such that higher frequency previews result in longer gaze durations (with no effect on skipping rates).

Given the marginal interactions of preview characteristics and word predictability, an analysis of a later reading measure was performed. There was no main effect of parafoveal preview condition on target word skipping rates. If it is assumed that skipping decisions are driven by word recognition (and hence lexical-semantic access) any consequences of skipping the target word under full preview conditions should be minimal, whereas, consequences of skipping phonological or orthographic previews should be observed when readers attempt to integrate the meanings of anomalous preview words into the ongoing message-level representation for sentence meaning. If there is a cost associated with skipping a contextually inappropriate word, it must arise in post-target word regions. Thus, an analysis of reading time on the word immediately following the target (i.e., the *post-target word*) was performed. The later reading measure used was *go-past duration*, the sum of all fixations beginning from the initial first-pass fixation in addition to all fixations subsequent to regressions into prior words in the text before the eyes move past the word to the right. Go-past duration captures the time spent re-reading prior text after initially fixating a particular word whereas regression rate captures the likelihood that a particular word is refixated after a reader has moved beyond its right boundary. If there is any processing difficulty associated with higher skipping rates it should be

revealed on this measure for the post-target word.

Go-past reading times for the post-target word are shown in Figure 2.4. There was a marginal effect of preview condition on go-past reading time on the post-target word, $F_1(2, 58) = 2.84, p = .06$; $F_2(2, 40) = 2.80, p = .06$, whereas the contrast of phonological preview and full preview did not reach significance. The analysis revealed longer go-past durations on the post-target word in conditions with orthographic previews for the target word when compared to full previews, $b = -36.27, SE = 17.84, t = -2.03$. There was also a marginal three-way interaction of preview, orthographic similarity of the preview, and word predictability, $F_1(2, 58) = 2.40, p = .09$; $F_2(2, 40) = 2.34, p = .10$. Contrasts suggested that word predictability and orthographic similarity had an interactive influence on the contrast of phonological preview and full preview conditions, $b = 24.07, SE = 11.20, t = 2.15$; furthermore, word predictability and orthographic similarity showed interactive effects in the contrast of orthographic control preview and full preview conditions, $b = -29.01, SE = 10.98, t = -2.64$. The combination of these interactions shows that there is a cost associated with the high skipping rates of contextually inappropriate words, particularly when those words do not share phonological consistency with the contextually appropriate word (as was the case for orthographic control previews). These analyses suggest that readers are sensitive to the processing difficulty induced by contextually inappropriate words in a way that results in longer reading times and more regressions into the preceding text.

Discussion

The results of Experiment 1 showed that predictable words were skipped more often during first-pass reading than the same words in less predictable contexts. There were also a number of marginal interactions involving preview condition and word predictability on first-pass skipping rates; the marginal interactions suggest that word predictability and orthographic similarity to the target word have appreciable influences on skipping rates for orthographic control previews but not for phonological previews. The pattern of effects on skipping could be taken as evidence that high predictability contexts reduce the likelihood of skipping orthographic previews, but the pattern also suggests that orthographic previews are skipped quite often in both word predictability conditions. It could be the case that the specific set of words used as orthographic control previews are more likely to be skipped in neutral contexts because of differences in some unmeasured lexical characteristics (particularly for the set of orthographically similar items).

Regardless of exact interpretation, the interactions of preview and word predictability are more consistent with interactive than with post-lexical, modular accounts of word recognition during reading. The increased skipping rates for full and phonological previews due to higher word predictability are directly predicted by interactive accounts. In contrast, post-lexical accounts require additional assumptions in order to explain how predictability could affect skipping rates when the parafovea does not contain recognizable words that differ in the ease with which they can be integrated into an ongoing message-level representation. Beyond suggesting that word predictability influences early stages of word recognition, the current results raise

questions about how exactly context mediates the use of parafoveal letter information when making decisions about whether to fixate the upcoming word during reading.

The first-pass reading time results for Experiment 1 were more straightforward than the skipping results. Phonological preview benefit was found over and above the benefit of orthographic consistency with the target. The phonological preview benefit was also maintained across the two word predictability conditions. Critically, preview benefit was not diminished by increasing word predictability, as shown by the lack of interactions of previews and predictability on gaze durations. Words in predictable contexts were still read more quickly than in less predictable contexts when they were preceded by a phonological or orthographic preview.

The supplemental analysis of go-past durations on the post-target word indicated that there was a higher cost associated with orthographic control previews than phonological previews. These findings suggest that orthographic and phonological consistency between the preview and target can influence processing difficulty, but there seems to be a general cost associated with presenting contextually inappropriate words as previews. Critically, this pattern of preview effects on later measures was mediated by word predictability, which lends general support to interactive accounts of word predictability effects. The supplemental analysis also revealed significant effects of word frequency on the parafoveal preview manipulation. Frequency of the parafoveal preview word exerted an influence on first-pass reading times but not first-pass skipping rates.

Failure to observe significant preview word frequency effects notwithstanding, the lexical status of the preview string could have influenced the

results. The word-level influences of the preview potentially complicate interpretation of orthographic and phonological preview effects as they relate to contextual constraint. These potential confounds can be avoided by using nonword previews which do not have intrinsic lexical characteristics. More to the point, nonwords do not have any semantic and syntactic entailments that might distort the assessments of processing influences related to sublexical consistency between previews and targets.

The overall pattern of skipping rates across preview conditions and the mediation from sentence context do not have an obvious interpretation with respect to distinguishing word predictability accounts. Importantly, skipping rates were not significantly influenced by target word frequency. However, if the pattern of skipping effects across conditions was driven by other lexical characteristics (independent of phonology and orthography), the use of nonword previews should alter or eliminate the skipping effects observed in Experiment 1.

The results of Experiment 1 cast doubt on post-lexical accounts of word predictability effects. The observed interactions of preview condition and word predictability are predicted according to interactive accounts but not post-lexical accounts. Furthermore, the distribution of interactive effects across early and later measures of eye movement behavior suggest that the influence of sentence context on the processing of information obtained during parafoveal preview has an impact on the full time course of word processing.

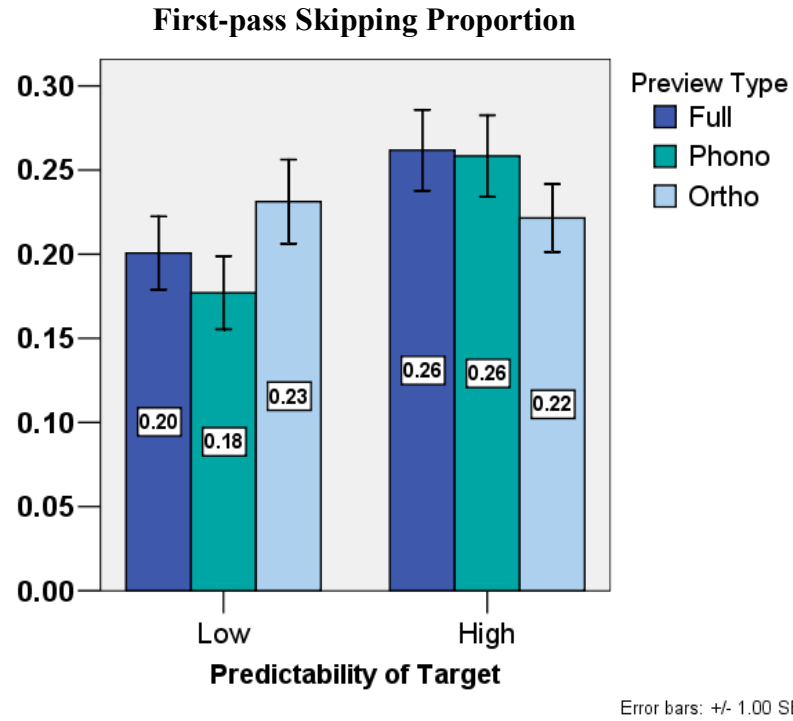


Figure 2.1 – Average first-pass skipping rates for target word across preview and predictability conditions.

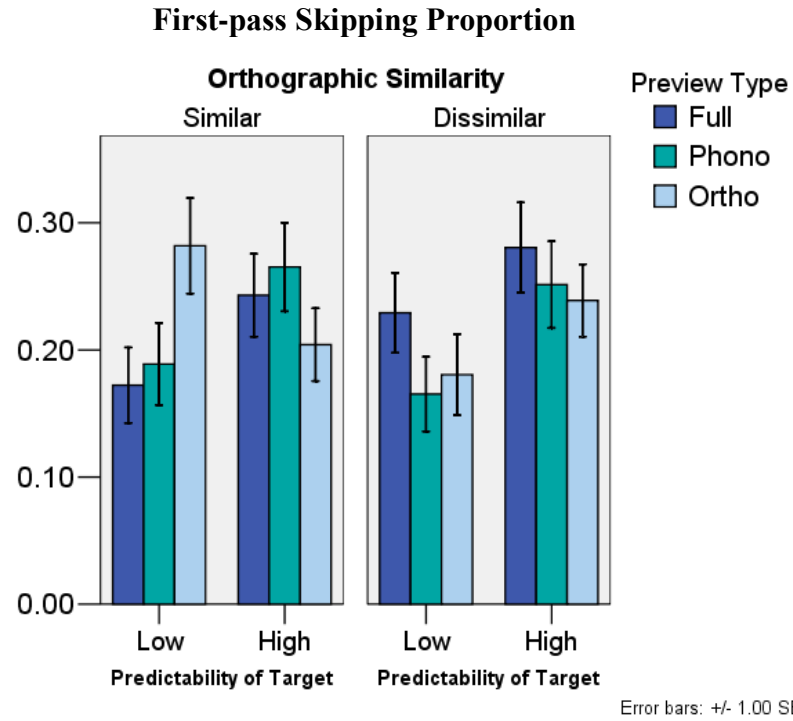


Figure 2.2 – Average first-pass skipping rates for target word across preview, similarity, and predictability conditions.

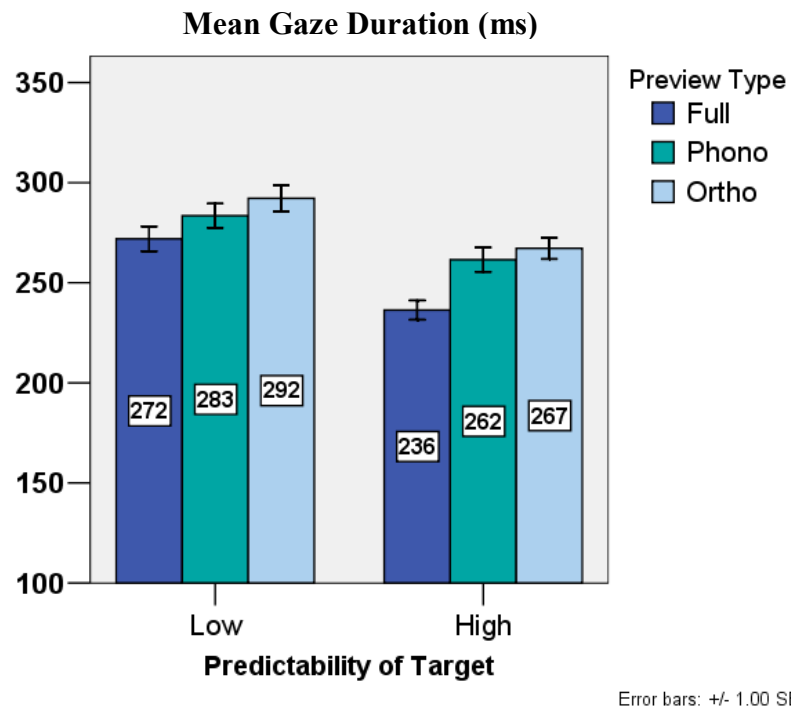


Figure 2.3 – Average gaze durations for target word across preview and predictability conditions.

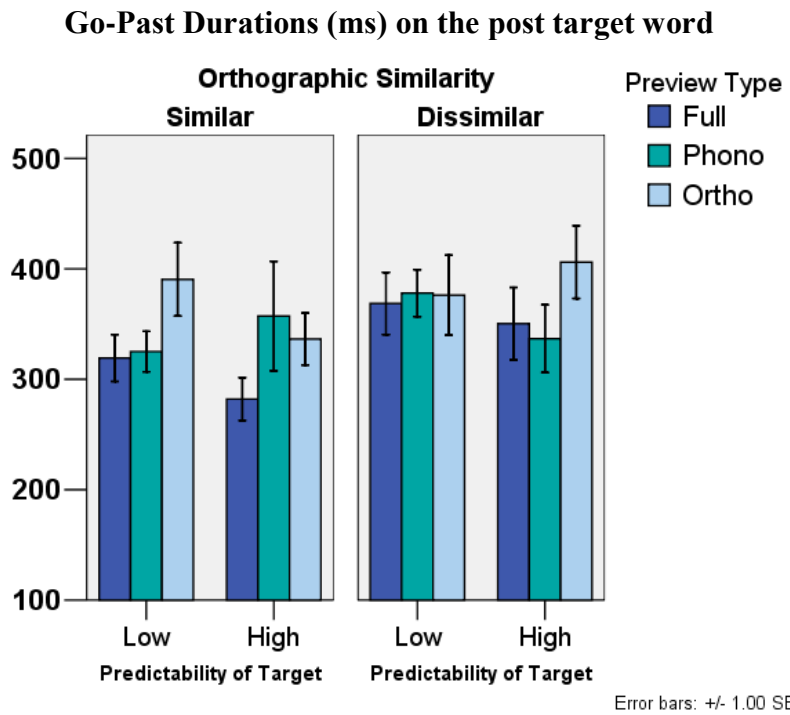


Figure 2.4 – Average go-past durations (ms) for post-target word across preview, similarity, and predictability conditions.

Chapter 3

Experiment 2a

Experiment 2a further examined the effects of word predictability on orthographic and phonological processing using the boundary paradigm. In this experiment, target words were relatively short (4 – 6 characters), because short words are more likely candidates for first-pass skipping (Brysbaert, Drieghe, & Vitu, 2005; Rayner & McConkie, 1976; Rayner, Sereno, & Raney, 1996). An increase in overall target word skipping that should accompany the use of shorter words provides an opportunity to further investigate the effects observed in Experiment 1 with regard to first-pass skipping rates.

This study was also designed to permit an investigation of the interaction of parafoveal information and sentence context on decisions readers make about whether to fixate a given word in text. It has been shown that, due in part to visual acuity limitations, the ability to reliably recognize letters and words rapidly decreases across the visual field (see Rayner, 2014 for review of the perceptual span during reading). The use of relatively short target words should increase the likelihood that subjects receive high-fidelity previews of the entire parafoveal letter string (i.e. complete phonological and orthographic codes). Short words are more likely to have all corresponding letters in the region of the parafovea during the time in which readers typically obtain preview benefits for words prior to direct fixation (or the decision to skip). Using a set of shorter target words should increase the number of instances

where a reader could potentially extract a complete phonological code for the parafoveal letter string, providing more opportunities to examine the respective influences of phonology and orthography on skipping as well as any interactive influences of word predictability.

The exclusive use of relatively short words also permits an examination of orthographic neighborhood size, the total number of words that can be obtained by substituting exactly one letter for a given word. Slattery (2009) conducted a reading study of orthographic neighborhood and sentence context effects. The results of the experiment indicate that words in unconstrained contexts can be misperceived as their higher frequency orthographic neighbors, as shown by inflated reading times and increased rates of refixation compared to control words without high frequency neighbors. Presumably, large orthographic neighborhoods increase the difficulty for some stages of word processing due to increased uncertainty regarding the identity of any letter string with a relatively high number of lexical candidates. The processing difficulty induced by orthographic neighborhood characteristics was eliminated when words were presented in a sentence context that constrained for the target word but not for its high frequency neighbor. These results suggest that characteristics of a message level representation can lessen or eliminate completely uncertainty about orthographic information.

The influence of orthographic neighborhood size may provide a means for evaluating various accounts of word predictability effects. These influences could arise as competition during word recognition or after recognition has been completed (or even during both time periods). To the extent that word predictability through

contextual constraint facilitates processing at any stage, smaller processing costs associated with neighborhood size should be observed for predictable target words. According to interactive accounts, elimination of processing difficulty should be observed on skipping rates. Contrastingly, according to post-lexical accounts, elimination of processing difficulty should not be observed on skipping rates (as skipping is a measure of early but not late word processing).

In Experiment 2a, the effects of sentence context on first-pass skipping rates, first-pass reading times, and indices of later processing difficulty were evaluated across preview conditions in conjunction with orthographic neighborhood size effects. As preview benefits are intrinsically intertwined with the initial processing stages of word recognition during reading, interactions of preview and sentence context were of particular interest. According to post-lexical accounts, the effects of contextual constraint and word predictability result from facilitation of post-lexical integration processes. These views predict that first-pass skipping rates should be unaffected by contextual constraint, and furthermore, the pattern of preview effects across first-pass and later measures should be identical across sentence context conditions. This is because the denial of valid preview information and the potential disruption of early processing should not differ as a function of sentence context.

According to interactive accounts of word predictability effects, the effects of contextual constraint and word predictability result, at least in part, from facilitation of lexical access. These views predict that first-pass skipping rates should be influenced by contextual constraint, as it is assumed word skipping reflects the ease of word recognition but not lexical integration. Interactive accounts also assume that word

predictability can influence the processing of parafoveal information about a word. Importantly, how word predictability should impact parafoveal preview benefit is not necessarily clear. Word predictability effects in reading could be driven primarily by inhibition or facilitation (or some combination of the two). If well-defined expectations for a particular word are produced, it is reasonable to assume that any letter string that does not stringently conform to the lexical prediction might incur some processing cost due to inhibition of less predictable letter sequences. Under these circumstances, phonological and orthographic preview benefit should both be reduced for highly predictable words; more precisely, only the full preview for a word will elicit parafoveal preview benefit. If contextual constraint drives expectations for specific phonological structures (independent of orthography), word predictability should result in the enhancement of phonological preview benefit but not orthographic preview benefit. Furthermore, orthographic previews should only offer benefits to the extent that they are phonologically consistent with the target. Given that the target words for Experiment 2a were relatively short, phonological distinctions across preview conditions should be relatively easy for readers to detect. However, expectations for explicit lexical form or changes in expectations across many words might increase the likelihood that phonologically or orthographically consistent preview strings are associated with predictable words, thus enhancing both phonological and orthographic preview benefit. Despite a range of possibilities, these accounts all predict that word predictability should interact with target word preview on first-pass or later reading measures.

In Experiment 2, as in Experiment 1, target words were embedded in highly

predictable or less predictable sentence contexts (see Example 3.1 with target word in bold). The boundary paradigm was also used. Experiment 1 used heterographic homophones and orthographically-matched control words to establish preview manipulations. One critical difference for Experiment 2a (and 2b) was the use of nonword letter strings to manipulate target word preview conditions. The use of nonwords ensured that no intervening influences of lexical characteristics could drive preview effects or interactions with sentence context (as was a possibility in Experiment 1). Experiment 2a evaluated the influence of context on sublexical processing in the parafovea without the imposition of discrepancies between previews and targets at the lexical level.

Example 3.1

High predictability Sentence: Jill left Susie a message because she did not answer her **phone** when she called Sunday.

Low predictability Sentence: Jill left the house without realizing that she did not have her **phone** in case someone called.

Experiment 2a involved four preview conditions: a full preview condition wherein the target word was presented for the entire trial (e.g., *phone*), a phonological preview condition using a pseudo-homophone of the target word (e.g., *phoan*), an orthographic-control preview condition (e.g., *pohan*), and an unrelated letter preview condition (e.g., *ghaun*). Orthographic-control previews were created by transposing internal letters of the pseudo-homophone preview to construct a pronounceable

nonword letter string with consistent orthography but distinct phonology. The unrelated letter previews were included to establish a comparison condition for the evaluation of orthographic preview benefit independent of phonological structure.

Method

Subjects

Fifty-one subjects from the University of California, San Diego campus community participated in the experiment for undergraduate class credit or \$10 per hour. All subjects were native speakers of English and were naive to the goals of the research project. Subjects were debriefed after completing the study.

Stimuli

Seventy-two target words were used. Table 3.1 displays average lexical characteristics for the target words. Target words ranged from 3 – 6 letters in length, with only one three-letter target word (*key*) and three six-letter target words. Target words ranged from relatively low in frequency (e.g., *thief & cider*) to relatively high in word frequency (e.g., *first & work*). None of the targets were function words. Lexical characteristics for target words were obtained from the SUBTLEX (US) Corpus (Brysbaert & New, 2009) via the English Lexicon Project (Balota et al., 2007). The SUBTLEX Corpus provides log-transformed frequency based on the raw number of occurrences (out of 51 million total words). The target words were specifically selected to encompass a wide range of orthographic neighborhood sizes, ranging from 0 – 19 in total.

The boundary paradigm was used to manipulate target word parafoveal preview during reading. Phonological, orthographic, and unrelated letter previews were always nonword letter strings. Unrelated letter previews were matched in rough visual similarity with the target, such that ascending and descending letters were replaced with ascenders and descenders, respectively. In cases where pronounceable nonwords could not be constructed under these restrictions, unrelated preview shape was matched with the phonological preview letter sequence. All nonword previews were constructed to be pronounceable (i.e., orthographically legal) letter strings that adhere to conventional restrictions for letter sequences in English. All previews were matched in character length with the target word and were designed to be pronounceable.

In addition to the established preview manipulation the target words were split into item groups based on specific aspects of the preview manipulation, namely, letter overlap. The 32 items wherein the phonological preview was created by transposing or substituting 1 - 2 letters of the target word were classified as *high letter overlap* items (e.g., *first - first*). The 40 items where phonological previews were created by transposing or substituting more than 2 letters of the target word were classified as *low letter overlap* items (e.g., *tube - toob*). The lexical characteristics of the low and high letter overlap groups are displayed in Table 3.2. There were no significant differences between lexical characteristics in the two groups (all t 's < 1.47).

Target words were embedded in high or low predictability sentence contexts. The average length of the word preceding the target word (pretarget word) in high predictability sentence contexts was 4.9 characters ($SD = 2.1$). The average length of

the pretarget word in low predictability contexts was 5.0 characters ($SD = 1.9$). Word frequency for the pretarget word was matched across high and low predictability contexts with log-transformed frequencies of 4.04 ($SD = 1.28$) and 3.93 ($SD = 1.18$), respectively. The average position of the target word within high predictability sentences was 11.9 words into the sentence ($SD = 1.7$) and the average position of target words within low predictability sentences was 11.5 words into the sentence ($SD = 1.68$). The difference in average target word position across predictability conditions was not significant, $t(142) = 1.56$. Forty UCSD undergraduates (who did not participate in the eye tracking experiment) completed the standard modified cloze task to confirm the predictability manipulation. The average cloze proportion for target words in high predictability sentences was 0.80 ($SD = 0.15$), whereas the average cloze proportion for target words in low predictability sentences was 0.02 ($SD = 0.03$); this difference was significant, $t(142) = 41.61$. The standard threshold for “high predictability” using the cloze task is 0.70, indicating that these items instantiate a very strong manipulation of word predictability. There were no significant differences between low and high predictability sentence contexts for target word position in the sentence frame, pretarget word length or pretarget word frequency. Furthermore, average cloze proportion, target word position in the sentence, and pretarget word length and frequency for high letter overlap and low letter overlap words did not differ with respect to high or low predictability conditions (all t 's < 1.23).

Apparatus and Procedure

The presentation apparatus was the same as in Experiment 1. Subjects read 112 total sentences for the experiment preceded by 3 practice trials. After the practice

trials, all sentences were presented in a randomized order for each subject. Subjects were required to answer Yes/No comprehension questions after 30% of the critical trials. On average, subject accuracy on the comprehension questions was near ceiling, indicating the subjects were reading for comprehension. The instructions given to subjects and the procedure for checking calibration accuracy between trials were the same as Experiment 1. Immediately following the end of the experiment, subjects were asked a series of questions to ascertain whether they noticed any display changes. Any subjects who reported noticing more than 4 display changes were replaced.

Data Analysis

In the current study, measures of reading behavior associated with early and later word processing were investigated. As with Experiment 1, the measures of early word processing were first-pass skipping rate (the average probability that a word does not receive a first-pass fixation during reading) and gaze duration (the sum of all fixations on a word during first-pass reading before moving off of the word to the left or right). The eye movement measures of later word processing included go-past duration on the target word (the sum of all fixations from the initial first-pass fixation and all subsequent fixations until the eyes move past the word to the right) and regression rate (the probability of a word being fixated after the eyes have moved beyond the word during first-pass reading). Again, go-past durations capture the time spent re-reading prior text after initially fixating a particular word whereas regression rate captures the likelihood that a particular word is refixated after a reader has moved

beyond its right boundary. These two measures are generally thought to index processing difficulty associated with post-lexical integration of word meaning into sentence contexts (see Rayner, 1998, for review of these and other informative eye movement measures).

The data for Experiment 2a were analyzed using the same method as in Experiment 1, with exceptions detailed below. The analysis models included fixed effects for target word predictability, preview condition, letter overlap group, and target word orthographic neighborhood size. Random effects structures for the analysis models were the same as in Experiment 1. For the analyses of gaze duration and go-past duration, linear regression models were used in the same way as in Experiment 1. Logistic regression models were used for the analyses of first-pass skipping and regression rates. Reporting of effect sizes and estimates of significance were the same as in Experiment 1. The analysis of target word predictability and the structure of the preview contrasts were the same as Experiment 1, except that full preview conditions were also compared to unrelated letter preview conditions (which were not present in Experiment 1).

Short fixations of 60 ms or below were merged with a fixation within one character distance. Any fixations of 60 ms or below that were not within one character of a longer fixation were eliminated prior to analysis. Long fixations of 600 ms above were eliminated prior to analysis. (Based on inspection of raw eye movement data from Experiment 1, fixation exclusion criteria were selected prior to data collection for all subsequent experiments). Trials in which the subjects blinked during first-pass reading for the target word, the word preceding the target word, or the word

immediately after the target word were excluded prior to analysis. Trials in which the boundary was triggered at an inappropriate time were also excluded prior to analysis. Display changes took an average of 8 ms to complete from the initial triggering of the boundary to the completion of the display change. Eighteen percent of the subjects (9 of 48) reported noticing at least one of the 54 total display changes during the experiment. Three subjects were replaced after reporting that they noticed more than 4 display changes. After all exclusion criteria and subject replacement, a total of 19% of the data were excluded.

Results

First-pass target word skipping

Target word skipping rates across preview and word predictability conditions are shown in Figure 3.1. The omnibus test revealed a significant main effect of preview condition for the target word, $F_1(3, 45) = 4.94, p < .01$; $F_2(3, 69) = 4.96, p < .01$. Target words were skipped more often under full preview conditions when compared to unrelated preview conditions, $b = 0.20, SE = 0.09, z = 2.26$, whereas phonological and orthographic previews did not significantly differ from full previews. The main effect of word predictability on first-pass skipping did not reach significance.

Target word preview condition showed a marginal interaction with letter overlap group, $F_1(3, 45) = 2.21, p = .08$; $F_2(3, 69) = 2.19, p = .09$. Contrasts showed that for low letter overlap items, skipping rates for orthographic preview conditions were lower than full preview conditions, $b = 0.21, SE = 0.09, z = 2.46$, however, this

was not the case for items that had high orthographic overlap. There was also a significant three-way interaction of word predictability, letter overlap group, and orthographic neighborhood size, $b = 0.02$, $SE = 0.01$, $z = 2.08$. The interaction is shown in Figure 3.2 based on a median-split of orthographic neighborhood size across the target words. The pattern shows that the effect of word predictability was larger for low letter overlap items when compared to high letter overlap items. This pattern was observed only for target words with large orthographic neighborhoods.

Gaze duration on target word

Gaze durations across preview and predictability conditions are displayed in Figure 3.3. There was a main effect of target word predictability such that high predictability words received shorter first-pass reading times than low predictability words, $b = -7.32$, $SE = 1.75$, $t = -4.19$. There was also a main effect of preview condition on first-pass reading, $F_1(3, 45) = 18.61$, $p < .01$; $F_2(3, 69) = 18.73$, $p < .01$. Gaze durations in full preview conditions were significantly shorter than gaze durations following unrelated previews, $b = -18.20$, $SE = 2.94$, $t = -6.19$, and marginally shorter than orthographic control previews, $b = -5.77$, $SE = 3.10$, $t = -1.86$. Gaze durations in the phonological preview condition did not differ significantly from gaze durations in the full preview condition, $t = 1.70$. Taken together, these contrasts revealed a phonological preview benefit over and above that of orthographic preview benefit.

There was an interaction of preview condition and word predictability on gaze duration, $F_1(3, 45) = 3.57$, $p < .05$; $F_2(3, 69) = 3.47$, $p < .05$. Contrasts revealed that

the difference between gaze durations under full preview and unrelated letter preview conditions was larger for high predictability words, $b = -6.54$, $SE = 2.49$, $t = -2.63$. In other words, the decrease in first-pass reading time associated with high word predictability was eliminated when preview letter string was not phonologically or orthographically consistent with the target word. Crucially, this elimination of word predictability benefits was not observed for any other preview condition.

There was also a three-way interaction of letter overlap, preview condition, and orthographic neighborhood size, $F_1(3, 45) = 2.58$, $p = .05$; $F_2(3, 69) = 2.72$, $p < .05$. Contrasts revealed that for high letter overlap items, the difference in gaze durations under unrelated letter preview conditions and full preview conditions increased as orthographic neighborhood sizes decreased, $b = -1.34$, $SE = 0.70$, $t = -1.96$. No other preview contrasts interacted with orthographic neighborhood size on first-pass reading time.

Later measures of target word processing

There was a main effect of word predictability on go-past durations for target words. Go-past durations were significantly shorter for words in highly predictable contexts, $b = -15.68$, $SE = 4.02$, $t = -3.90$. There was also a main effect of parafoveal preview condition, $F_1(3, 45) = 14.97$, $p < .01$; $F_2(3, 69) = 15.12$, $p < .01$. Target words preceded by unrelated letter previews showed longer go-past durations than target words preceded by full previews, $b = -32.04$, $SE = 7.53$, $t = -4.26$. No other preview contrasts showed significant differences.

For regression rates into the target word there was a main effect of target word

predictability. Readers regressed back into highly predictable words less often than into less predictable words, $b = -0.12$, $SE = 0.06$, $z = -2.01$. There was also a main effect of preview condition, $F_1(3, 45) = 2.80$, $p < .05$; $F_2(3, 69) = 2.77$, $p < .05$. Unrelated previews resulted in higher regression rates when compared to full previews, $b = -0.29$, $SE = 0.12$, $z = -2.46$, but no other preview contrasts were significant. There was a marginal interaction of preview condition and letter overlap, $F_1(3, 45) = 2.49$, $p = .06$; $F_2(3, 69) = 2.46$, $p < .06$. There was an increase in regression rates back into the target word following phonological previews, but only for items that had low letter overlap, $b = -0.21$, $SE = 0.10$, $z = -2.12$; on the other hand, there was a marginal increase in regression rates following orthographic previews, but only for items that had high letter overlap, $b = 0.19$, $SE = 0.10$, $z = 1.79$. No other interactions with preview condition were observed in the omnibus test. Taken together, the effects across later reading measures demonstrate that a lack of sublexical consistency between target words and preview strings prompts downstream processing difficulty.

Discussion

The results of Experiment 2a, as in Experiment 1, revealed interactions of word predictability and parafoveal preview condition. As such, the results of both experiments lend more support to interactive accounts of word predictability effects than to post-lexical accounts. Interactive accounts posit that word predictability might mediate the impact of phonological and orthographic information on first-pass skipping and first-pass reading times. Interestingly, the effect of word predictability

on first-pass skipping was contingent on letter overlap between preview and target, and was also mediated by orthographic neighborhood size. Critically, the word predictability effect on first-pass reading time was eliminated when predictable target words were replaced by unrelated letters during parafoveal preview, but not when replaced by phonological or orthographic control previews.

Furthermore, these findings suggest that word predictability effects are not exclusively mediated by all-or-none lexical predictions. If word predictability arises strictly through a reader's ability to verify a specific lexical prediction using parafoveal letter input, the relative utility of phonologically or orthographically consistent previews should have been diminished by high contextual constraint, as these preview conditions were not entirely consistent with the spelling of the predictable word. Instead, word predictability facilitated processing for predictable target words as well as letter strings that share phonological and orthographic information with the predictable word. Thus, the effects of word predictability appeared to be facilitatory rather than inhibitory. As with target word skipping results, these findings suggest that contextual constraint leads to processing benefits for a wide range of visual input, so long as those sublexical features are consistent at some level with the target word.

These interactions involving letter overlap group did not clearly fall in line with any account of word predictability effects. While interactions involving orthographic neighborhood size and word predictability were observed on first-pass skipping rates, they do not offer clear support for either account of word predictability effects. Furthermore, effects of orthographic neighborhood were contingent on letter overlap between the target and preview. Importantly, the interactive effects were not

contingent on preview condition, so the results could be driven by unmeasured differences across target word groups.

Experiments 1 and 2a both revealed consistent differences in how distinct eye-movement measures, associated with different stages of language processing, were affected by contextual constraint. There was no clear advantage of phonological over orthographic previews for first-pass skipping rates. However, there was an advantage of phonological over orthographic previews for first-pass reading times. Later reading measures revealed a clear advantage for both valid previews over and above unrelated letter previews. Moreover, conditions under which nonwords or contextually inappropriate words were skipped during first-pass reading generally corresponded to higher regression rates back into the target region. Crucially, the combination of skipping rates and later reading measures suggest that decisions to skip over words during first-pass reading are influenced by evaluations of word recognition difficulty. The findings indicate that when nonwords or contextually illegal words are encountered in the parafovea, the extent to which they can be associated with a contextually appropriate word has an impact on whether readers will decide to fixate the letter string directly. When words do receive direct fixation, the relationship between the preview string and target word, and potentially the ease of integrating parafoveal and foveal input during word processing, influence how long readers fixate before moving their eyes.

The findings of Experiment 2a cast doubt on post-lexical accounts of word predictability effects. According to these views, the influences of parafoveal preview condition should not be mediated by word predictability. The interactions of preview

condition and word predictability are more likely to appear in the eye-movement record according to interactive accounts of word predictability effects. Relatively short target words were used for Experiment 2a in order to increase skipping rates overall and more closely examine how preview and sentence context influence skipping rates. While the results on first-pass skipping suggest that a word's predictability in context and the size of its orthographic neighborhood are both important factors for skipping decisions, ultimately, the findings do not clearly distinguish post-lexical and interactive accounts of word predictability effects. However, the interactions observed on first-pass reading time demonstrate that word predictability effects are driven (at least in part) by contextual mediation of parafoveal preview benefit. These findings suggest that word predictability does in fact influence the early stages of orthographic and phonological processing necessary for word recognition.

Table 3.1 – Lexical characteristics of Experiment 2a target words. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Mean	4.44 (0.6)	3.31 (0.68)	6.99 (4.66)
Range	3 - 6	6.4 - 13.2	0 - 19

Table 3.2 – Lexical characteristics of Experiment 2a letter overlap groups. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Low letter overlap	4.45 (0.55)	3.36 (0.75)	7.70 (3.94)
High letter overlap	4.44 (0.67)	3.28 (0.64)	6.09 (5.36)

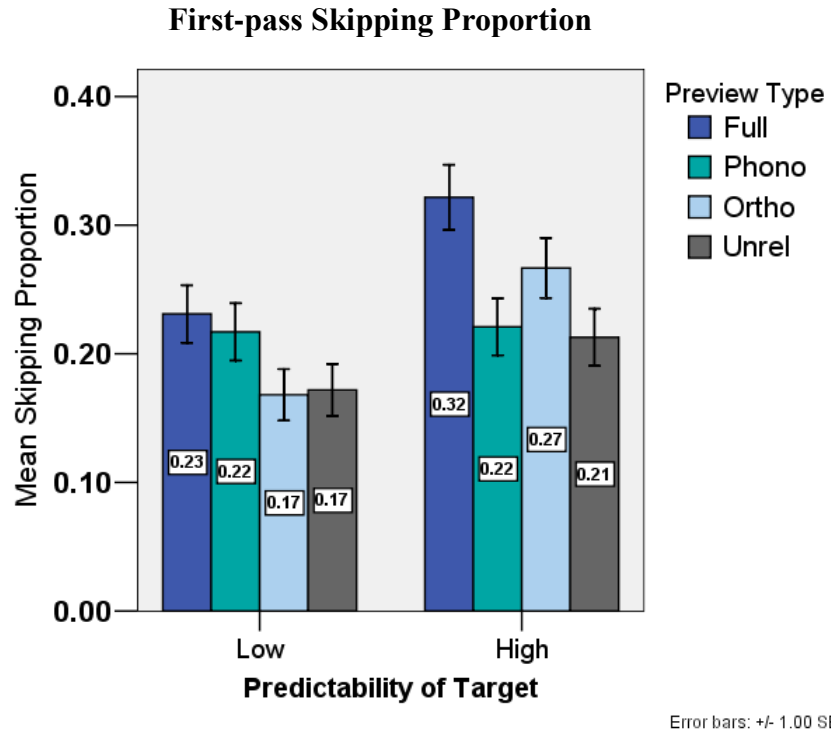


Figure 3.1 – First-pass skipping rates on the target word across word predictability and preview conditions.

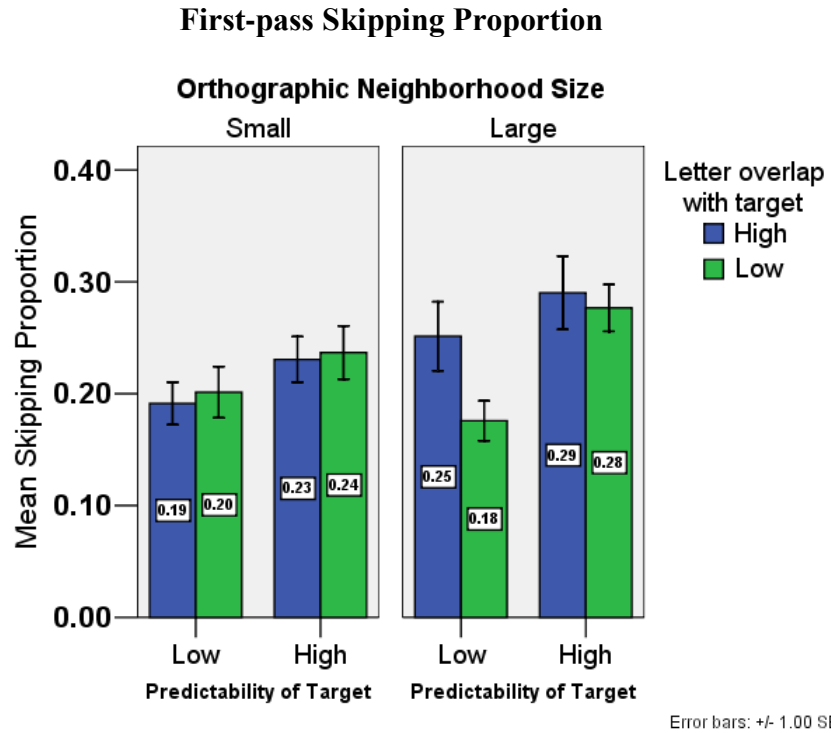


Figure 3.2 – First-pass skipping rates on the target word across word predictability condition and orthographic neighborhood size for high and low letter overlap.

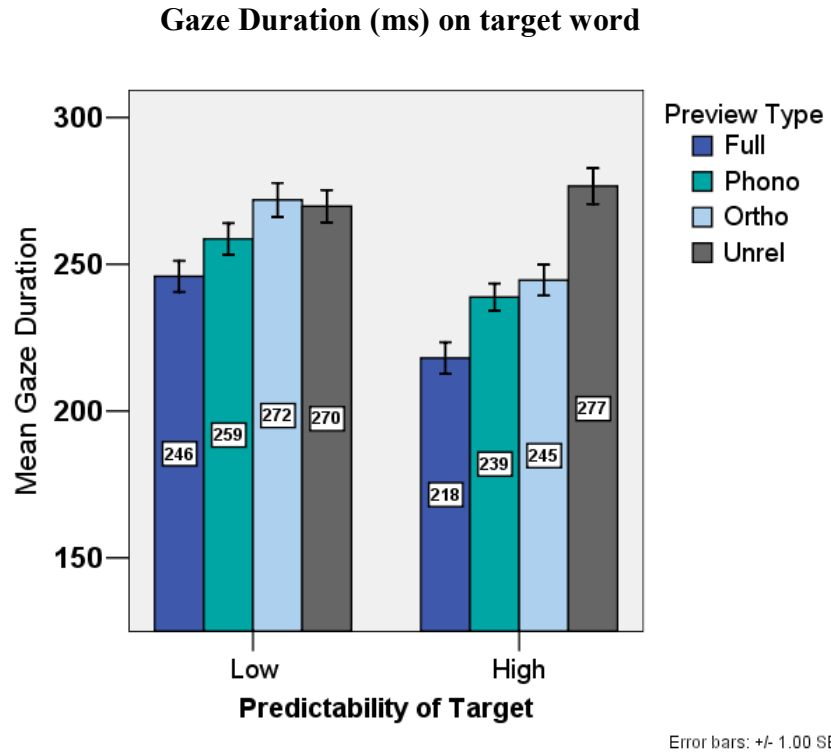


Figure 3.3 – Gaze durations (ms) on the target word across word predictability and preview conditions.

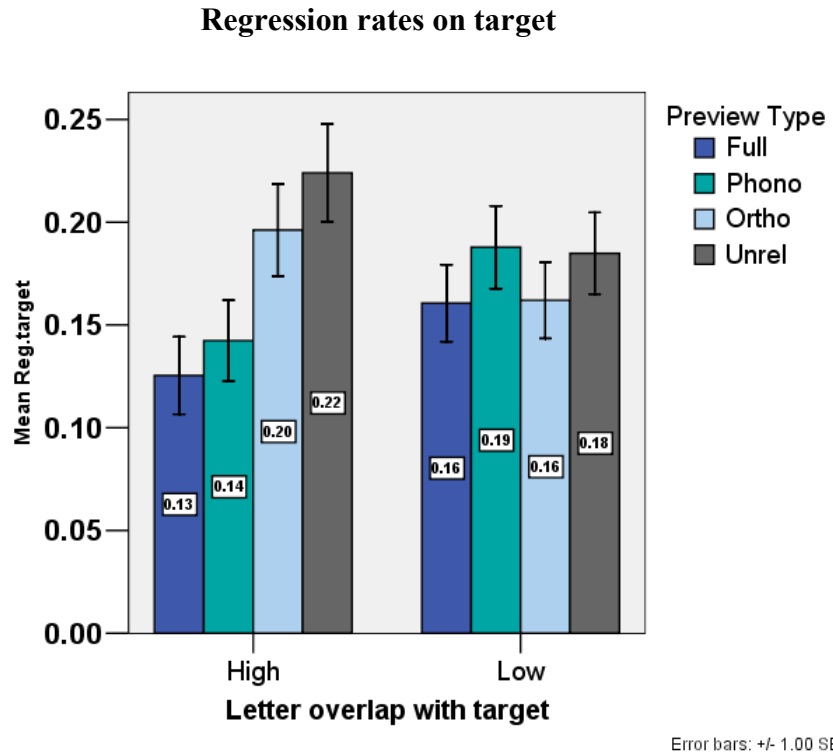


Figure 3.4 – Regression rates on target word across word preview and predictability conditions.

Chapter 4

Experiment 2b

Experiment 2b was designed to examine the effects of contextual constraint, word frequency, and word length on sublexical processing during reading. Target words ranged from short to relatively long in length. The use of short words for Experiment 2a was intended to increase skipping rates to more closely examine distinctions between word predictability effects across different measures as well as how sentence context affects skipping decisions. Experiment 2b used longer words in order to reduce first-pass skipping and increase the likelihood that the effects of contextual constraint will be localized on the measure of first-pass reading time. Experiment 2b also examined the effects of word predictability across a wider range of word frequencies.

The current experiment used target words across a wide range of the word-frequency distribution. Word frequency has been demonstrated as a strong influence on the speed of word recognition. Words that occur more often in a language are fixated for less time during first-pass reading when compared to words that occur less often (Inhoff & Rayner, 1986). Word frequency also interacts with stimulus quality such that lower frequency words show larger effects of degrading visual stimulus quality on word processing time (Norris, 1984). These effects might reflect the increased ease with which skilled readers process the visual features and encode orthographic and phonological information, or the speed with which the semantic

representations are activated given the visual word form. Increased repetition of exposure may serve to increase the level of resting activation for particular word form. It might also establish stronger connections between sublexical units (i.e., orthographic and phonological representations) and the corresponding lexical-semantic representation. Whatever the explanation for frequency effects, it is clear that the measure is a strong determinant of word processing difficulty. As such, research has aimed to examine how frequency effects might interact with linguistic context.

Rayner, Ashby, Pollatsek, and Reichle (2004) conducted a crossed manipulation of word frequency and word predictability in reading. In the study either high or low frequency members of target word pairs were read in sentence frames that rendered one of the words highly predictable. Example 4.1 shows example high and low frequency target words (in bold) in predictable or unpredictable contexts from their study.

High Frequency – Predictable: Before warming the milk, the babysitter took the infant's **bottle** out of the travel bag.

Low Frequency – Unpredictable: Before warming the milk, the babysitter took the infant's **diaper** out of the travel bag.

Low Frequency – Predictable: To prevent a mess, the caregiver checked the baby's **diaper** before leaving.

High Frequency – Unpredictable: To prevent a mess, the caregiver checked the baby's **bottle** before leaving.

The results showed main effects of both frequency and predictability for first-pass reading time. First-pass reading times for predictable words were shorter than those for unpredictable words. First-pass reading times for high frequency words were significantly shorter than low frequency words. There were no significant interactions of frequency and predictability on any first-pass reading measures. This is a finding that conflicts with previous word naming and lexical decision studies which contrasted predictability and frequency (Stanovich and West, 1979; 1982; 1983). Predictability effects were in fact larger for low frequency words compared to high frequency words across all first-pass measures (approximately twice the size). However, first-pass target word skipping rates showed a significant interaction of frequency and predictability whereby predictable, high frequency words were significantly more likely to be skipped compared to all other experimental conditions, with no other comparisons showing significant differences.

Despite a number of studies having directly examined the influences of word frequency and predictability, there are very few consistent findings regarding the joint influences of the two variables on word processing and eye movement behavior during reading. Some studies have observed predictability interact with word frequency (Gollan et al., 2011; Hand et al., 2010; Rayner et al, 2004), while others have observed no interactions of frequency and predictability (Rayner et al. 2001; Belanger & Rayner, 2013). One issue with comparisons across these studies is the variety of ways that frequency and predictability can be manipulated in a factorial design. For some studies, high or low frequency words were paired and then placed in a context where

one target word is highly predictable or the other target word is highly predictable. In these cases, low predictability conditions are actually conditions wherein some word other than the target word is predictable in the sentence context (sometimes a much higher frequency word). Using other designs, target words can also be placed in sentence contexts where either the target word is predictable or no specific word is predictable. These experimental design choices might constitute important differences in the processing conditions under which frequency and predictability are contrasted directly.

Research has demonstrated that skilled readers utilize phonological input at the earliest stages of the recognition process during reading (Pollatsek et al., 1992; Chace et al. 2006). Studies have also suggested that phonological information is used during the recognition of low and high frequency words (Folk, 1999). However, it is still not clear if the activation of phonological codes is necessary for lexical access, or if it simply runs in parallel with other recognition processes contributing in part to the ultimate goal of lexical access (see, Leininger, 2014 for review). Examining word frequency with regard to parafoveal preview benefit could address some of these issues. Word frequency, as with orthographic neighborhood size, is correlated with word length; yet it provides an independent index of word processing difficulty on which to test various accounts of contextual influences on word recognition. Studies have also shown that word frequency effects are eliminated by invalid (i.e., unrelated) parafoveal previews (Inhoff & Rayner 2006; Staub et al., 2010). Studies have also found that denial of valid preview information can eliminate word predictability effects in a similar fashion (Balota et al., 1985; Drieghe et al. 2005). Given the body of

literature regarding the interplay of frequency and predictability, it is not entirely clear what pattern of effects should be expected when more or less frequent words are replaced with orthographic and phonological previews. Based on previous findings, it is also difficult to predict how parafoveal preview effects would unfold across the broad range of word predictability and word frequency. The specific impact of sublexical input may differ as a function of the time or effort required for word recognition. Accounting for intrinsic word processing difficulty might further illuminate the nature of previously observed interactions between contextual constraint and parafoveal preview information. The effects of parafoveal preview and predictability observed in the previous experiments may differ as a function of word length or word frequency. For instance, the time required for phonological encoding or the reliance on phonological codes may differ between high and low frequency words. The impact of sublexical information in the parafovea may also differ across longer and shorter words. If this is the case, there may be more uncertainty as to letter identities and relative positions for longer words which could influence decisions about eye movements.

As with Experiments 1 and 2a, the current study examined the extent to which parafoveal preview effects on eye movement measures reflecting early word processing were influenced by contextual constraint imposed by the prior sentence context. As with previous experiments, post-lexical accounts of predictability effects in reading predict that there should be no modulation of word skipping and (to a lesser extent) first-pass reading times by sentence context. Critically, post-lexical accounts predict that contextual constraint should not interact with any indices of word

recognition difficulty, such as word frequency or word length and should not impact parafoveal preview effects. Furthermore, if there are interactive influences of lexical characteristics and preview condition, there should be no mediation of effects through word predictability.

Interactive accounts of word predictability effects predict that both first-pass reading measures should be affected by sentence context, as word recognition processes are mediated, in part, by contextual cues. This influence should come in the form of considerable reduction of word processing difficulty. Word predictability should have a larger impact on the processing of longer words and lower frequency words, as they are intrinsically more difficult to process. Word predictability (in addition to word length and frequency) could also mediate the effects of preview condition, as more difficult words may rely more heavily on bottom-up sublexical processing. In general, interactive accounts predict that interactive effects of contextual constraint could be observed for word frequency, word length, and parafoveal preview information, as these are all factors that impact the ease of lexical access.

The design of Experiment 2b focused on the examination of word-frequency, length, predictability, and preview effects. Target words for Experiment 2b were selected to encompass a wide range of word frequencies, spanning from less than one occurrence per million to over 100 occurrences per million. This range was considerably larger than in Experiment 2a and as a result average word frequency for the target words was lower overall. When selecting target words for Experiment 2b, an attempt was made to ensure that word frequency and word length were not

confounded (as they are across the language). For Experiment 2b the manipulation of word predictability was performed in the same fashion as the previous two experiments (as shown in Example 4.1 with target word in bold).

The current experiment also manipulated the information available for target words prior to direct fixation using the boundary paradigm. Target word preview was either a full preview for the target word (e.g., *scripts*), a phonological preview of the target word (e.g., *skripts*), an orthographic control preview which was matched with the phonological preview in orthographic similarity to the target (e.g., *stripsk*), or an unrelated letter preview (e.g., *coaqihe*). For Experiment 2b, the orthographic preview for each item was matched in exact letter identity with the target word to the same extent as the phonological previews. For example, if the phonological preview was matched with the target on every letter except the last four (e.g., *evolution-evolushun*) then the orthographic control previews was matched to the same degree (e.g., *evolution - evolushun - evoluskun*). After this point of discrepancy, orthographic previews were achieved with transpositions or substitutions of the remaining letters of the phonological preview string. Construction of the unrelated letter previews (in regard to rough visual similarity to the target word) was performed in the same fashion as Experiment 2a. All previews were matched in character length with the corresponding target word and designed to be pronounceable.

Of particular note, as compared to the stimuli for Experiment 2a, pseudo-homophone previews varied more widely in orthographic inconsistency relative to the target word, such that letter differences between targets and their phonological previews may not occur until the latter half (or the end) of each word. For example,

the pseudo-homophone preview for *wagons* was created using *waguns* which substitutes letters at the latter half of the word, whereas the same preview condition for 'accident' was achieved using *aksident* that substitutes word-initial letters.

Example 4.2

Low Constraint Context: The group went to the convenience store to find the most expensive **liquor** they could afford.

High Constraint Context: The group at the bar ordered shots of the most expensive **liquor** they could see on the shelf.

Method

Subjects

Fifty-three subjects from the University of California, San Diego campus community participated in the experiment. All subjects were native English speakers and were naïve as the goals of the research project. All subjects were obtained through on-campus flyers, receiving \$10 per hour or through the undergraduate subject pool, receiving class credit for compensation. Subjects were debriefed after completing the study. Three subjects were replaced due to a data file transfer error that occurred at the end of the experiment, and two subjects were replaced after noticing too many display changes.

Stimuli

Ninety-six target words were selected. Table 4.1 displays average lexical

characteristics for the target words. As with Experiment 2a, lexical characteristics for target words in Experiment 2b were obtained from the SUBTLEX (US) Corpus (Brysbaert & New, 2009) via the English Lexicon Project (Balota et al., 2007). Target words ranged from 4 - 12 characters in length; however the vast majority of words (approximately 80%) were between 6 and 9 characters in length.

Average lexical characteristics for target items after median splits of target word frequency are shown in Table 4.2, whereas median splits of target word length are listed on Table 4.3. Median splits revealed that orthographic neighborhood sizes were larger for higher frequency target words ($M = 1.23$) when compared to lower frequency target words ($M = 0.48$) and this difference was significant, $t(94) = 2.17$. As expected, median splits also revealed that orthographic neighborhood sizes were larger for shorter words ($M = 1.70$) when compared to longer words ($M = 0.17$) and this difference was also significant, $t(94) = 4.80$. Critically, there were no significant differences in word length when comparing across the median split for word frequency and there were no significant difference in word frequency when comparing across the median split for word length (all t 's < 1.60).

The average position of the target word in high constraint conditions was 10.91 words into the sentence frame ($SD = 2.04$). The average position of the target word in low constraint conditions was 10.93 words into the sentence frame ($SD = 2.03$). Twenty-four Mechanical Turk subjects (who did not participate in the eye tracking study) completed a cloze task. Average cloze proportion for target words in low constraint sentence contexts was 0.05 ($SD = 0.10$) and the average cloze proportion for target words in high constraint sentence contexts was 0.54 ($SD = 0.33$). The

difference between the two context's cloze proportions was significant, $t(190) = 14.14$. While these items clearly differ in their degree of word predictability across sentence contexts, conventionally speaking, cloze scores below 70% would not be considered "high" predictability. As such, these items can be thought of as "high constraint" or "low constraint". The average level of constraint, as measured by the number of unique cloze responses for an item (out of 12 total responses) was used to further verify the manipulation of sentence context. The average number of unique responses for low constraint contexts was 7.64 ($SD = 2.52$), whereas the average number of unique responses for high constraint contexts was 3.90 ($SD = 1.93$); this difference was significant, $t(190) = 11.54$. Importantly, these norming results demonstrate that the low constraint contexts are truly low in that they do not license a constrained set of responses (let alone one particular word).

Based on the median split of word frequency there were no strong differences in target word predictability for high constraint sentences when comparing cloze proportions for higher frequency words ($M = 0.55$, $SD = 0.32$) and lower frequency words ($M = 0.53$, $SD = 0.33$). On the other hand, there was a slightly higher cloze proportion for higher frequency words in low constraint contexts ($M = 0.07$, $SD = 0.13$) when compared to the cloze proportion for lower frequency targets in low constraint contexts ($M = 0.03$, $SD = 0.07$); however, this difference did not reach significance $t(94) = 1.45$. There were also no differences in cloze proportions (within constraint conditions) when comparing long and short words and there were no significant differences in the position of the target word or the number of unique responses (within constraint conditions) when comparing across word length and

frequency median splits (all t 's < 1.31).

Apparatus and Procedure

The presentation apparatus and experimental procedures were the same as in Experiment 2a, with the exception of the total number of trials. Subjects read 172 total sentences for the experiment preceded by three practice trials. Any subjects who reported noticing more than seven of the total 72 display changes were replaced.

Data Analysis

In the current study, measures of reading behavior associated with early and later word processing were investigated. As with previous experiments, the measures of early word processing were first-pass skipping rate and gaze duration. The eye movement measures of later word processing included go-past duration on the target word and regression rate.

The data for Experiment 2b were analyzed using the same method as Experiment 2a, with any exceptions detailed below. The analysis models included fixed effects for target word length, frequency, cloze proportion, and preview condition. During the analysis word length, cloze proportion, and log-transformed word frequency were entered as (centered) continuous variables and allowed to interact with parafoveal preview condition. For the analyses of gaze duration and go-past duration, linear regression models were used. Mixed-effects models identical to those used in Experiment 2a were used in Experiment 2b. Reporting of effects size estimates and significance is the same as in Experiment 1 and 2a. The analysis of

preview effects was the same as in Experiment 2a.

Short fixations of 60 ms or below were merged with a fixation within one character distance. Any fixations of 60 ms or below that were not within one character of a longer fixation were eliminated prior to analysis. Long fixations of 600 ms above were eliminated prior to analysis. Trials in which the subjects blinked during first-pass reading for the target word, the word preceding the target word, or the word immediately after the target word were excluded prior to analysis. Trials in which the boundary was triggered at an inappropriate time were also excluded prior to analysis. Display changes took an average of 8 ms to complete from the initial triggering of the boundary to the completion of the display change. Eighteen percent of the subjects (9 of 48) reported noticing at least one of the 72 total display changes during the experiment. One subject was replaced after reporting noticing more than seven display changes. After all exclusion criteria and subject replacement a total of 16% of the data were excluded.

Results

First-pass skipping rates

Figure 4.1 shows first-pass skipping rates across preview and contextual constraint conditions. The main effect of contextual constraint on target word skipping rate was significant, $b = 0.29$, $SE = 0.13$, $z = 2.16$. Target words were skipped more in high constraint contexts. There was also a main effect of word length such that short words were skipped more than long words, $b = -0.89$, $SE = 0.11$, $z = -8.04$. The main effect of preview was not significant, but the effect was marginal, $p =$

0.12, for subjects and items. This was largely due to low skipping rates for unrelated letter previews.

The omnibus test of preview effects did not confirm any significant interactions target word preview. However, in the regression analysis, there was a three-way interaction of preview, contextual constraint, and word length showing that first-pass skipping rates for phonological previews and full previews did not differ for shorter words in more constrained contexts, $b = 0.18$, $SE = 0.08$, $z = 2.15$. When shorter words were embedded in less constrained contexts first-pass skipping rates were higher for full previews as compared to phonological previews. First-pass skipping rates for full and phonological previews did not differ in either sentence context condition for longer words. These results suggest that high word predictability mediated the likelihood of skipping phonological previews but not orthographic previews.

For the contrast of full preview and unrelated letter preview, there was an interaction with word frequency as well as a three-way interaction with word frequency and contextual constraint suggesting the processing benefits of high frequency and high contextual constraint are reduced by unrelated letter previews. This pattern of results (as in previews experiments) indicates that the processing advantages associated with high word frequency and predictability can both be eliminated by invalid preview information.

Gaze Duration on target word

Figure 4.3 shows gaze durations for the target word across preview and

constraint conditions. There was a main effect of contextual constraint on gaze duration for the target word. Target words received shorter gaze durations in high constraint contexts than low constraint contexts, $b = -5.39$, $SE = 1.51$, $t = -3.58$. There was also a main effect of preview condition, $F_1(3, 45) = 13.43$, $p < .01$; $F_2(3, 93) = 13.52$, $p < .01$. Contrasts showed that target words in full preview conditions had shorter gaze durations than unrelated preview conditions, $b = 11.35$, $SE = 2.46$, $t = 4.62$. No other preview contrasts reached significance. There was a main effect of target word frequency showing that higher frequency words received shorter gaze durations than lower frequency words, $b = -11.73$, $SE = 3.25$, $t = -3.61$ and a main effect of target word length showing that longer words received longer gaze durations than shorter words, $b = 4.44$, $SE = 1.49$, $t = 2.98$.

The omnibus test of preview effects showed a significant interaction of preview and word length, $F_1(3, 45) = 2.78$, $p < .05$; $F_2(3, 93) = 13.52$, $p < .01$, a marginal three-way interaction of preview, word length, and contextual constraint, $F_1(3, 45) = 2.23$, $p = .08$; $F_2(3, 93) = 2.46$, $p = .06$, and a marginal four-way interaction of preview, word length, contextual constraint, and word frequency, $F_1(3, 45) = 2.15$, $p = .09$; $F_2(3, 93) = 2.21$, $p = .09$. No preview contrast reached significance for interactions with word length. The marginal three-way interaction of preview, contextual constraint, and word length suggested that the typical word predictability effect was eliminated under unrelated letter preview conditions, $b = -3.37$, $SE = 1.31$, $t = -2.57$. The marginal four-way interaction of preview, contextual constraint, target word frequency, and target word length was observed in the contrast of full previews and orthographic control previews, $b = -4.87$, $SE = 2.02$, $t = -2.42$.

Concisely stated, phonological preview benefit was observed for both high and low frequency words while orthographic preview benefit was only observed for high frequency words. This interactive pattern was only present when words were short. For long words there was an orthographic preview benefit for targets in constrained as well as unconstrained sentence contexts. It is important to note that these interactions did not reach statistical significance in an omnibus test of preview effects. Figure 4.4 shows gaze durations for short words and Figure 4.5 shows gaze durations for long words. Each figure shows gaze durations across preview and sentence constraint conditions (only showing orthographic and full preview conditions) based on the median-split of word frequency across the target words.

Broadly, these complex interactive patterns indicate that orthographic preview benefit is more sensitive to mediation by target word frequency and predictability when compared to phonological preview benefit. Furthermore, the theoretically relevant interactions were largely confined to shorter words. The results also indicate that unrelated letter previews eliminate the processing benefits of word predictability irrespective of word length or frequency.

Later measures of target word processing

There was a main effect of contextual constraint on go-past durations for the target word. Go-past durations were significantly shorter for high predictability words when compared to lower predictability words, $b = -13.28$, $SE = 3.69$, $t = -3.60$. There was also a main effect of preview condition, $F_1(3, 45) = 5.43$, $p < .01$; $F_2(3, 93) = 5.49$, $p < .01$. Go-past durations for target words were significantly shorter for full

previews when compared to unrelated letter previews, $b = 13.80$, $SE = 6.12$, $t = 2.25$. No other preview contrasts reached significance. There was also an effect of word length showing that go-past durations increased as target word length increased, $b = 8.07$, $SE = 2.82$, $t = 2.86$. There were no significant interactions of any predictors.

There was a marginal effect of contextual constraint on regression rates into the target word such that more predictable words received fewer regressions than less predictable words, $b = -0.10$, $SE = 0.06$, $z = -1.76$. There was also a main effect of word length showing that short target words received fewer regressions than long target words, $b = -0.23$, $SE = 0.06$, $z = -3.91$. There was a significant interaction of word frequency and contextual constraint, $b = 0.24$, $SE = 0.07$, $z = 3.39$, showing that regression rates into low frequency words in less constrained contexts were higher than all other conditions.

Discussion

The results of Experiment 2b demonstrated that words in high constraint contexts were skipped more often than words in low constraint contexts. The marginal interaction of preview condition and contextual constraint suggests that, for shorter words, sentence context mediated skipping for phonological previews, whereas orthographic preview skipping rates were not affected by contextual constraint. These findings suggest that contextual constraint can mediate the influence of phonological processing on first-pass skipping decisions, but this influence is not independent of word length. It could be the case that contextual constraint increases the likelihood of skipping a phonologically consistent preview, but only when words are sufficiently

short, allowing for phonological processing of the entire parafoveal letter string.

Contextual constraint also led to shorter first-pass reading times for target words. Importantly, the marginal interaction on first-pass reading time suggest that as target words increased in frequency and contextual constraint, the processing costs associated with orthographic previews was reduced (i.e., the orthographic preview benefit was larger). Furthermore, the effects of orthographic and phonological information in the parafovea were independent of one another in regard to their respective influences on eye-movement control (as shown by first-pass reading measures). Whereas the effect of orthographic preview on first-pass reading time was modulated by contextual constraint, in addition to word length and frequency, the effect of phonological preview was more consistent. Across the wide range of word length and frequency, phonological preview benefit was observed on first-pass reading times.

Across both Experiments 2a and 2b, unrelated previews were considerably more disruptive than phonological or orthographic previews. For both experiments, the interaction of preview and context was such that the effects of contextual constraint on first-pass reading times were considerably reduced, or eliminated altogether, with unrelated pronounceable nonword previews. As in Experiment 2a, only unrelated preview conditions compromised the beneficial effects of contextual constraint on first-pass reading times, suggesting that context influences word processing by mediating difficulty at relatively early stages of word recognition.

The interactive patterns of target word preview, length, frequency, and contextual constraint suggests that parafoveal preview benefit was modulated both by

how difficult a word is to recognize in general, and how likely it is to occur in the context of the sentence. These interactions of contextual constraint and preview condition (while not reaching statistical significance) support interactive accounts of word predictability effects more than post-lexical accounts. According to post-lexical accounts, contextual constraint should not mediate the influences of word length or frequency on word recognition difficulty.

Overall, the high constraint words for Experiment 2b had considerably lower cloze proportions than the high predictability words in Experiment 1 and Experiment 2a. Based on the average cloze proportion for target words in high constraint contexts, the results of Experiment 2b further suggest that word predictability effects can arise for moderately predictable words in sentence contexts where no single word is highly predictable (see Rayner & Well, 1996; Smith & Levy, 2013, for similar results). Taken together, these findings offer some evidence that the time course of contextual constraint influences can vary with the strength of constraint and the predictability of a given word. The pattern of effects across Experiment 1, Experiment 2a, and Experiment 2b suggests that contextual constraint facilitates processing for a relatively wide range of linguistic representations rather than a single letter string that corresponds precisely to a highly predictable word.

Table 4.1 – Lexical characteristics of target words in Experiment 2b. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Mean	7.59 (1.48)	2.54 (0.68)	7.70 (1.72)
Range	4 – 12	1.32 – 4.75	0 – 10

Table 4.2 – Lexical characteristics of target words in Experiment 2b based on median split of word frequency. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Low Frequency	7.83 (1.24)	2.00 (0.34)	0.48 (0.98)
High Frequency	7.35 (1.67)	3.08 (0.48)	1.23 (2.19)

Table 4.3 – Lexical characteristics of target words in Experiment 2b based on median split of word length. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Short words	7.83 (1.24)	2.65 (0.68)	1.70 (2.28)
Long words	8.70 (0.82)	2.46 (0.67)	0.17 (0.38)

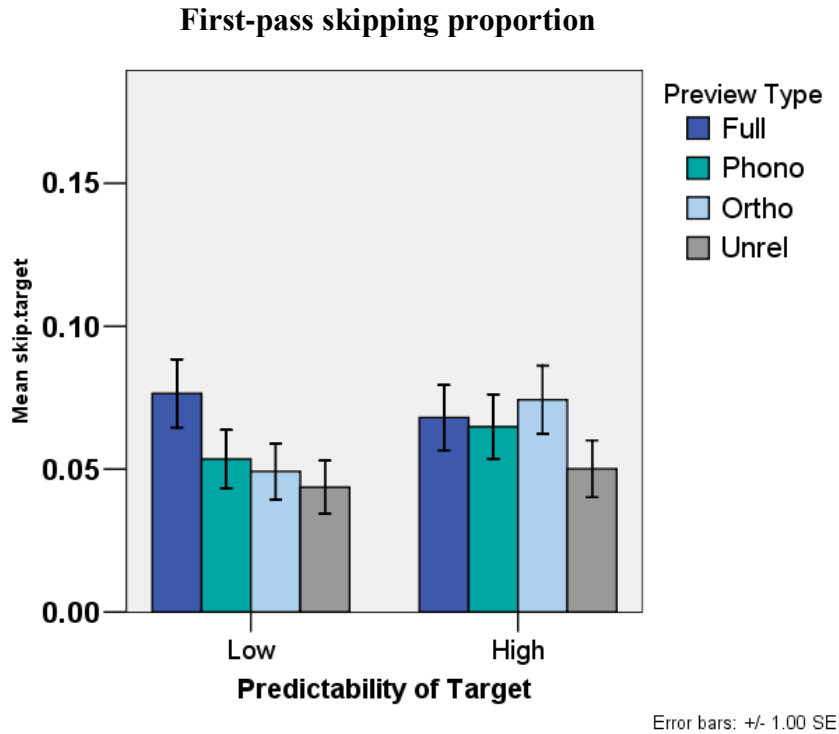


Figure 4.1 – First-pass skipping proportion across all preview and predictability conditions.

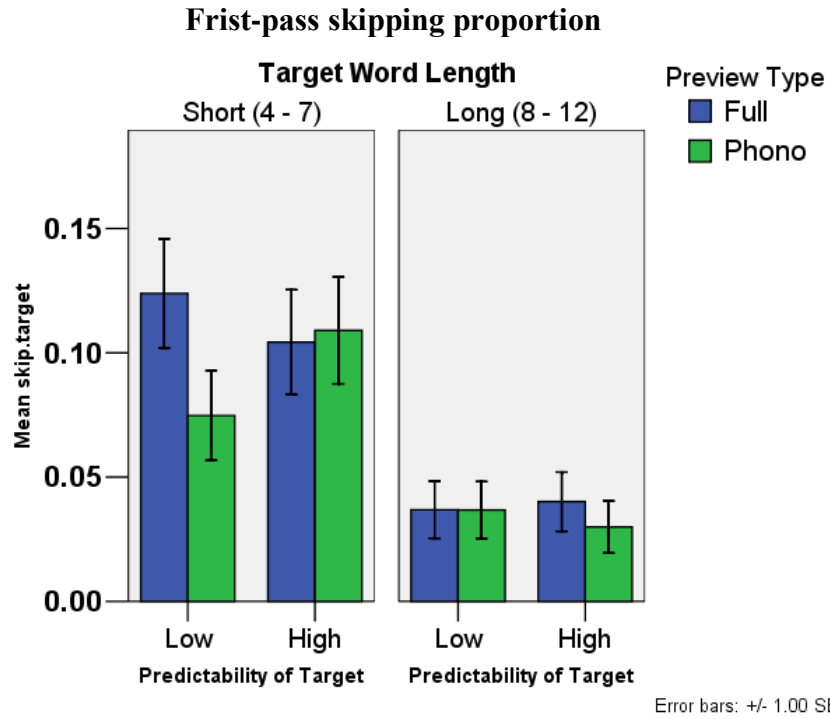


Figure 4.2 – First-pass skipping proportion for full previews and phonological previews across word length.

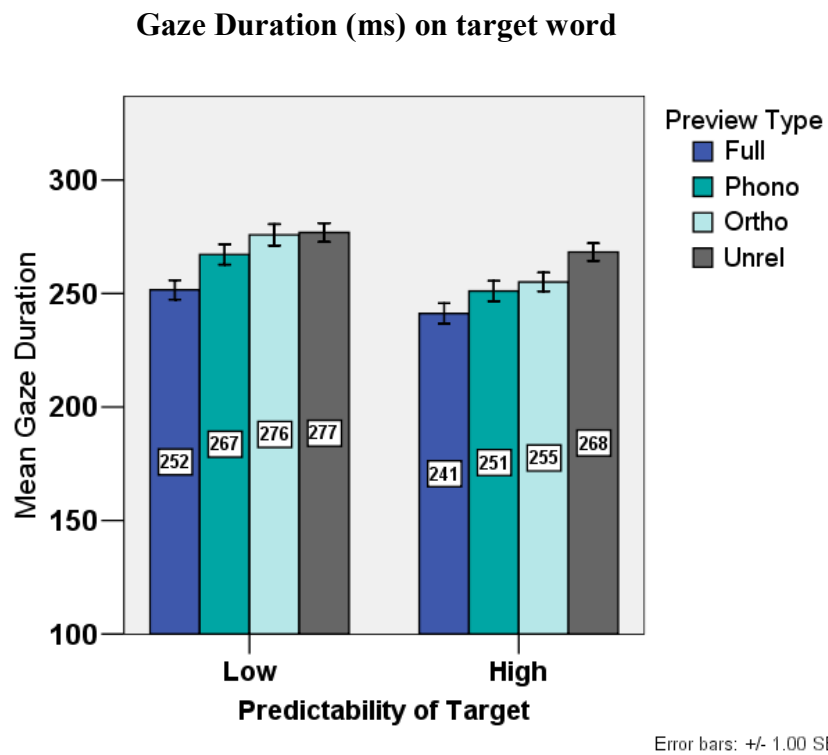


Figure 4.3 – Gaze durations (ms) across full and orthographic control preview conditions for lower frequency words.

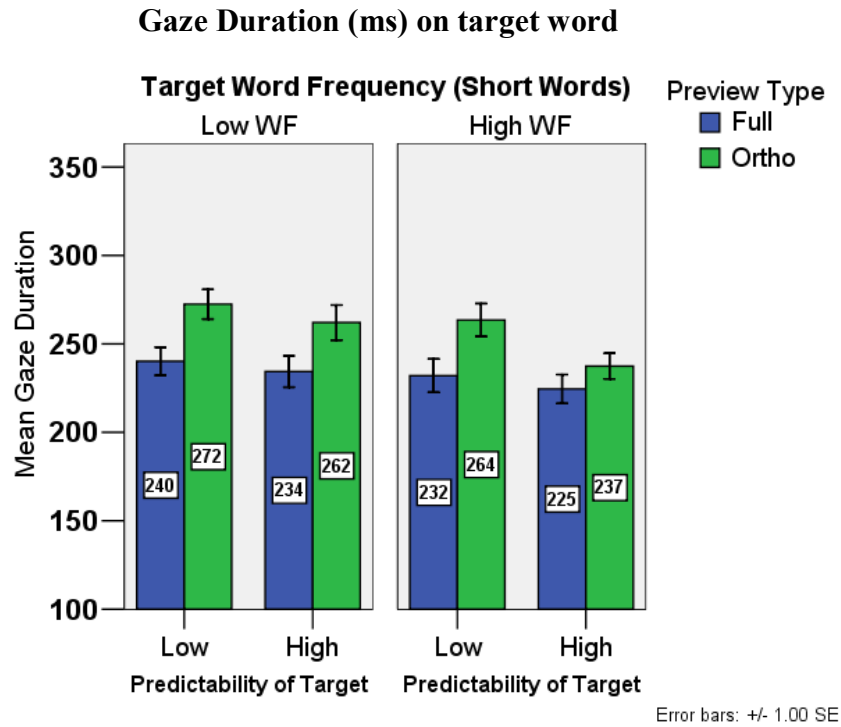


Figure 4.4 – Gaze durations (ms) across full and orthographic control preview conditions for short words.

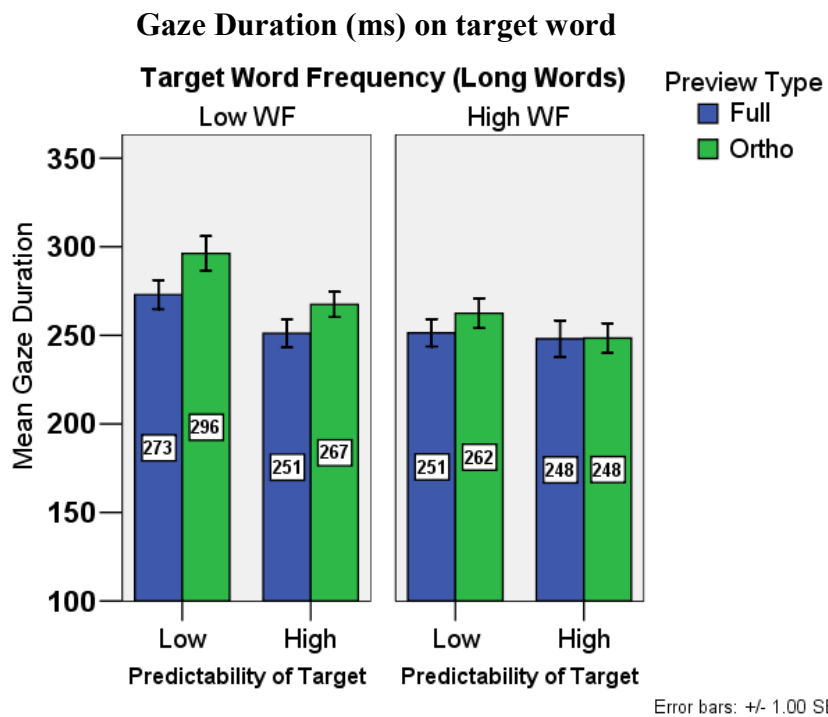


Figure 4.5 – Gaze durations (ms) across full and orthographic control preview conditions for long words.

Chapter 5

Experiment 3

Experiment 3 examines the effect of orthographic characteristics (independent of phonology) in conjunction with lexical characteristics in order to obtain a clearer picture of how context guides the use of orthographic information. The influence of orthographic input was investigated by contrasting words of high and low orthographic familiarity (without a parafoveal preview manipulation). The study also manipulated the predictability of target words in sentence context to investigate contrasting accounts of word predictability effects. Orthographic familiarity was operationalized using measures of letter *n-gram frequencies* (e.g., letter bigram frequencies). That is, as the specific letter bigrams (i.e., two letter sequences) that constitute a word occur more often across words in the language, the letter bigram frequency increases.

One primary distinction between conflicting accounts of word predictability effects rests on the extent to which contextual constraint can mediate the processing demands associated with orthographic processing during word recognition. Post-lexical accounts posit that orthographic processing is completely unaffected by context, whereas interactive accounts posit that orthographic processing should be affected by context. As in previous experiments, first-pass reading measures were examined to contrast the assumptions of conflicting accounts of word predictability effects. Post-lexical accounts assume that word recognition precedes the influences of

context on comprehension. These views predict that first-pass skipping rates will not be influenced by word predictability. These views also predict that word predictability effects on first-pass reading times are less likely than effects on later reading measures. Post-lexical views also assume that no interaction of letter bigram frequency and contextual constraint should be observed on any reading measure. While the effects of letter sequence familiarity in reading are not clear, it is almost certainly the case that any influences exert an influence on lexical access rather than post-lexical integration.

Alternatively, interactive accounts of word predictability effects assume that contextual constraint can exert an influence on word recognition. According to these views, first-pass skipping rates and first-pass reading times should be reliably influenced by contextual constraint. Critically, interactive accounts of word predictability effects predict that contextual constraint should interact with letter sequence familiarity and other indices of word processing difficulty. If contextual constraint routinely impacts early stages of word processing then the difficulty associated with processing less familiar letter sequences may be alleviated by sentence contexts in which the word is predictable. If readers are generating predictions about upcoming letter sequences, then those expectations might be more helpful when they facilitate low frequency letter sequences. In particular, if skilled readers are making explicit predictions for upcoming words when context is sufficiently constraining or if processing of sublexical information is facilitated by constraining contexts, then the processing of constituent letter sequences should be influenced. Contextual constraint may also facilitate the processing of high frequency letter sequences, as there should

be more uncertainty regarding word identity. If contextual constraint biases the processing of letter sequences in a way that increases the likelihood of associating a letter string with a predictable word, then any difficulty typically associated with eliminating potential competitors should be reduced. In either case, any modulatory effects of word predictability may unfold differently as a function of familiarity of a word's constituent letter sequences.

A considerable amount of research has investigated the influence of orthographic familiarity and regularity. Given the importance of sublexical characteristics in word processing, the rationale is that unique, rare, or “informative” orthographic sequences should facilitate efforts to distinguish words from other lexical candidates during recognition. Intuitively, if given exact word length information and the initial letters 'dw---' many native English speakers could complete the word 'dwarf' with relative ease. Hypothetically, this completion would also be relatively unambiguous and responses would not be variable across individuals. However, given a word length and the initial letters 'mo---' there would presumably be high variability across completions among native English speakers (e.g., *month*, *mouse*, *mouth*, or *mopey*). Given this intuition, rare (i.e., relatively infrequent) orthographic sequences should aid readers in disambiguating word identity more so than orthographic sequences that occur often and across a wide range of words.

Interestingly, this rational intuition does not necessarily correspond with the observed influences of sublexical characteristics during reading. Lima and Inhoff (1985) framed this issue in terms of constraint. They hypothesized that if more informative initial letters are used to constrain candidates for lexical access, then

reading times with more words with more unique initial letters should be faster.

However, their results showed a contrasting effect whereby low constraint words (i.e., words with more frequently occurring initial letters) were read faster than high constraint words. In fact, the majority of extant studies have observed evidence of processing difficulty for words containing low frequency orthographic sequences when compared to matched words with higher frequency orthographic sequences (Lima & Inhoff, 1985; Clark & O'Regan, 1998; White, 2008).

Word frequency (i.e., frequency at the lexical-level) is another important factor to consider when examining the impact of letter sequences on eye movement behavior, as it is intrinsically related to the frequency of orthographic input. In a reading study, White (2008) contrasted the effects of word-frequency and orthographic familiarity (as measured by letter bigram and trigram frequency measures). Her results showed significantly slower first-pass reading times for target words with unfamiliar orthography as compared to targets with familiar orthography when matched on word frequency. Her results also showed a small but statistically reliable effect whereby fixations on the word immediately preceding the target word were longer when the target was orthographically unfamiliar compared to instances when the target was orthographically familiar. Similar patterns of early orthographic familiarity effects can be found in several other reading studies (Lima & Inhoff, 1985; Gagl, Hawelka, Richlan, Schuster, Hutzler, 2013; White, 2008; White & Liversedge, 2004). In summary, extant studies have demonstrated that in neutral sentence contexts words containing less familiar initial letter sequences are more difficult to process than words containing more familiar sequences.

Experiment 3 examines the effects of contextual constraint and orthographic familiarity while controlling for other important lexical variables. As with the previous experiments, target words were embedded in more constrained or less constrained sentence contexts. Considering that previous familiarity effects were observed prior to directly fixating the target word, the lexical characteristics of the word preceding the target in the sentence was controlled and matched across conditions for each target word (see Example 5.1 with target words in bold). Experimental items consisted of target words ranging in overall orthographic familiarity but controlled on other important lexical characteristics. Target words ranged from items with very low letter bigram frequencies (e.g., *khakis*) to items with relatively high letter bigram frequencies (e.g., *crates*). Target words varied in word length from 4 – 8 characters long. Word frequency was matched across the range of letter bigram frequencies, resulting in a relatively low average word frequency for the target words overall (i.e., it is difficult to find high frequency words with very low *n*-gram letter frequencies).

Example 5.1

High orthographic frequency - Low Constraint: The national and local forces came together to control the drug **cartel** activity in the city.

High orthographic frequency - High Constraint: The Mexican and US authorities cooperated to bring down the drug **cartel** activity on the border.

Low orthographic frequency - Low Constraint: The family had a meeting to get information about the drug **addict** before it was too late.

Low orthographic frequency - High Constraint: The family had an intervention to get treatment for the drug **addict** before it was too late.

Method

Subjects

Forty-four subjects from the University of California, San Diego campus community participated in the experiment. All subjects were native English speakers who were naïve as to the research goals. All subjects were obtained through on-campus flyers, receiving \$10 per hour or through the undergraduate subject pool, receiving class credit for compensation. Subjects were debriefed after completing the study.

Stimuli

Experimental items consisted of 76 target words ranging in overall orthographic familiarity but controlled on other important lexical characteristics. Orthographic familiarity was operationalized using the mean bigram frequency for each target word obtained from the English Lexicon Project (Balota et al. 2007). Mean bigram frequency takes summed token bigram frequency for each successive bigram in a word and divides the quantity by the number of total bigrams in the word. Target words ranged from 4 - 8 characters in length. Lexical frequency measures were obtained from the HAL corpus (Lund & Burgess, 1996) also via the English Lexicon Project (Balota et al. 2007). Table 5.1 contains lexical frequency characteristics for the target words in Experiment 3.

To observe the extent to which mean bigram frequency correlates with other important lexical characteristics, a median split based on mean letter bigram frequency was performed to test for significant differences across other measures. Average lexical characteristics based on the median split are provided in Table 5.2. The average size of the orthographic neighborhood for higher bigram frequency items was significantly larger than that of the lower bigram frequency items, $t(74) = 4.30$. No other lexical characteristics showed statistically significant differences (all $ts < 1.74$). The effort to match items across the range of mean letter bigram frequency resulted in relatively low word frequencies overall. This was unsurprising as it is difficult to find many words that are truly high frequency while having low n -gram letter frequencies.

The average position of the target word in high constraint contexts was 12.1 words into the sentence ($SD = 1.8$) and the average position of the target word in low constraint contexts was 11.9 words into the sentence ($SD = 1.79$). Twenty-four Mechanical Turk subjects (who did not participate in the eye tracking study) completed the cloze task for these items. The average cloze proportion for targets in high constraint contexts was 0.44 ($SD = 0.34$) and the average cloze proportion for low constraint contexts was 0.06 ($SD = 0.14$); the difference between the two conditions was significant, $t(150) = 8.99$. As with Experiment 2b, these contexts produce different cloze proportions but the high constraint context does not meet the conventional criterion for “high” word predictability. The average number of unique responses (out of 12) for low constraint contexts was 8.29 ($SD = 2.08$) whereas the average number of unique responses for high constraint contexts was 5.05 ($SD = 2.70$); this difference was statistically significant, $t(150) = 8.28$. As with Experiment

2b, this measure of constraint is important because it demonstrates that neutral contexts are truly neutral. More specifically, when target words in these stimuli were read in low constraint contexts there was no other word that is highly predictable. Median split of the items by mean bigram frequency revealed no differences in cloze proportion or number of unique responses (with constraint conditions) between higher and lower bigram frequency items (all $t_s < 0.93$). There was also no differences in the position of the target word in the high or low constraint sentence frames or the length and frequency of the word preceding the target word across higher and lower mean bigram frequency items (all $t_s < 1.34$).

Apparatus and Procedure

The presentation apparatus and experimental procedures were the same as in Experiment 2b, with the exception that the current procedure was not a boundary paradigm. Because there were no boundary manipulations, subjects were debriefed without a series of questions.

Data Analysis

The dependent measures for Experiment 3 were the same as those for Experiments 2a and 2b. The data for Experiment 3 were analyzed using the same method as the previous experiments with exceptions detailed below. The analysis models included fixed effects for word length, word frequency, average bigram frequency, and cloze proportion. All continuous predictors, with the exception of word length, were log-transformed. All continuous predictors were centered on their

mean in the data. For the analyses of gaze duration and go-past duration, linear regression models were used. Reporting of effect size estimates and significance is the same as in the previous experiments. Short fixations of 60 ms or below were merged with a fixation within one character distance. Any fixations of 60 ms or below that were not within one character of a longer fixation were eliminated prior to analysis. Long fixations of 600 ms above were eliminated prior to analysis. All figures for Experiment 3 were produced using median splits based on the distribution of each predictor variable in the set of items, with the exception of contextual constraint which is shown in figures based on the categorical sentence context manipulation.

Results

First-pass skipping of target word

There was a main effect of cloze proportion such that more predictable words were skipped more during first-pass reading, $b = 0.21$, $SE = 0.06$, $z = 3.64$. There was also a main effect of word length wherein shorter words were skipped more than longer words, $b = -0.67$, $SE = 0.07$, $z = -9.81$. As shown in Figure 5.1, there was an interaction of mean bigram frequency and contextual constraint showing that the effect of contextual constraint on word skipping was confined to target words with high average bigram frequencies, $b = -0.39$, $SE = 0.20$, $z = -1.98$. There was also an interaction of contextual constraint and word length, $b = 0.10$, $SE = 0.05$, $z = 2.12$, and a three-way interaction of contextual constraint, word length, and average bigram frequency, $b = -0.40$, $SE = 0.17$, $z = -2.33$. As shown in Figure 5.2, these interactions

demonstrated that the increase in skipping rates that resulted from high contextual constraint was largely confined to short words with high average bigram frequency.

Gaze duration on target word

As shown in Figure 5.3, there was a main effect of contextual constraint on first-pass reading times. Gaze durations were shorter for target words in higher constraint contexts than in lower constraint contexts, $b = -8.85$, $SE = 1.73$, $t = -5.12$. There was also a main effect of mean bigram frequency such that words with higher frequency bigrams overall received longer gaze durations than words with lower bigram frequencies overall, $b = 26.91$, $SE = 11.24$, $t = 2.39$. There was also a main effect of word frequency, $b = -5.23$, $SE = 2.29$, $t = -2.28$, showing that high frequency words received shorter first-pass reading times than low frequency words and a main effect of word length, $b = 6.31$, $SE = 2.55$, $t = 2.47$, showing that short words received shorter first-pass reading times than long words.

There was a three-way interaction of contextual constraint, average bigram frequency, and word frequency, $b = 10.06$, $SE = 5.11$, $t = 1.97$ and a significant four-way interaction of contextual constraint, average bigram frequency, word frequency, and word length, $b = 11.03$, $SE = 4.69$, $t = 2.35$. As shown in Figures 5.3 and 5.4, these interactions suggested there was no word predictability effect on short high frequency words with low bigram frequency. For all long words and lower frequency short words, gaze durations were shorter for more predictable words. This higher-order interaction was revealed along with corresponding lower order interactions of mean bigram frequency, word frequency, and word length, as well as word frequency

and mean bigram frequency.

Later measures of target word processing

Go-past durations on the target word showed a significant effect of word predictability, wherein predictable words led to shorter go-past reading times, $b = -15.48$, $SE = 3.30$, $t = -4.69$. There were also main effects of word length showing that long words received longer go-past durations, $b = 9.33$, $SE = 4.39$, $t = 2.12$, and word frequency showing that low frequency word received longer go-past durations, $b = -7.48$, $SE = 3.80$, $t = -1.97$. There were no interactions on go-past durations. There was a main effect of word predictability on regression rates into the target word, $b = -0.21$, $SE = 0.08$, $z = -2.66$. Words in more constrained contexts were regressed into less than target words in less constrained contexts.

Discussion

The results of Experiment 3 showed that word predictability interacted with the effects of orthographic familiarity on first-pass skipping and first-pass reading times. Experiment 3 also showed that words with high average bigram frequency are subject to more processing difficulty when compared to words with low average bigram frequency. Target words in high constraint contexts were skipped more often than in low constraint contexts, but only for short words with high average bigram frequency. Contextual constraint also influenced first-pass reading times. Importantly, the effect of word predictability on gaze duration was also mediated by orthographic familiarity. Across both measures, target words with low bigram frequency were less influenced

by contextual constraint. First-pass reading times also revealed interactive patterns of contextual constraint, word frequency, word length, and average bigram frequency, indicating that these factors may influence the same stages of word processing. These findings show that contextual constraint modulates the processing difficulty for words with higher frequency (i.e., more familiar and ambiguous) letter sequences more so than words with lower frequency (i.e., more distinct or even unique) letter sequences.

The results of Experiment 3 revealed effects of letter bigram frequency when controlling for lexical frequency and word length. As stated earlier, several studies have found that words with unfamiliar or distinct initial trigrams are read more slowly during first pass reading when compared to counterparts with more familiar initial trigrams (Lima & Inhoff, 1985; White, 2008; White & Liversedge, 2004). The gist of these findings contrasts with the results observed for the current experiment. In the current study, words with high bigram frequencies were subject to more processing difficulty than words with low bigram frequencies. Importantly, these effects were observed while controlling for the influence of lexical frequency. Studies have often observed that low frequency letter sequences impose more processing difficulty than high frequency letter sequences. Nevertheless, the apparent discrepancy is explainable. Whereas previous studies have manipulated orthographic familiarity by controlling the frequency of the initial letter trigram, the current experiment manipulated orthographic familiarity using a measure of letter n-gram frequency that is sensitive to the entire word (mean bigram frequency). Furthermore, the current experiment used words that vary in length substantially. Many of the previous studies on the topic restricted target words to four or five letters, whereas the current

experiment used target words that were as much as twice that length. Word length and letter bigram frequency could also interact in unexpected ways. For instance, across different classes of word length, measures of n -gram letter frequencies could vary in the extent to which they capture morphological regularities. For instance, mean bigram frequency for longer words might be more related to the presence or absence of familiar (i.e. regular) morphological constituents. It may also be the case that longer words with low frequency letter strings are more likely to be truly unique or entirely informative given some subset of the letters. This circumstance for shorter words, even matched on n -gram frequencies, should occur far less often.

Critically, observing differences in the degree to which contextual constraint can modulate first-pass reading measures as a function of orthographic familiarity offers more support to interactive accounts of word predictability and offers evidence against post-lexical accounts that would predict no interplay of context and sublexical processing difficulty. The task of distinguishing a word from its orthographic competitors is presumably a task that must be undertaken prior to full lexical access. Importantly, observing that words with higher frequency letter sequences overall receive more processing benefit from context than words with lower bigram frequency provides evidence against explicit prediction accounts. Any well specified prediction should offer processing benefits irrespective of the specific letters involved in the expectation. However, the ease of selecting a particular word prediction, or the time required to do so, may vary as a function of lexical characteristics. It is unclear how closely a prediction process would mirror the typical recognition process. The context independent lexical characteristics that influence word recognition difficulty might

bias a time sensitive predictive process toward words that can be retrieved from memory more quickly. Predictions may also be more or less informative based on intrinsic uncertainty about word identity, such as how many lexical candidates are being evaluated.

The results of Experiment 3 suggest that readers make use of contextual cues when recognizing words with high frequency letter sequences. The interactive effects of orthographic familiarity and sentence context were also independent from the effects of overall lexical frequency. Taken together with the results of Experiment 2b, the findings suggest that contextual constraint can mediate lexical and sublexical sources of word processing difficulty. Critically, these interactions are more likely to occur according to interactive accounts of word predictability effects.

Table 5.1 – Lexical characteristics of target words in Experiment 3. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Mean	5.5 (1.22)	7.85 (1.34)	2.86 (4.42)
Range	4 – 8	4.19 – 9.92	0 – 19

Table 5.2 – Lexical characteristics of target words in Experiment 3 based on median split of mean bigram letter frequency. Standard deviations in parentheses

	Word Length	Word Frequency	Orthographic Neighborhood Size
Low bigram frequency	5.29 (1.16)	7.59 (1.40)	0.89 (2.01)
High bigram frequency	5.68 (1.27)	8.12 (1.23)	4.82 (5.25)

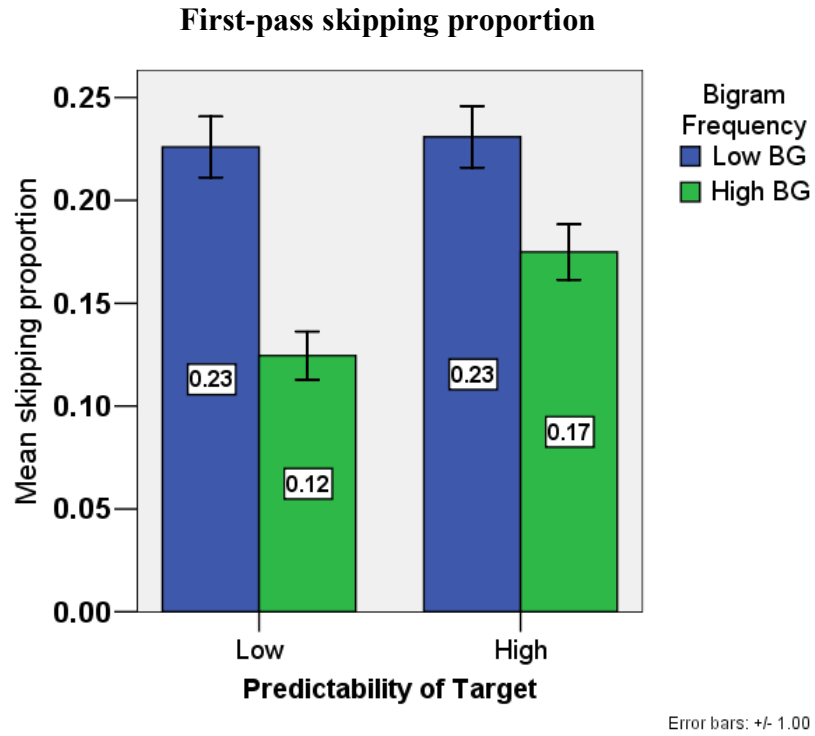


Figure 5.1 – Target word first-pass skipping rates across word predictability and bigram frequency.

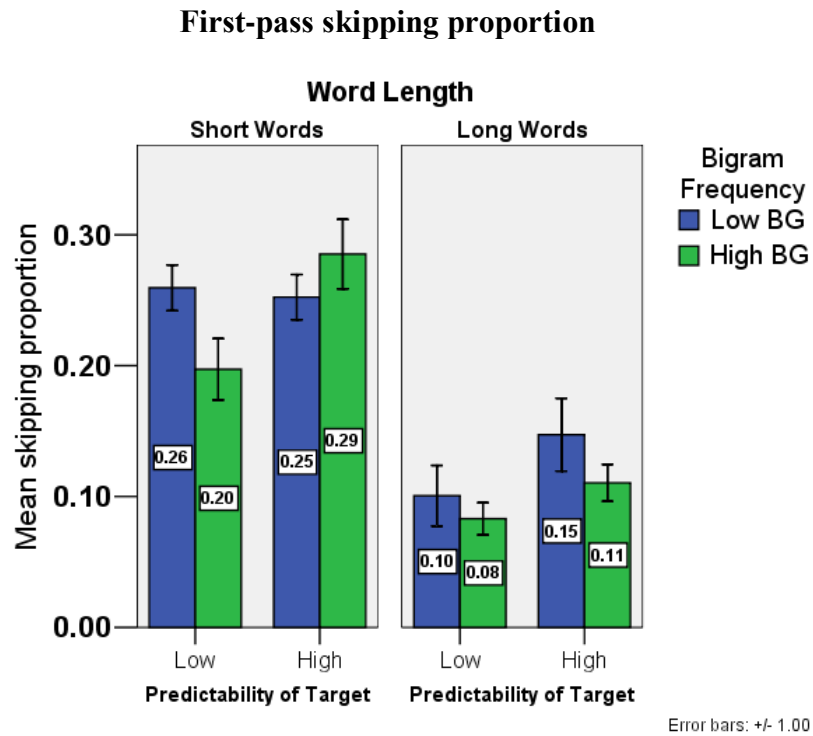


Figure 5.2 – Target word first-pass skipping rates across word predictability, word length, and bigram frequency.

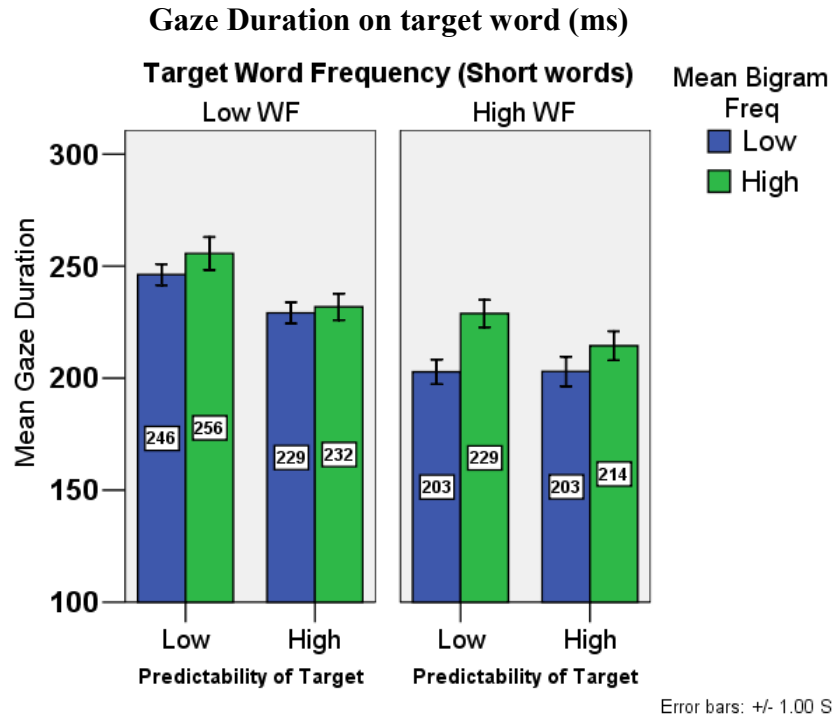


Figure 5.3 – Gaze duration (ms) on short target words across predictability conditions and median-splits of word frequency and bigram frequency.

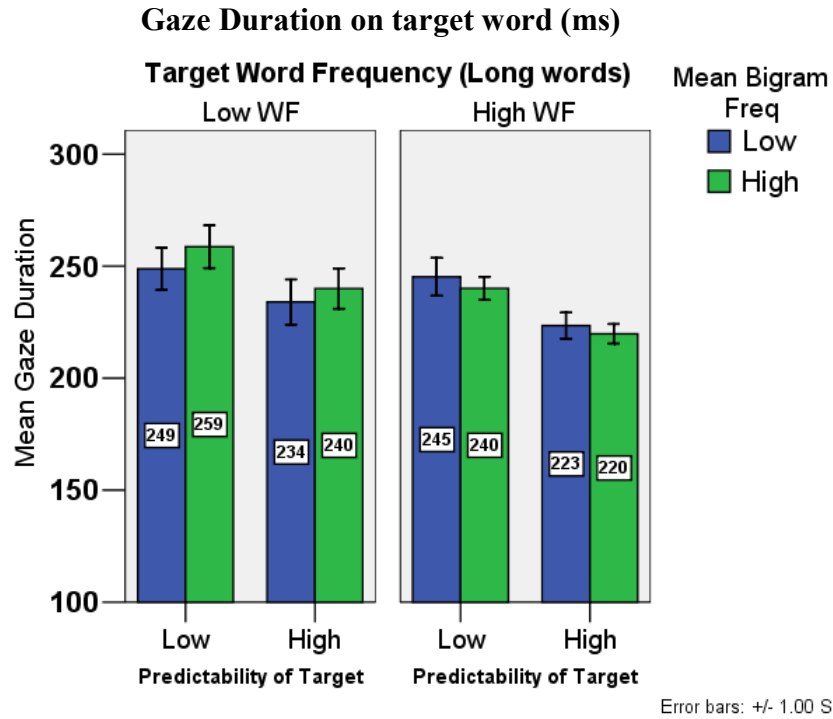


Figure 5.4 – Gaze duration (ms) on long target words across predictability conditions and median-splits of word frequency and bigram frequency.

Chapter 6

General Discussion

The purpose of this dissertation is to investigate the influence of contextual constraint and word predictability on the eye-movement behaviors that are known to index word recognition processes at the earliest possible stages. Across all of the current experiments, word predictability influenced first-pass reading measures. Experiment 1 found interactive patterns of target word preview and predictability on skipping rates and later measures of processing difficulty. The interactions on go-past duration for the post target word suggest that the processing benefits of parafoveal previews are mediated by context. Experiments 1 and 2a found that orthographic preview effects are largely contingent on letter overlap with the target word and, critically, this mediation is influenced by contextual constraint. Experiment 1, 2a, and 2b found that word predictability effects on first-pass skipping rates and reading times were preserved under phonological and orthographic preview conditions. Both Experiments 2a and 2b found that unrelated previews reduced predictability effects on first-pass reading times. Experiments 2b and 3 both used words across a wide range of frequency and length (as compared to Experiments 1 and 2a) and found that word predictability interacts with context-independent measures of word processing difficulty. Importantly, skipping rates for lower frequency and longer words were lower across the board, but to the extent that target words were skipped, the influence of word predictability and parafoveal preview was similar across all of the

experiments of the current study. The broader range of processing difficulty did however result in changes to the time-course of word predictability effects across reading measures. Critically, Experiments 2b and 3 showed that lexical characteristics known to influence word processing difficulty interact with contextual constraint on first-pass reading measures.

The current studies provide evidence that contextual constraint reliably influences the eye-movement measures most closely associated with word recognition during reading. Furthermore, the findings demonstrated that contextual constraint interacts with lexical characteristics and influences how parafoveal information about a word dictates decisions about whether to fixate a word and for how long. Taken together, these findings provide strong evidence against post-lexical accounts of word predictability effects. In each of the current experiments, target word predictability exerted an influence on the likelihood of skipping the target word. Importantly, word skipping is the earliest possible measure of processing for a word and is the only measure considered to be an exclusive index of early word recognition processes. Moreover, the effect of contextual constraint tended to be localized on earlier, rather than later, measures of word processing. It is difficult to propose a timeline wherein post-lexical effects can take hold prior to fixating a word during first-pass reading. Furthermore, according to post-lexical accounts, word predictability increases skipping rates due to increased ease of post-lexical integration. The effects of target word skipping across preview conditions in Experiments 2a and 2b cast further doubt on this possibility. In these experiments skipping rates were higher in high constraint contexts, even when readers encountered nonwords in high constraint context (so long

as the nonwords were orthographically or phonologically consistent). If predictability effects on word skipping were driven by integration ease, a cost associated with all nonword previews should have been observed along with higher skipping rates. Irrespective of the time course for word recognition, any observed interactions of contextual constraint and lexical variables (e.g., orthographic familiarity or preview characteristics) provide evidence against post-lexical accounts. This type of interaction was observed in each of the current experiments.

Interactive accounts of word predictability effects propose that word recognition is mediated by contextual constraint. The current findings cast doubt on some potential mechanisms for interactive word predictability effects. A lexical prediction strategy wherein only one letter string can receive the benefits of word predictability (i.e., an all-or-none prediction method) assumes that preview benefit should be inhibited for any preview condition that is not fully identical to the predictable target (even if the preview is consistent with the sublexical characteristics of the target word). Furthermore, phonological preview benefit in high constraint contexts should have been restricted to high letter overlap previews. The current results suggest that word predictability does affect the evaluation of parafoveal information, but not in a way that only benefits one potential string of letters. The results lend more support to potential prediction strategies that increase the probability of a preview string being associated with a predictable word to the extent that the parafoveal string is consistent with the sublexical characteristics of the predictable word at various levels of representation. In general the results of the current research study support an account of contextual constraint effects whereby a large subset of

lexical (or linguistic) representations are subject to the processing benefits afforded by word predictability and in some cases, constraint is such that only one or a small set of words are predictable.

In summary, the current study observed a great deal of evidence suggesting that word predictability effects actually have influences on word recognition processes. These influences cannot be accounted for by proposing an exclusively post-lexical account of contextual constraint effects. In general, the current findings fit with interactive accounts of word predictability wherein one important factor for word recognition difficulty is the word's predictability in context. Distinguishing various potential alternatives for word guessing strategies will require exact specification of linguistic representational structure and the probabilistic process used to generate linguistic predictions.

Appendix 2.1

Target word preview conditions from Experiment 1.

Target Word	Phonological Preview	Orthographic Preview
illusion	allusion	alluring
foul	fowl	foal
ball	bawl	bail
soles	souls	sorts
beach	beech	beast
paste	paced	packs
rose	rows	rope
heal	heel	heap
bear	bare	beam
fur	fir	fig
pairs	pears	pecan
brakes	breaks	breath
poor	pore	poem
meat	meet	mean
mail	male	mate
cereal	serial	served
cells	sells	soils
cent	sent	send
jeans	genes	genre
pier	peer	peas
accept	except	expect
week	weak	went
loot	lute	lull
rain	rein	ream
wear	ware	warn
sun	son	sum

muscle	mussel	muster
principal	principle	primarily
waist	waste	watch
weather	whether	whereas
descent	dissent	disrupt
write	right	ridge
steak	stake	stale
sweet	suite	suits
tale	tail	tall
plane	plain	plant
sails	sales	salts
peace	piece	piano
witch	which	where
maid	made	make
tide	tied	ties
pole	poll	pots

Appendix 2.2

Stimuli sentences embedded in high and low constraint sentence frames from Experiment 1. Target words presented in bold text.

At the show, Brandon and Chris saw an interesting **illusion** performed by a magician. Many popular magic tricks involve at least one optical **illusion** played on the eyes.

As he took his morning walk, David detected something **foul** smelling in the air. The referee gave the angry basketball player a technical **foul** after arguing with officials.

Lillian spent hours searching for the missing **ball** after school on Friday. When Lillian and Joe were playing she kicked the soccer **ball** over the fence.

Harrison knew after so long a time the weak **soles** were bound to give out soon. After too much running Harrison's gym shoes had worn out **soles** and uneven heels.

On Monday night Kate and her friends drove to the nearest **beach** wearing new wetsuits.

On a hot summer day, Kate walked along the beautiful sandy **beach** wearing a new swimsuit.

The digital file was large so Ian needed to copy and **paste** the text instead of retyping it.

At midnight, Ian went to the only open store to buy more **paste** for the project.

As an apologetic gesture, Kevin gave Alex a cheap **rose** with an old card.

In the garden, a sharp thorn on the red **rose** pricked his finger.

To Susan's surprise, the strange substance helped **heal** Brenda's bruised leg.

Since the bone was broken Jan needed to let her injury **heal** before playing again.

At the show Derek saw a large elephant and a small **bear** perform various tricks.

When Derek was camping he was fearful of grizzly **bear** attacks at night.

The devious criminal was buying and selling illegal **fur** without proper authorization.

When it is very cold in Alaska, the natives use animal **fur** to keep dry and stay warm.

When the large bag was stolen Kim lost seven **pairs** of her favorite shoes.

Everyone found a partner when the class split up into **pairs** for a short assignment.

While she was going to work yesterday morning, Tina used the **brakes** many times on the road.

When the car in front of her stopped suddenly Tina slammed on her **brakes** to slow

down.

After Rick went shopping for new clothes, he felt **poor** at the end of the day. Most people in homeless shelters are extremely **poor** and down on their luck.

The demanding boss sent his employees to the store to purchase **meat** products for the barbeque.

Erica is a vegetarian and has not eaten animal **meat** since she lived with her parents in high school.

Donna remembered she had to go back to the office so she could **mail** important files off.

Donna would need stamps and more envelopes before she could **mail** thank you notes out.

Last night Dan went to the store for organic **cereal** and paper towels.

Most mornings Dan eats a bowl of healthy **cereal** for breakfast.

The construction grid was divided into many **cells** to keep different things separated. In most prisons, the inmates live in small and confined **cells** with toilets and a bed.

On the way back home Stephanie found a single **cent** lying on the ground next to the road.

Stephanie spent exactly twenty-seven dollars and a single **cent** buying winter clothes.

Before the first day of school, Alexis and her mom went to buy **jeans** from the shopping mall.

Alexis was upset when she fell and ripped a hole in her new blue **jeans** she bought from the mall.

Joshua and Donny wanted to go to the crowded **pier** last Saturday, but everyone else did not.

While at the bay Donny went fishing on the crowded **pier** last Saturday, but all of the fish were gone.

When Diane's friends call her, sometimes she will **accept** the phone call immediately. As soon as the job offer was made Diane decided she would **accept** the position in the new town.

Linda was upset that she lost almost an entire **week** because she hasn't been feeling well.

Linda always worked more than forty hours per **week** because of her financial problems.

Most pirates and robbers refer to stolen treasure as **loot** in old movies and books.

After Jim came home from shopping, he looked at all his **loot** on the couch.

Saturday morning Katherine opened the window and saw **rain** and strong winds outside.

Pollution from the factory was proven to be the cause of acid **rain** and dense smog layers.

When Ron and Ben went to the casino, they would always **wear** their lucky hats. When it snows during the winter, Ron would always **wear** thick wool socks.

Justin walked outside to find that the excessive **sun** dried out the dirt. As Justin was outside he felt the heat of the bright afternoon **sun** glaring down upon him.

While he was in the office, Matt suffered a bruised **muscle** when he dropped a file cabinet.

While he was working out, Matt suffered a pulled **muscle** because he didn't stretch.

Since she dealt with so many complaints the exhausted **principle** went home early on Friday.

Since she dealt with teacher and student complaints, the high school **principle** went home early on Friday.

Kenneth's old socks were too short and his large **waist** made the pants useless.

Patrick's old belt was too short to fit around his large **waist** after so many years.

Martin didn't know if he was sad because of how unexpected the **weather** has been recently.

While they aren't always right, meteorologists can usually predict the **weather** most of the time.

While traveling, Todd slept through every moment of the fast **descent** toward the busy airport.

After climbing the tall mountain Tommy feared the long **descent** toward the base of the mountain.

Politicians in important positions must speak and **write** effectively so they can get reelected.

Children in elementary school learn how to read and **write** before they become too old.

Although Edward wanted to stay home, he was willing to go to buy **steak** from the market.

Although Edward wanted it rare, he was willing to eat the well done **steak** despite how hungry he was.

The mysterious plant had long vines and bright flowers with a very **sweet** smelling aroma.

The cake was full of sugar and covered in icing so it was very **sweet** according to customers.

Before taking the exam, Chris would need to study the long **tale** with an eye for details.

Before going to bed, every child likes to hear a fairy **tale** with a happy ending.

The first thing that Shannon did was purchase a luxury **plane** after she got rich. Investigators needed the flight path to find the crashed **plane** after it went down.

Everyone knew that it would take time to repair the white **sails** before the long trip. The boat moved faster as the strong wind filled the white **sails** during the long trip.

It is common for dedicated students to seek out a location with **peace** and quiet before reading.

Many pageant contestants express their desire for world **peace** and an end to hunger.

Mae drove to her grandmother's house to borrow the classic **witch** costume for the party.

The scary Halloween story described spells cast by a wicked **witch** living in a dark cave.

Before leaving the party, Alana noticed that the tired **maid** was cleaning up after everyone.

Before checking out, Alana left a huge tip for the hotel **maid** for cleaning the filthy room.

Over the last month Ron took measurements using a simple **tide** clock for his study of climate changes.

To catch the best waves Ron went to the coast during high **tide** last Friday afternoon.

Sofia and Tim both fell over after leaning on the weak **pole** because it couldn't hold their weight.

Sofia and Tim leaned against the school's metal flag **pole** because their feet hurt from walking all day.

Appendix 3.1

Target word preview conditions from Experiment 2a.

Target Word	Phonological Preview	Orthographic Preview	Unrelated Preview
phone	phoan	pohen	qhaun
feel	feal	flae	toet
girl	gurl	grul	yamb
white	whyte	wethy	uelto
brain	brane	banre	fiaul
green	grean	geran	qamun
train	trane	tarne	hezew
joke	joak	jeko	guhnl
lake	laik	leik	tunt
leaf	leef	leof	buct
goal	gole	gleo	jats
wire	wyre	wrye	ugol
tube	toob	tebu	hiof
moon	mune	mnue	wism
room	rume	remu	onzu
dirt	durt	drut	kwad
team	teme	taem	linm
cider	sider	seDIR	irtus
toad	tode	tado	dufi
stove	stoav	satov	olaue
goat	gote	geto	quls
safe	saif	sifa	cezt
jail	jale	jeal	pufa
seat	seet	soet	nurf
broom	brume	burem	faoem
home	hoam	haom	kuwr

chain	chayn	cahyn	skego
rose	roze	rese	aceo
scare	skair	sarik	elram
leash	leesh	leseh	fosuh
stone	stoan	soten	chenu
field	feeld	fleed	toshl
dream	dreem	derem	bonew
soup	supe	speu	noju
grows	groaz	goraz	pausm
rain	rane	rnae	mern
road	roed	reod	nist
herd	hurd	hrud	bont
nail	nale	nele	vute
knot	nott	natt	meff
mean	mene	meun	coaz
comb	kome	keom	fian
wide	wyde	weyd	ugho
senses	sinses	sisnes	vamsen
ocean	oshen	oneca	nukus
work	wurk	wrok	serl
grade	graid	giard	qerut
reef	refe	rofe	nide
soap	sope	spoe	wegu
save	saiv	svia	uxum
key	kee	koe	bav
firm	ferm	frem	decr
female	femal	famile	hanerl
wife	wyfe	wefy	splo

meal	meel	mlea	zoub
bake	baik	biak	tuef
first	furst	frust	brusk
deal	deel	dael	toub
robe	roab	rabo	oard
thief	thefe	tehef	klato
game	gaim	gima	yrue
bleed	blead	beald	thuoh
month	munth	mutnh	woolk
stale	stail	satil	chasf
bones	boans	benas	hinsm
grape	graip	garip	juong
wheel	whele	wlehe	shotu
smoke	smoak	samok	reash
hope	hoap	hape	kigm
hurt	hert	hret	dasb
plate	playt	palyt	gheph
proven	pruven	praven	juerum

Appendix 3.2

Stimuli sentences embedded in high and low constraint sentence frames from Experiment 2a. Target words presented in bold text.

Jill left for the airport without realizing she did not have her **phone** packed in her luggage.

Garrett left Susie a message because she did not answer her **phone** when he called Sunday.

The interior designer made a few minor alterations to improve the **feel** of the new bedroom.

The impressive full size model tiger was made to look and **feel** like the real thing.

Yesterday the farm boy watched intently as the young **girl** ran through the field back to the farm.

The shy boy was always afraid to talk to the pretty **girl** in class because he was not confident.

Sitting alone in the dark and empty room Jennifer could clearly see the **white** light coming towards her.

Lily separates her laundry and uses bleach on the clothes that are **white** so they stay looking clean.

The doctors were most concerned about the possibility of severe **brain** injury due the car crash.

A great deal of psychological research has examined the human **brain** during recent decades.

Stephanie mentioned that she wanted to buy a few more **green** dresses to wear to parties this year.

After lots of sunshine and water the long grass was more **green** than it had been in the winter.

The company was proud to announce at the conference the new **train** that would be used next year.

Jim and Dre ran to the railroad station to see the speeding **train** before it passed by them all.

The journalist thought that the news was an absurd **joke** and did not take the report seriously.

Todd could not stop laughing because of the funny **joke** his sister told him at the restaurant.

On some quiet nights they heard coyotes howling outside by the small **lake** until early

morning.

Every summer Dan's family rented a boat to take out onto the small **lake** where they would fish.

All he could do to fight off his boredom was **leaf** through an old magazine in the waiting room.

The Canadian flag is red and white with a big maple **leaf** in the middle center of the fabric.

The dedicated worker devoted months to completing the unfair **goal** before the factory closed.

The famous soccer player scored an amazing game winning **goal** during the World Cup final.

Sam tripped walking through the office because there was a bulky **wire** that was in the pathway.

In movies, experts disarm most bombs by cutting a specific **wire** while leaving the rest intact.

Heather's mom was angry with her when she found her empty **tube** of face cream lying on the counter.

The premature baby in need of nutrients was fed through a plastic **tube** until he could eat normally.

After finals the student spent all night relaxing while gazing at the **moon** and stars in the sky.

In most stories werewolves only come out during a full **moon** and disappear immediately after.

After a long work day the crew was ready to get back the quiet **room** for a good night's rest.

After every dinner the family spends quality time together in the living **room** before going back to work.

Diana brought home leftovers from work but the food was covered with **dirt** from the picnic tables.

After sliding into third base her uniform was covered with grass and **dirt** for the rest of the game.

The manager of the company had to organize a **team** of advisers to help make decisions.

After the World Series victory the winning **team** was presented with a huge trophy.

At the dinner he poured himself a tall glass of fresh **cider** and enjoyed his juicy steak and salad.

Before getting food I ordered a glass of hot apple **cider** when I ate dinner at the popular restaurant.

The elementary school teacher brought her students a fish and a **toad** to be their class pets.

Tracy did not really know the difference between a frog and a **toad** until she saw them together.

The movers had a difficult time lifting the big **stove** and maneuvering it into the kitchen.

Leaving the kitchen Connie made sure to turn off the hot **stove** so that nothing would catch on fire.

The old farmer was filled with joy as he was awarded for his prized **goat** at the county fair.

Farmers who cannot afford cows to produce dairy products often use **goat** milk as a substitute.

Not knowing what to expect, they all slowly approached the locked **safe** inside the old cellar.

The skilled bank robbers quickly broke into the locked **safe** during the well planned heist.

The two experienced volunteers met outside of the county **jail** before going inside to help.

The local police officers transported the prisoners to the county **jail** after a long wait.

After the remodeling is finished the movie theater will **seat** nearly twice as many people.

In any crowded movie theater it gets hard to find a good **seat** after the lights go out.

Before bed Alan made sure that the wooden **broom** was in the right place in the closet. Alan swept the dusty floor with the wooden **broom** before Susan dropped by for a visit.

The company owners were very excited when they finally found the ideal **home** for their headquarters.

Larry had lots of assignments to finish at work before he could return **home** and rest after a long day.

Brandon looked everywhere in the garage for the yellow **chain** they used to lock the gate.

Many large mammals, like tigers, are at the top of the food **chain** without any natural predators.

At the main warehouse Helen kept a bright red **rose** inside a glass vase on her desk. Christopher gave his girlfriend a fresh red **rose** because it was their anniversary.

The middle school teacher used the medical news article to **scare** the students into not smoking.

Gustavo enjoyed Halloween because he loved to use a frightening costume to **scare** people at night.

The alcoholic man knew he needed to keep a tight **leash** on his drinking on nights and weekends.

When walking his disobedient dog Tim had to keep a tight **leash** on the animal for safety.

The real estate advertisement had a picture of a kitchen with **stone** counter tops around the oven.

The entry level position that Nate accepted was an ideal stepping **stone** to a higher paid position.

The researcher was working in the barren **field** when she made the archaeological discoveries.

The grounds crew cut the grass on the football **field** so it would be ready for the championship game.

The award winning researcher had achieved his professional **dream** in only ten short years.

Melissa screamed in bed when she suddenly woke up from a strange **dream** she was having.

All the kids who played in the band tried the very filling **soup** when they were on the trip.

All the kids who have colds stay home and have chicken noodle **soup** until they feel better.

Alexander must be careful because if his reputation **grows** much larger he will likely become arrogant.

Ray goes to the barber every month because his hair **grows** fast and he wants to keep the same length.

The professional boxer struck his foe with a heavy **rain** of blows to his head.

The sky was dark and cloudy before the heavy **rain** on the hot summer night.

The economist stated that the nation is on a short **road** to a financial collapse in the report.

The family had to slowly drive down the long dirt **road** before reaching the isolated cabin.

During the summer tourists are always hope to spot the wandering **herd** known to inhabit the area.

The startled buffalo calf raced back to rejoin the stampeding **herd** after the bear approached.

Pete looked in the drawer to see if he had an extra **nail** he could use to build the bench. Jackie paid for an expensive manicure after the broken **nail** she got hanging a picture.

Nellie was so nervous before going onstage that she felt a tight **knot** in her stomach. Samuel reached down to his laces to try and untie the tight **knot** in his running shoes.

In class the high school student had to find the **mean** number of students on each floor of the school.

The child thought the bullies on the playground were **mean** because they would make fun of his clothes.

The police officers were given specific instructions to fully **comb** the city until the suspect was found.

When the girl's hair was tangled her mother would always **comb** it right after giving her a bath.

The charismatic salesman said this new truck features an extra **wide** bed for hauling stuff around town.

Quin has trouble finding shoes because his feet are so long and **wide** that they don't fit in most sizes.

Inventions like the microscope allow scientists to extend our **senses** past normal human limitations.

For humans, vision may be the most important of the five **senses** which we use to experience the world.

The overworked salesman stretched out and admired the clear **ocean** view while on his vacation.

The TV special explained that the Pacific is the biggest and deepest **ocean** on the entire planet.

The award winning doctor was known worldwide for his **work** in the development of new medicine.

Tanner just got the new job and on his first day of **work** he enjoyed learning the new skill set.

The truck shifted into a lower gear when maneuvering the steep **grade** road while coming down the valley.

After the last exam I was anxious to find out my final **grade** because I didn't think I

did very well.

Something that Kyle was excited to do on his trip was to see the famous **reef** at the coast.

In Australia a diverse group of sea animals live in the large coral **reef** off the coast.

The man wanted to pick up everything on his list but could not find **soap** anywhere at the store.

After taking out the trash Meg washed her hands thoroughly with **soap** because she hates germs.

The skilled soccer player was able to run quickly and **save** the ball from going out of bounds.

After his promotion, Marvin opened a bank account so he could **save** the money he was earning.

Patricia suddenly realized that she had thrown away the lost **key** to her office drawer. Elva could not get into the storage locker because her lost **key** had not been found.

All the villagers hoped that the large barrier would stand **firm** when the troops attacked.

The bright attorney quickly made a partner at the most successful law **firm** in the country.

After so many years, the dog trainer preferred to work with **female** dogs and felt a bond with them.

The freshman undergraduates reported their gender as male or **female** before being placed with roommates.

He searched the train station for almost an hour before he found his **wife** in the cafe buying coffee.

During the reception the priest announced John and Ann as husband and **wife** while their families cheered.

The girl pushed her way into the crowded line to get another **meal** for her brother. My mother always told me that breakfast is the most important **meal** of the day.

Michael does not know if Stephanie can **bake** a pie for dessert so he plans to teach her. I made the two cakes and put them in the oven to **bake** before the party this afternoon.

The printing press was one of the important inventions of the **first** part of the fifteenth century.

Because she was the fastest runner Alice got to the finish line **first** and won the race easily.

The Saturday morning farmer's market is the reason for the great **deal** of people in the streets.

With the store going out of business, shoppers thought they could get a good **deal** on old inventory.

The man went into the closet looking for his best **robe** and proceeded to offer it to his guest.

On long winter nights I love to wear my mother's old bath **robe** because it keeps me warm and cozy.

The reporter spoke to the woman not knowing she was the skilled **thief** responsible for the heist.

Sandra opened the vault to discover that everything had been stolen by a crafty **thief** during the night.

Sue and Ali put weeks of work into the new educational **game** before they put it on the market.

Emily and Dave will miss the championship basketball **game** tomorrow because of their finals.

The doctor was concerned that the patient had started to **bleed** internally after the surgery.

When Kerry cut her finger slicing an apple it quickly started to **bleed** before she found a bandage.

After a long time the engaged couple carefully selected a convenient **month** for their wedding ceremony.

According to the book for most of the major cities January is the coldest **month** of the year by far.

After so many long hours he had grown **stale** on the job and needed a long vacation. Tonya thought the old potato chips tasted **stale** so she threw them in the trash.

The constructor workers dug a deep hole and found broken **bones** buried beneath the surface.

Ric wore casts for months after suffering nasty bruises and broken **bones** during the horrible fall.

Henry became annoyed at the party when he saw the last **grape** he was saving was not on his plate.

Jerry hoped to make his own wine so he started to grow **grape** vines in his backyard last summer.

The corporate recall letter strongly advised owner to replace the front **wheel** before failure occurred.

Everyone at the park was in the line to ride the giant Ferris **wheel** before it was even lunchtime.

The rangers at the remote outpost are always on the lookout for **smoke** and other signs of danger.

Danielle had a cigarette in her car and it left the inside smelling like **smoke** the entire week.

The greatest fear his mom thinks he could ever have is the fear of losing **hope** amid his challenges.

When the doctors said her mother was improving Jane knew there was still **hope** for a full recovery.

The widespread news of the shocking political scandal seriously **hurt** the senator's reputation.

She didn't jump over the wall because she was afraid of getting **hurt** and did not want to fall.

Before leaving the house Andrew put the large **plate** into the sink and turned out the lights.

The fast baseball player slid into home **plate** before the ball got to the catcher's mitt.

The company has stated that the new drug has not been **proven** toxic to humans or animals.

In our justice system defendants are innocent until **proven** guilty in a court of law.

Appendix 4.1

Target word preview conditions from Experiment 2b.

Target Word	Phonological Preview	Orthographic Preview	Unrelated Preview
diapers	diepers	direeps	Kuezegs
flight	phlyte	plythe	gluhfa
schools	sckools	scloosk	mehuant
priest	preest	proest	qusawd
skunks	scunks	suncks	rivotz
gladiators	glatiadors	glaridatos	phurnkoles
people	peapol	peloap	yioyat
screaming	scrieming	scrigenim	nuoerning
writer	rhyter	hertry	muclep
skinny	sckiny	snicky	ulourp
liquor	lickor	lirock	faturh
league	leegue	leogue	hexper
cloudy	clowdy	clondy	slocty
running	wruning	wurning	euaneyy
drawers	droores	drouser	taosuwe
zone	zoan	zoaw	wium
chlorine	kloorine	kroanile	drieshke
nurses	nerses	nesers	vosezs

forecast	fourcast	foturacs	loeamment
noodle	newdle	nawlde	wemite
shoes	shues	shaes	ubris
wagons	waguns	wagsun	sejuir
scripts	skripts	stripsk	coaqihe
accident	aksident	adkients	seerfiat
chores	choors	chooms	adunns
screens	screans	screvae	reawnoz
nervous	nurvous	nosurvs	zesunis
problems	problums	problurs	yaudhers
suits	sutes	suset	viobs
squirrels	squourrls	squlorurs	nyasoerds
vinegar	viniger	vinreig	ereogas
fiction	ficshun	ficulns	keastux
werewolf	wearwulf	wualwerf	sezoueth
eruption	erupshun	erupleze	suaylias
pencils	pinsils	pilsins	yumoalc
recycle	resicle	rewicle	naspefs
flowers	floures	floseru	thremes
advantage	advantege	advantepe	whinoubye
bacteria	bakteria	barlieat	toafenea

cellphone	cellphoan	cellphoas	nethyoone
orchestra	orkesstra	orutorlse	seefrehat
bikini	bikene	bikepe	dakren
submarine	submerine	submezine	ertescent
syllabus	sillabus	saublils	opliobes
satellite	satelight	satelthig	ceduffean
umbrella	umbreala	umbreate	arfustle
volunteer	voluntear	voluntesm	ridamboas
intelligence	intellijense	intellipense	erbutteqarne
gymnast	jimnest	jetmins	pejerad
evolution	evolushun	evoluskun	wartoheve
dinosaurs	dinosours	dinoseems	fasamouwn
comedian	cumedian	canedium	merubern
critic	kritic	kitric	nialen
caffeine	capheine	cahipene	valteman
dandruff	dandrief	dandreat	kealmitt
elections	elekshins	eleskihns	atisleave
dozen	dozin	doniz	beour
fugitive	fujetive	fupetevi	kepulaun
elephants	ellefants	elfanelts	shoghouts
fountain	fowntain	fonatiwn	bicuhnes

bartender	bartindur	bartrudin	teshconan
bedroom	bedrume	bedemur	kubnems
alcoholic	alkoholic	alholkcio	sheatedis
groom	grume	gremu	joass
dashboard	dashbored	dashboder	fecklebis
skeleton	skeletun	sekeltun	abudalen
snowing	snohing	snofing	rauning
scrolls	skrowls	slowrks	clomnty
swimsuit	swemsoot	smewsoot	ornzeret
suburbs	suberbs	subesrb	intaste
strangers	stranjers	stransrej	chemarpoe
ornaments	ornemints	ornsitekn	wecurnads
skateboard	skeghtbord	skodghrebt	chedaleant
fertilizer	fertiliser	frulistier	harbedanun
gentlemen	gentulmen	genthowie	poolferem
honeymoon	hunnymoon	humononyn	dariegsiw
evaporate	evapurate	evapueart	cragonite
scholar	skahler	sheklan	citudas
officials	offishals	offisalds	attirelke
graduate	grajuate	grapaute	peshawls
criminal	creminal	crominal	ozinerat

grains	greins	grunis	quasim
main	mayn	marn	crov
scored	scoard	scodra	wennab
drain	drane	drase	becem
stroller	stroaler	stroeral	chaslter
whisper	wispper	wisperg	obeejun
secretary	secritery	secreyirt	vracating
elevator	elivater	elarivet	atamohon
addiction	addicshun	addiculns	uffonpeon
practice	practiss	practier	jesufrie
hypnosis	hipnosis	honisips	agyrezim
fluorescent	floouessent	flenorsonts	tharvinnard
operation	opuration	oparnuoit	agroulaou
servants	survents	sunverst	cozenete
utensils	utinsuls	utonsuls	alercert

Appendix 4.2

Stimuli sentences embedded in high and low constraint sentence frames from Experiment 2b. Target words presented in bold text.

Rachel and Peter always found several bags of dirty **diapers** in the dumpster behind the garage.

Rachel and Peter take turns changing the baby's dirty **diapers** whenever the sitter is gone.

Most people check popular websites to find the cheapest **flight** before buying their tickets.

Most people check airline websites to find the cheapest **flight** before buying their tickets.

The company sent the shipment of computers to the largest **schools** before the smaller ones.

The company sent the shipment of textbooks to the largest **schools** before the smaller ones.

Last Tuesday, Maria spotted her childhood **priest** driving around the shopping center. Last Sunday at church, the compelling **priest** inspired the attendees with his message.

On the way home through the neighborhood we avoided the smelly **skunks** by quickly running by.

While hiking we avoided being sprayed by any of the smelly **skunks** by quickly running by.

Neither of the ambitious explorers had expected to find frantic **people** roaming the rugged land.

During the holidays, shopping malls are always packed with frantic **people** looking for gifts.

The mother had to keep herself from suddenly **screaming** when she couldn't see her child.

The children on the playground were loudly **screaming** for their busy mother's attention.

Kailey was an ambitious and talented **writer** and thus drew a lot of attention.

The local newspaper hired the talented **writer** for a full time position in the fall.

After buying the new clothes Peggy found that she was too **skinny** for the pants she had chosen.

After dieting Peggy's pants would not fit because she was too **skinny** so she had to go

shopping.

The group went to the convenience store to find the most expensive **liquor** they could afford.

The group at the bar ordered shots of the most expensive **liquor** they could see on the shelf.

It was the aging father's dream to make it to a major **league** game one day.

It is the baseball player's dream to make it to a major **league** team one day.

The unknown beverage in the container was quite **cloudy** near the bottom of the glass. The weather report predicted high temperatures and partly **cloudy** skies with a chance of rain.

Despite her busy schedule at work, Bea started **running** every day after her class at night.

Afraid of being late for her class, Bea started **running** across the campus to get there in time.

Ally spent all day shopping online for the sturdy **drawers** that she needed for her supplies.

Most of Ally's clothes were stored in stackable plastic **drawers** that she brought from home.

The regional company set up a base **zone** where they planned to focus their marketing efforts.

The couple landed in a different time **zone** after the long flight so they had to sleep all day.

He heard the big mess on the road last night came from a simple **chlorine** spill from a truck.

The water polo player's hair was dyed a lighter color by the pool's **chlorine** last summer.

The rambunctious group at the restaurant was full of loud **nurses** unwinding after a long day.

The hospital is full of patients getting treated by the busy **nurses** running through the halls.

The children refused to let an unfavorable **forecast** keep them from playing outside. Fred stopped to check the daily weather **forecast** before driving to work.

Aunt Rachel was known for her famous **noodle** dish which was loved by all.

Yesterday at dinner Timmy dropped a spaghetti **noodle** on the floor.

After many weeks of jogging Alice will need to buy new running **shoes** before the big race.

After getting hired as the manager Alice will need to buy better **shoes** for her first day.

The engineering students were all asked to design **wagons** for their final project.

The parking lot was unusually full of station **wagons** and old minivans last Sunday.

He had written many novels but had little experience writing **scripts** for plays and TV shows.

Broadway performers spend a lot of time reading through movie **scripts** and memorizing lines.

No one seemed surprised at all when the bad **accident** occurred outside the studio.

Last year, Stacy was in an extremely bad car **accident** before the school year started.

Unlike most people, Kailey really loved **chores** and looked forward to completing them.

Kailey quickly tried to finish her household **chores** before going out with her friends.

Tim rushed to the store to buy one of the newly released computer **screens** that were on sale.

Tim rushed to the store to buy one of the high-definition computer **screens** that were on sale.

The hard working senior in high school was quite **nervous** to hear back from the universities.

The neuroscience major studied the functions of the central **nervous** system for her final exam.

Sheila was running out of time to get to the last **problems** given the time constraints.

Sheila needed the tutor to help her solve the weekly math **problems** given by her teacher.

When entering his new trade, Nick spent lots of money on expensive **suits** before his first day.

When starting his new job, Nick spent lots of money on tailored **suits** before his first day.

They did not expect to find so many **squirrels** roaming so closely to the beach.

The park was full of furry and curious **squirrels** searching for nuts and other food.

The classic homemade sauce recipe called for pungent **vinegar** mixed with a cup of oil.

The sauce recipe called for a cup of balsamic **vinegar** mixed with a cup of oil.

Joey had the skill and passion for developing creative **fiction** novels and comic books. Joey spent many days reading comic books and science **fiction** novels in his basement.

In the old building crowds watched competitions between **gladiators** before the fall of Rome.

In the Roman Colosseum crowds watched fights between **gladiators** before the fall of the empire.

At the start of the movie a dark silence was ended by the huge **werewolf** coming on screen.

On the night of a full moon the boy was bitten by the huge **werewolf** deep in the forest.

After much arguing it was clear that an emotional **eruption** was inevitable from both parties.

After years of no seismic activity the sudden volcanic **eruption** came as a surprise.

The interns were always wasting supplies and throwing **pencils** when the office manager was out.

The students made sure to sharpen their test taking **pencils** before the exam started.

Amanda was trying hard not to **recycle** themes in her novels and poetry.

The waste processing facility will reuse or **recycle** most of the material that comes in.

The chef used many rare types of garnishing **flowers** to perfect the looks of his dishes.

The florist had a surplus of beautiful **flowers** so she marked down the regular prices.

The blue team had a clear **advantage** after scoring a fifth goal against the opposing team.

The home team had a clear **advantage** after scoring a fifth goal against the opposing team.

Mya acquired the powerful treatment to stop the dangerous **bacteria** from spreading further.

Mya is prescribed powerful antibiotics to stop the dangerous **bacteria** from spreading further.

Maria was going through her bags and realized that her expensive **cellphone** had been lost.

Maria is always talking and texting on her expensive **cellphone** while out with the girls.

The renowned artist performed the famous piece with the talented **orchestra** at the old venue.

The violinist performed the famous symphony alongside the talented **orchestra** at the

old venue.

Jane's parents hated when she went out at night wearing her pink **bikini** over the summer.

Jane's parents hated when she went to the beach wearing her string **bikini** over the summer.

The company worked in secret to design a faster **submarine** unlike any they had built before.

The Navy worked in secret to design a faster **submarine** unlike any they had built before.

The professor was quite absent minded and misplaced her laptop, **syllabus** and phone charger.

The students audibly groaned as they read through the semester's **syllabus** for the hard class.

The new and improved version of the advanced **satellite** should help restore communications.

Launched into orbit by NASA, the advanced **satellite** monitors electrical activity on the ground.

Gabby finally found a place to store her bulky **umbrella** when she organized her room.

Gabby would rather be drenched than carry such a bulky **umbrella** when it rains.

The entire charity organization was staffed by great **volunteer** workers and funded by donations.

The entire private organization was staffed by great **volunteer** workers and funded by donations.

Many thought Maria's driven personality and intimidating **intelligence** kept others at a distance.

People classified as geniuses have above average **intelligence** according to standardized tests.

Alana practiced hard every night while striving to be an Olympic **gymnast** in the coming years.

Alana practiced on the balance beam striving to be an Olympic **gymnast** in the coming years.

The high school science teacher completely refused to accept **evolution** as a credible theory.

When teaching biology, many schools treat the theory of human **evolution** as a controversial one.

Billy loved science classes where he learned about ferocious **dinosaurs** and other animals.

With special effects, the film Jurassic Park depicted extinct **dinosaurs** that died long ago.

Initially, no one pegged Andrew for a successful **comedian** due to his shy disposition. Eddie Murphy started out working as a standup **comedian** and eventually moved towards acting.

Roberta was happy to get constructive feedback from the harsh **critic** after her job evaluation.

All the directors wanted good reviews from the renowned movie **critic** who influenced the masses.

Every afternoon Jack needed to have his daily **caffeine** fix before getting any work done.

Carla loved coffee and the invigorating buzz from **caffeine** so she drank it often.

Sally the cheerleader secretly had a serious **dandruff** problem she hid from her peers. Samuel used Head and Shoulders shampoo to prevent **dandruff** and make his hair smell nice.

Most registered members of the club take part in the entertaining **elections** every few years.

Most registered voters in America take part in the presidential **elections** every four years.

At some stores and markets, shrimp can be bought by the **dozen** in special bags.

At most stores and markets, eggs can be bought by the **dozen** in special containers.

Special trackers and locals search the area for the vicious **fugitive** while he tries to flee.

Special agents and local police search the area for the escaped **fugitive** while he tries to flee.

Poachers that violate hunting laws are the primary threat to most **elephants** still in the wild.

Poachers hunting for ivory tusks are the main threat to most **elephants** still in the wild.

In the hallway there was a line of kids waiting to use the short **fountain** before the bell.

At recess there was a line of kids waiting to drink from a water **fountain** before the bell.

Mark had too much on his mind so he refused the offer by the busy **bartender** before going home.

Mark had too much to drink so he was refused service by the busy **bartender** before going home.

The couple went into debt when paying for their master **bedroom** in the new house. The couple slept on couches while waiting for their master **bedroom** to be completed.

Social activities can lead anyone to become a serious **alcoholic** under certain conditions.

Social drinking can lead anyone to become a serious **alcoholic** under certain conditions.

The tension was building as the quiet guests watched the nervous **groom** standing at the altar.

There was romance as the bride locked eyes with the nervous **groom** standing at the altar.

Russ bought the car used and wasn't concerned about the glass in the **dashboard** that was cracked.

Russ could not check his car's gauges when the lights on the **dashboard** were not working.

The renowned practitioner used a large monitor to view an entire **skeleton** when assessing injury.

The radiologist used full body x-rays to view an entire **skeleton** when assessing the trauma.

In order to get home in time, they hurried back before it started **snowing** on the roads. With the blizzard on its way, they hurried home before it started **snowing** on the roads.

Many historians have examined the ancient cave **scrolls** discovered back in the 1950s. Many historians have examined the Dead Sea **scrolls** discovered back in the 1950s.

The movie star was featured in the most popular **swimsuit** magazine last year.

The celebrity model was featured on the Sports Illustrated **swimsuit** magazine cover last year.

The couple didn't want to raise kids without help so they moved to the **suburbs** near their family.

The couple did not want to raise kids in the city so they moved to the **suburbs** after saving up.

Evan and Will hoped to avoid talking to any **strangers** whenever they went out.

Young children are taught to avoid talking to any **strangers** without their parents

around.

In spring, the family will decorate the tree with bright **ornaments** before the flowers bloom.

In December, the family will decorate the tree with Christmas **ornaments** before the holidays.

Jordan told the story of starting his day off by losing his **skateboard** in the parking lot. Jordan tried a new trick and hurt his arm falling off his **skateboard** last Saturday afternoon.

The vendor sold quite a few items through his catalog but expensive **fertilizer** was in demand.

The farm had such bad soil that nothing grew without expensive **fertilizer** and lots of water.

The host of the award show sang and joked with the **gentlemen** during the opening speech.

The host of the award show addressed all the ladies and **gentlemen** during the opening speech.

The organized couple took some extra money with them on their **honeymoon** in the Caribbean.

The newlywed couple took extra time off work to go on their **honeymoon** in the Caribbean.

At the last city council meeting they all agreed that the funds would **evaporate** before too long.

During the drought they built reservoirs to collect rain before it could **evaporate** in the sun.

The whole group attended the presentation from the distinguished **scholar** visiting the college.

All the academics attended the lecture from the distinguished **scholar** visiting the college.

The news report exposed the crimes committed by many company **officials** during the last year.

The news report exposed the bribes taken by local government **officials** during the last year.

After finishing his tasks last month Doug knew he could finally **graduate** from high school.

After passing his classes senior year Doug knew he could finally **graduate** from high school.

It took several willing bystanders to stop the scary **criminal** running through the streets.

It took several police officers to arrest the scary **criminal** running through the streets.

The convoy of trucks carried the very large shipment of whole **grains** needed for the region.

The organic market only sold bread made from the finest whole **grains** grown in the region.

The guests drank their beverages and waited excitedly for the **main** course to arrive. The guests devoured their appetizers and waited excitedly for the **main** course to arrive.

The tired competitor was not able to stop the opponent who quickly **scored** at the end. The tired goalkeeper could not get back before the opponent quickly **scored** in her absence.

He left the project site without realizing the cleaning supplies could **drain** out of the bucket.

He reached into the dishwasher and pulled the plug so the water could **drain** out of the sink.

Genie was tired of looking through stores and websites to find the right **stroller** for the baby.

When Genie was tired of carrying her infant she put him in the baby **stroller** for a while.

Sitting in bed by the open window, Catherine could hear the gentle **whisper** of the wind.

Catherine didn't want others to hear so she spoke in a gentle **whisper** to the girl nearby.

The successful leader really needed to find a new **secretary** for the office.

The disorganized businessman really needed to hire a new **secretary** for the office.

The interns watched in amusement while the new guy tried to fix the **elevator** near the hall.

The interns didn't have time to take the stairs so they waited for the **elevator** to come back.

Jim has been in jail because of his serious problems with **addiction** and deep depression.

Jim has been in rehab trying to conquer his problems with **addiction** and deep depression.

After the bad night the crew knew their boss would make them **practice** harder that week.

After the bad loss the team knew their coach would make them **practice** harder that week.

The unconventional specialist pulled her client from the deep **hypnosis** after the session.

The unconventional therapist put her patient under deep **hypnosis** during the session.

Ben needed a long nap after being exhausted by the bright **fluorescent** lights at his job.

Ben needed some natural light after being inside under the bright **fluorescent** lights at his job.

Simon bought a book to learn how to perform the delicate **operation** of computer repair.

The surgeon needed to prepare her patient for the delicate **operation** on his spinal cord.

The leader knew he would have to recruit more loyal **servants** for the cause.

The wealthy family's mansion was maintained by a number of loyal **servants** roaming the property.

Quinton looked through the mail order catalog for new metal **utensils** to use in his kitchen.

Quinton hated plastic forks and would only use metal eating **utensils** in his kitchen.

Appendix 5.1

Stimuli sentences embedded in high and low constraint sentence frames from Experiment 3. Target words presented in bold text.

Everyone at the variety show was impressed by the skilled **oboe** player at the end.
Everyone at the band recital was impressed by the skilled **oboe** player in the back.

The boy constantly used his ointment because of the awful **lice** that spread to him at camp.
The boy constantly scratched his scalp because of the awful **lice** that spread to him at camp.

The popular reality show follows the daily lives of seven **dwarfs** who live in middle America.
The popular fairy tale about Snow White and the seven **dwarfs** ranks highly among kids.

Their first day on the job, the interns had to organize all the huge **crates** in the basement.
The textiles and food products were shipped overseas inside of huge **crates** made of steel.

The influential artist in the painting is one of the most famous **jazz** musicians from the past.
The American musician, Miles Davis, is one of the most famous **jazz** artists from the past.

Jocelyn stopped by the convenience store to pick up her favorite **wine** from the shelf.
At the vineyard Jocelyn picked out a bottle of her favorite **wine** from the cellar.

Kyle went to the grocery store to pick up cheap **vodka** for the house party.
Kyle went to the liquor store to pick up cheap **vodka** for the house party.

Tommy rarely gets chances to go to the store and buy the cheap **lager** he has loved for years.
Tommy likes all kinds of beer but his favorite is still the cheap **lager** he has loved for years.

The storage facility had a special area where workers were laying **eggs** onto specialized plates.
Their farm would lose money if it weren't for the chickens laying **eggs** on a regular basis.

On the trail, we could hear the loud calls of the impressive **lion** while he was eating.

At the zoo, we could hear the fierce roar of the impressive **lion** while he was eating.

On his jog through the forest Marcus found a bright red **ruby** on the ground under a tree.

The central jewel of the beautiful ring was a bright red **ruby** cut into a triangular shape.

Jenny saw that the walls were covered with red **ants** from somewhere under the house. The persistent exterminator followed the long line of red **ants** back to their nest.

The siblings fell asleep on the couch watching a special on green **algae** living in the ocean.

The water's surface was covered in seaweed and green **algae** stopping the people from swimming.

The view from the bedroom window was blocked by the thick **vines** growing around the aging home.

The jungle floor was covered by large roots and thick **vines** growing in every direction.

The girls got time this weekend to test out the new recipe for spicy **wings** at the house. The sports bar and restaurant offered a variety of flavors for their spicy **wings** on the menu.

The girl carefully guided the clumsy **puppy** toward the pile of blankets. The dog carefully guided her clumsy **puppy** toward the pile of blankets.

Patrick went to the hospital for the cracked hip and broken **fingers** he got falling over. Patrick slammed his hand in the car door and got a few broken **fingers** that took years to heal.

Maintenance workers will need to come back and replace the main **circuit** before next week.

The electrician will need to come back and replace the main **circuit** before next week.

The group took many pictures of the rocky **barrier** protecting the primitive town. The group had to climb over the rocky **barrier** protecting the primitive town.

The man loved to watch movies about simpler times and the brave **knights** of historical lore.

The boy loved stories about medieval times and the brave **knights** of the medieval period.

Federal agencies took extra steps to reduce the threat of socialist **attacks** at the meeting.

Homeland Security took extra steps to reduce the threat of terrorist **attacks** at the event.

The majority of the people had not been able to meet the experienced **teacher** before she moved.

The rest of the faculty at the school looked up to the experienced **teacher** for her wisdom.

During the review, the stubborn citizen was caught **cheating** on his taxes by the IRS. During the exam, the struggling student was caught **cheating** by the teaching assistant.

The hard trivia question asked about the most famous movie **vampires** over the decades in film.

Count Dracula is the most famous of all the movie **vampires** over the decades of films.

They enjoyed the afternoon relaxing and eating snacks in the large **canoe** floating on the river.

They enjoyed the afternoon floating down the river in a large **canoe** carved by hand.

The party ended when the group was charged by an angry **rhino** concealed by the bushes.

The safari ended when the group was charged by an angry **rhino** concealed by the bushes.

The national and local forces came together to control the drug **cartel** active in the city.

The Mexican and U.S. authorities cooperated to bring down the drug **cartel** active on the border.

The family had a meeting to get information about the drug **addict** before it was too late.

The family had an intervention to get treatment for the drug **addict** before it was too late.

They used equipment to digitally capture every moment of the solar **eclipse** in the sky. Everyone used equipment to protect their eyes while watching the solar **eclipse** in the sky.

The trained technicians needed a strategy for addressing the unstable **reactor** near the core.

The nuclear technicians needed equipment to protect against the unstable **reactor** near the core.

Through hard work she persuaded the most powerful **judges** in the country.

The Supreme Court justices are the most powerful **judges** in the country.

The new design would get rid of an old flaw in all of the modern **planes** built by the company.

You can move hundreds of miles per hour on any of the modern **planes** built by the company.

The couple found a highly regarded expert to help them **invest** their money more wisely.

The aging couple found a financial advisor to help them **invest** their money more wisely.

The long workout left Doug with a sore **throat** and a nagging cough from the weather. The bad cold left Doug with a sore **throat** and a nagging cough for a few days.

All the products in the box had expired except for the one juicy **pear** on the top of the pile.

All the fruit in the box had gone bad except for the juicy **pear** on the top of the pile.

Sebastian spent all last week trying to figure out how to make a white **toga** for the frat party.

Sebastian bought clean sheets to go to the frat party dressed in a white **toga** before the break.

James looked online to see whether he could get around the very steep **fin**es he had to pay.

James parked his car illegally but was still upset about paying the steep **fin**es to get his car.

Every night he came to the diner and ordered an entree with **sy**rup in a cup on the side.

Every morning he came to the diner and ordered pancakes with **sy**rup and fruit on the side.

She spent hours figuring out how to work the costly **cam**era she got as a gift.

She spent hours outside taking photographs with the costly **cam**era she got as a gift.

David and Steph were both huge fans of strong **co**ffee in the morning.

David got a refill from the pot of strong **co**ffee before going back to work.

The agents examined the files on one of the remote **is**lands they planned on infiltrating.

The ship lost at sea landed on one of the remote **is**lands they found by chance.

All the town and county residents came to the organized **pro**test of local police

corruption.

All the activists and civil rights leaders came to the organized **protest** of social injustice.

In their course unit on biological topics the group saw a diseased **louse** under a microscope.

In their course unit on parasites the biologists studied a diseased **louse** under a microscope.

The experienced specialist came to treat the wounded **hyena** at the wildlife reserve.

The canine zoologist came to treat the wounded **hyena** at the wildlife reserve.

The teacher showed the kids how to work the parts of the special **puppet** from the school play.

The entertainer showed the kids how to control the arms of the special **puppet** from the show.

At the company event the kids were introduced to a distant **cousin** who knew their father.

At the family reunion the kids were introduced to a distant **cousin** who knew their father.

While jogging in a school zone she stepped over the large drainage **grate** on the sidewalk.

While jogging in a construction zone she stepped over the large drainage **grate** on the sidewalk.

The researchers had to fly in the main source of food for the young **koala** in their lab.

The eucalyptus tree is the main source of food for the young **koala** shown in the photo.

Gia was short on cash but that didn't stop her from taking **yoga** classes in the evening.

In order to improve her flexibility and balance Gia started taking **yoga** classes in the evening.

On the first day of spring, they went to buy a brightly colored **kite** from the strip mall.

On the first windy day, they went out to fly the brightly colored **kite** as high as it could go.

Everyone was watching Candice while she was throwing **darts** yesterday at the bar.

Candice hit the bullseye three times when throwing **darts** yesterday at the bar.

There was no time to waste on the assignment so they bought a large **pizza** from the restaurant.

There was no food to cook in the house so they ordered a large **pizza** from the

restaurant.

The government will most likely spend many more years studying human **genes** at a detailed level.

Scientists can unlock the secrets of our heredity by studying human **genes** at a detailed level.

After the long day of work the interns returned to the foreign **embassy** for a night of rest.

After the long treaty talks the diplomat returned to the foreign **embassy** for a night of rest.

They were very busy on the hard task when they passed by the forest **rangers** on the long trail.

They were lost on the trail and lucky to be found by the forest **rangers** before time ran out.

In the old photo albums, she saw pictures of the terrible **acne** that covered her face years ago.

The teenager went to the dermatologist because of the terrible **acne** covering his face and body.

The old cultural practice requires that one party pay a generous **dowry** to the other.

In many cultures a marriage involves one family paying a generous **dowry** to the other.

The stressed out workers spent all their time preparing for the final **exam** they had next week.

The stressed out students spent all their time studying for the final **exam** they had next week.

The corporation had intended to conceal the designs for the luxury **hotel** on the beach.

For the upcoming business trip they will be staying in a five-star luxury **hotel** on the beach.

No one at the bar wanted to confront the dangerous **judo** master yelling at the staff.

No one at the tournament wanted to fight the dangerous **judo** master defending his title.

On the weekend trip, Kaitlin had some trouble with the large **kayak** in the water.

On the camping trip, Kaitlin had trouble paddling in the large **kayak** with her friends.

Her machine was in need of repair because the faulty **muffler** she bought did not work.

Her car's engine was very loud because the faulty **muffler** she bought only worked

sometimes.

The old actor made his name playing the role of a lovable **tramp** in early films.
Charlie Chaplin made his name playing the role of a lovable **tramp** in early films.

Stephen went to the old antique shop to find classic **vinyl** records for his collection.
Stephen went to the old record store to find classic **vinyl** records for his collection.

Geno dreaded having to tell the unsympathetic boss he was getting **divorced** from his wife.

Geno and Donna dreaded telling the kids they will be getting **divorced** in the coming weeks.

The class had all summer to learn the tricky **waltz** before the competition.
The ballroom couple had trouble dancing the tricky **waltz** at the competition.

Much can be learned about technology by studying our traditional **myths** and oral histories.

The core beliefs of ancient cultures are visible through traditional **myths** and oral histories.

The new film series is mainly focused on the massive **tsunami** and its impact on the coast.

The entire coastline was evacuated because of the massive **tsunami** heading in that direction.

He had just gotten a raise at his job, so Dale went to buy premium **khaki** pants and shoes.

His new job required business casual attire, so Dale went to buy premium **khaki** pants and shoes.

The crowd watched in anticipation of the performance from the masterful **acrobats** at the circus.

The crowd marveled at the high wire stunts performed by the masterful **acrobats** at the circus.

Before the exciting trip they would need to purchase a larger **tent** to accommodate everyone.

Before the camping trip they would need to purchase a larger **tent** to accommodate everyone.

Last week, Walter asked all of his friends if they could help him buy a spare **tire** for his car.

Walter was late because he ran over a nail and had to put on the spare **tire** from his car trunk.

At the shopping center he stood in a long line for the interactive **kiosk** that guides customers.

At the airport he printed his boarding pass from the interactive **kiosk** before going to the gate.

In the gift basket under the cards and treats, she saw the small **kiwi** next to the chocolate.

In the fruit basket, under the oranges and apples, she saw the small **kiwi** next to the peach.

They worked on a design that could deal with the high **voltage** electrical discharge safely.

The electric generator had warning signs about the dangerously high **voltage** for general safety.

He visited the new website to learn more about the famous **battles** from many periods. He visited the military history museum and learned about famous **battles** from many periods.

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