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An investigation into the perceptual and cognitive factors affecting word recognition during normal reading

Christopher James Hand

School of Psychology

University of Glasgow

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Abstract

The present thesis examines the effects of a range of factors on the processing of written language. The present thesis principally uses eye movement recording technology while participants read short passages of text. Factors known to influence written language processing range from lower-level perceptual constraints to higher-level discourse contingencies. Examples of lower-level to higher-level variables are, respectively, intraword orthographic constraints, such as *word-initial letter constraint* (WILC) – how many other words share the same three initial letters of a given word; lexical level *word frequency* – how often a word occurs in written language; and extraword *contextual predictability* – how likely a word is to occur given the discourse up to the position of the word in the passage. The present thesis not only investigates the main effects of these factors, but also studies the simultaneous effects that these factors have on written language processing.

Information acquired from the right of current fixation location – *parafoveal preview* – is essential for reading to proceed at a normal rate. Preview is typically studied using gaze-contingent display change paradigms – non-foveal text is obscured or manipulated, and effects on eye movement behaviour recorded. The present thesis studies an additional method of measuring the effects of preview, without manipulating the text displayed: *launch distance* – how far readers' prior fixation is from a given word, before foveal processing of that word. Visual acuity diminishes as retinal eccentricity increases. The present thesis examines the how the effects of the above factors, and any interactions between them, are modulated by launch distance.

Standard effects of frequency and predictability were found across all studies. Lower-frequency words (LF) were processed with greater difficulty than higher-frequency

words (HF); low-predictability words (LP) were processed with greater difficulty than (HP) words. Consistent with prior research (Rayner, Ashby, Pollatsek, Reichle, 2004), *Experiment 1* found additive effects of frequency and predictability on eye movement behaviour. However, further investigation revealed that when preview was highest (i.e., Near launch distances), frequency and predictability exerted an interactive effect.

Experiment 2a further investigated the simultaneous effects of frequency and predictability, addressing methodological concerns about *Experiment 1*. Principally, that HP contexts in *Experiment 1* were medium-predictability (MP), potentially obscuring any interaction, as the acquisition of parafoveal information is influenced by the frequency and predictability of the parafoveal word. Comparing very low-predictability (VLP) items to very high-predictability (VHP) items, the interactive pattern of effects observed in the Near launch distance condition of *Experiment 1* was replicated in the global analyses of *Experiment 2a*. In *Experiment 2b*, comparisons of HF and LF words in VLP and specifically-designed MP items yielded an additive pattern of effects, consistent with *Experiment 1*. Furthermore, conditionalised analyses of these items by launch distance showed an interactive pattern of effects, but only at Near launch distances. Conditionalised analyses of HF and LF words in VLP and VHP materials from *Experiment 2a* revealed an interactive pattern of frequency and predictability effects at both Near and Middle launch distances. It is argued that frequency and predictability can interact under two distinct conditions, but both manners are dependent on preview. When HF and LF words are presented in MP contexts, a high level of preview must be provided by a Near launch distance for an interaction to be observed; when HF and LF words are presented in VHP contexts, sufficient information can be extracted at further launch distances, generating an interactive pattern of effects in global analyses.

Experiment 3 examines whether fixation durations are inflated prior to skipping a word in text. An overall non-significant effect of word skipping on prior fixation durations was observed. However, this result was somewhat misleading – inflated fixation durations prior to skipping were observed, but only when to-be-skipped words were either HF or HP; indeed, the largest mean inflation prior to skipping was observed when the to-be-skipped word was both HF and HP. These results suggest that when readers are able to extract most information about parafoveal words (e.g., when those words are HF or HP), fixation durations prior to skipping these words are inflated. It is tentatively suggested that these effects reflect a longer accumulation of information from parafoveal to-be-skipped word. These effects are consistent with models of eye movement control permitting parallel processing of written information, as opposed to a strictly serial approach.

Experiments 4a and *4b* tested the effects of WILC. *Experiment 4a* employed a lexical decision task, examining the separate and combined effects of WILC and frequency. LF words were responded to less quickly than HF words. Words with low WILC (LC words; e.g., "*clown*" shares its initial trigram "*clo*" with many words) were processed more quickly than words with high WILC (HC words; e.g., "*dwarf*" shares its initial trigram "*dwa*" with few words). It is suggested that LC words in a lexical decision task are responded to quickly as their initial trigram is shared by a large number of viable words, facilitating a "word" response. The initial trigrams of HC words are not shared by many other words, potentially hindering a "word" response. *Experiment 4b* re-tests the role of WILC on eye movement behaviour during reading, based on an earlier study by Lima and Inhoff (1985). Unlike Lima and Inhoff's study, the frequency and predictability (known to influence the extraction of parafoveal information) of LC and

HC target words was also manipulated. In contrast to the findings of Lima and Inhoff (*but*, consistent with their original *prediction*), HC words were found to exhibit a processing advantage over LC words in measures of eye movement behaviour reflecting early, lexical processing. Further analyses based on launch distances from, and landing positions within target words suggested that the pattern of effects observed may be due to the accumulation of WILC information from the parafovea.

The present thesis finds that word frequency and contextual predictability can yield interactive effects on processing, but that any possible interaction is dependent on acquisition of parafoveal information. Evidence of inflated fixation durations prior to word skipping were observed, but these effects are modulated by the characteristics of the parafoveal to-be-skipped word. Initial letters of words have a substantial effect on processing, but this effect is task-dependent. In lexical decision, activation of "wordness" is advantageous, and LC words exhibit an advantage over HC words. In natural reading, information is available from sentential context and the parafovea, and HC words carry an advantage over LC words. The present thesis argues for the use of launch distance as a metric for measuring preview benefit, albeit in a necessarily post-hoc fashion. Reliable effects of launch distance were found across all experiments where it was examined as a factor – eventual fixation time on a word increases as the distance of prior fixation from beginning of that word increases. Launch distance was also shown to influence the effects of a range of factors which influence written language processing, and the interactions between these variables.

Declaration

This thesis has been composed by the undersigned. It has not been submitted or accepted in any previous application for any degree at this or any other university. This thesis has been completed by myself, unless otherwise indicated in the text.

Christopher James Hand

September, 2010.

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Previous Published Dissemination

Publications:

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Hand, C.J., O'Donnell, P.J., Sereno, S.C. (under review). Word-initial letter combinations influence fixation time in fluent reading.

Conference Presentations:

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Hand, C.J., O'Donnell, P.J., & Sereno, S.C. (2007). Fixation durations before and after word skipping: Evidence from eye movements. Poster presented at the 13th Annual Architectures and Mechanisms of Language Processing (AMLaP) Conference, University of Turku, Finland.

Hand, C.J. (2007). Interactive effects of word frequency, contextual predictability and parafoveal preview on eye movements during reading. Talk presented by C.J. Hand at the Scottish Psycholinguistics Meeting, Department of Psychology, University of Dundee, United Kingdom.

Hand, C.J., Miellet, S., O'Donnell, P.J., & Sereno, S.C. (2006). Parafoveal processing influences word frequency and contextual predictability effects on eye movements during reading. Talk presented by S.C. Sereno at the 47th Annual Meeting of The Psychonomic Society, Houston, Texas.

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Chapter 1

Introduction

The subjective experience for most adults when processing written information is an automatic, sequential, and smooth progression from word to word across lines and throughout pages of text. The psychological reality, however, is that reading involves a series of discrete eye movements, known as *saccades*, punctuated by short periods where the eye is almost stationary, called *fixations*. It is during these fixations that word meaning must be accessed and integrated into a developing discourse context.

A range of factors determines where and when saccades and fixations occur. Such factors range from low-level visual and oculomotor factors – e.g., the display quality of the text – to higher-level factors – e.g., the ease or difficulty of integrating a word into the developing discourse, given the context up to that point. The present thesis examines a range of factors involved in the processing of written language, principally using the recording of eye movements as participants read short passages of text. In one experiment, however, lexical decision times in response to visually presented words in isolation were examined.

Visual lexical decision tasks

Visual lexical decision tasks involve the presentation of either a written word (e.g., "*bullock*") or string of letters that do not constitute a valid word (non-word, e.g., "*blimble*"; see Figure 1.1). Participants are required to make a manual response indicating whether they have been presented with a word or a non-word. Participants' reaction times are related to the difficulty associated with processing the visually presented stimulus – generally, longer reaction times reflect greater difficulty in processing the stimulus.

Figure 1.1. Schematic diagram of a visual lexical decision experiment

Fixation cross displayed for 500ms

Displayed for 1500ms or until participant makes manual response

Either a blank screen or a screen giving feedback as to accuracy of response

A related measure of processing is the *self-paced reading technique*. In non-cumulative self-paced reading, participants execute a manual response in order to begin presentation of a short text. Each word in the passage is displayed in isolation until the participant executes a manual response, and this process is repeated until the end of the passage. Again, longer response times are indicative of increased processing difficulty. However, a limitation of this technique is that participants have no opportunity to re-read earlier parts of the passage. Since the early 1970s, in order to investigate written language processing in a more naturalistic setting, language psychologists have utilised advances in technology in order to record participants' eye movements while they read.

<u>Eye movements in reading</u>

As mentioned previously, during normal reading, individuals make a series of saccadic eye movements in order to bring text into foveal vision for detailed processing. Saccadic eye movements are punctuated by moments where the eyes are almost stationary – known as fixations. It is during these fixations that individual word meanings are accessed and integrated on-line into a developing discourse representation. Measuring eye movements during fluent reading is an established technique that is sensitive to on-line perceptual and cognitive aspects of lexical processing (Rayner, 1998, 2009; Sereno & Rayner, 2003). As a response measure, fixation time possesses certain advantages over traditional behavioural measurements – namely, there is no secondary task involving overt decisions, and fixation times are faster than, for example, word naming or lexical decision latencies. Eye movement reading research in recent decades has revealed that reading behaviour can be accurately assessed by measuring the position, duration, and sequence of eye fixations in text (for reviews, see Rayner, 1998, 2009).

How a reader determines the location to which to make a saccadic movement, their likelihood of fixating a given word, and the duration of their fixations are determined by a number of factors (McConkie, Kerr, Reddix, & Zola, 1988). One variable that influences eye movement behaviour is *word length*, with longer (and more) fixations made on longer words (e.g., Just & Carpenter, 1980; Kliegl, Olson, & Davidson, 1982; Rayner, Sereno, & Raney, 1996). After controlling for word length, however, two higher-level variables in particular have been shown to strongly influence fixation time on a word – namely, a word's frequency and its contextual predictability.

Word frequency effects

The frequency of a word is a measure of how often that word occurs in written text. Word frequency is calculated by collating an extremely large body of text (a corpus) and counting the number of times individual word tokens occur. There are several corpuses in use, among the more commonly used being the 1-million word tokens of Francis and Kučera (1982), and the 100-million word British National Corpus, which consists of a 90-million written word corpus, and a supplementary 10-million word spoken corpus (1995; http://natcorp.ox.ac.uk). Words can be categorised as either low frequency (LF) or high frequency (HF) based on experimenter-specified frequency thresholds. Typically, LF words are words with a written frequency of <10-15 occurrences per million words; HF words are words with a written frequency of >40-50 occurrences per million words.

Numerous studies have utilised visual lexical decision and eye movement recording techniques to investigate the effect of a word's frequency and its processing. These studies have reliably demonstrated that readers take longer to process LF (e.g., *erupt*, *quilt*, *barge*) than HF (e.g., *house*, *water*, *floor*) words (Inhoff & Rayner, 1986; Just & Carpenter, 1980; Kennison & Clifton, 1995; Kliegl, Grabner, Rolfs, & Engbert, 2004; Kliegl, Nuthmann, & Engbert, 2006; Rayner & Duffy, 1986; Rayner & Raney, 1996; Rayner et al., 1996; Rayner, Ashby, Pollatsek & Reichle, 2004; Schilling, Rayner, & Chumbley, 1998; Sereno, O'Donnell, & Rayner, 2006; Sereno, Pacht, & Rayner, 1992; Sereno & Rayner, 2000; Slattery, Pollatsek, & Rayner, 2007; Stanovich & West, 1981, 1983).

Contextual predictability effects

The contextual predictability of a word refers to how likely it is that the specified word will occur at a given point in a developing discourse given the context up to that point. For example, the word "*plate*" would have a higher contextual predictability when included in the passage "*The chef carefully arranged the food on the plate*", as opposed to a lower contextual predictability if included in the passage *"The chef angrily threw the spoiled food on the plate*.

Unlike word frequency, unfortunately, there is no database of contextual predictability values – experimenters must spend a great deal of time and care generating contexts which are supportive of a particular word, or are especially supportive of one word at the top of a short list of viable alternatives. Contextual predictability must then be measured off-line. Consider the earlier sentence "*The chef carefully arranged the food on the plate*". If the target word of this short passage is "*plate*", in order to measure how predictable this word is, typically one or both of two established norming techniques would be used – the *Cloze probability task* and the *word rating task*.

In a Cloze probability task, a group of participants would be presented with the experimental passage, up to, but not including the target word (See Figure 1.2) The participants' task is to generate the next word or words in the passage. In order to determine the predictability of the word "*plate*", the experimenter records the number of occurrences of the word "*plate*" as a proportion of the total number of responses. Although a very useful technique, this can often pose difficulties in coding – for instance, how would the experimenter treat the response of a participant who wrote: "*The chef carefully arranged the food on the plates*"? or "*The chef carefully arranged the food on the dinner plate*"?. Typically, researchers only count responses in which the first word written is an exact match to their target words as a "hit". Unfortunately, this may occlude the true predictability of the target word if a number of responses were made wherein participants in the Cloze task had been visualizing a chef placing food onto a plate, but chose to use a slightly different word token when making their response.

Figure 1.2. An example material from Cloze probability and word-rating tasks

Cloze Probability

The chef carefully arranged the food on the ______

Word-rating task

The chef carefully arranged the food on the <u>plate</u>

1	2	3	4	5	6	7
Highly Unpredictable						Highly Predictable

An alternative task to the Cloze probability task, but one which is normally used in conjunction with it, is the word rating task. A word rating task involves a separate group of participants to those involved in the Cloze task being presented with the entire experimental passage, along with a Likert scale with which to rate the predictability of the target word (which is usually presented in underlined or bold font) given the context up to that point (See Figure 1.2). In order to calculate a word's rating, experimenters typically take the mean or mode response value to the word. When conducting a word rating task, filler passages containing anomalous target words are often included (e.g., *"The teacher wiped the blackboard with a bagel"*), so that participants use the full range of the scale when they are completing the task.

Although well-established techniques, reliance on these tasks poses problems for researchers of contextual predictability. As mentioned previously, coding responses in either or both of these tasks is also very time-consuming and resource intensive – separate groups of participants must be tested, paid, and their responses coded. Furthermore, it is conventional not to test participants who have been involved in the norming of materials in behavioural experiments involving the same materials. This can often place severe limitations on the subject pool available to experimenters. For instance, researchers using English-language sentences can only test native English-speaking subjects; therefore, if a large number of the available native speakers have been required to complete norming tasks, this can often lead to an extension in the time required to recruit and run a sufficient number of experimental participants.

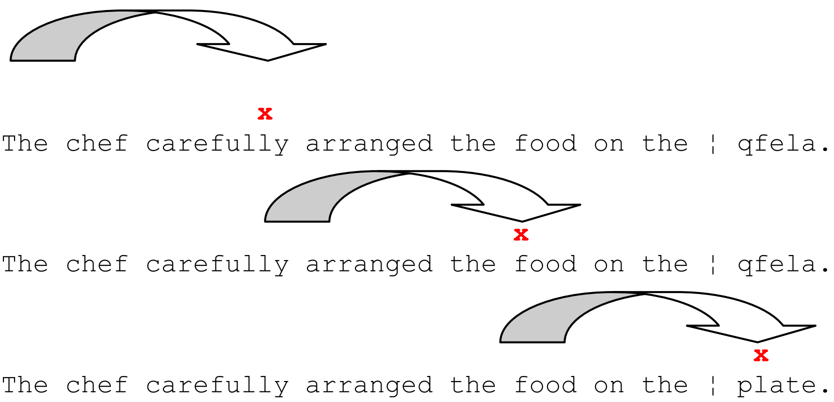
It has recently been argued by some researchers (McDonald & Shillcock, 2003a, 2003b) that such limitations can be overcome by eschewing these subjective tasks, instead adopting a more computational approach to generating and assessing contextual constraint. From the results of their studies, McDonald and Shillcock argue for a different kind of predictability effect – *low-level predictability* or *forward transitional probability*. Forward transitional probability is the statistical likelihood that word $n + 1$ will occur given word n. According to McDonald and Shillcock, transitional probability effects could reflect the ability of readers to access and manipulate low-level statistical knowledge about the probability of one word being adjacent to another, used in a bottom-up fashion. McDonald and Shillcock (2003a) reported eye movement data that suggested that the statistical likelihood of two words occurring together in text influences readers' eye movements. It may be the case that the processes underlying the effects observed by McDonald and Shillcock are different from those which underlie "typical" context effects, and may also differ from the processes used by participants in subjective word-rating and Cloze probability judgements. McDonald and Shillcock's findings appear to lend considerable support towards adopting a systematic computational approach to context construction in favour of traditional, subjective tasks when investigating the effects of contextual predictability. However, in a subsequent study, Frisson, Rayner and Pickering (2005) examined predictability and transitional probability and found compelling evidence to suggest that effects of transitional probability are actually a part of traditional predictability effects.

Several studies have demonstrated that words which are less constrained by a prior context are processed slower and skipped less often than more constrained (or predictable) words (Balota, Pollatsek & Rayner, 1985; Carroll & Slowiaczek, 1986; Drieghe, Brysbaert, Desmet, & De Baecke, 2004; Ehrlich & Rayner, 1981; Kliegl et al., 2004, 2006; McDonald & Shillcock, 2003a, 2003b; Morris, 1994; Rayner et al., 2004; Rayner & Well, 1996; Zola, 1984).

The importance of parafoveal preview benefit

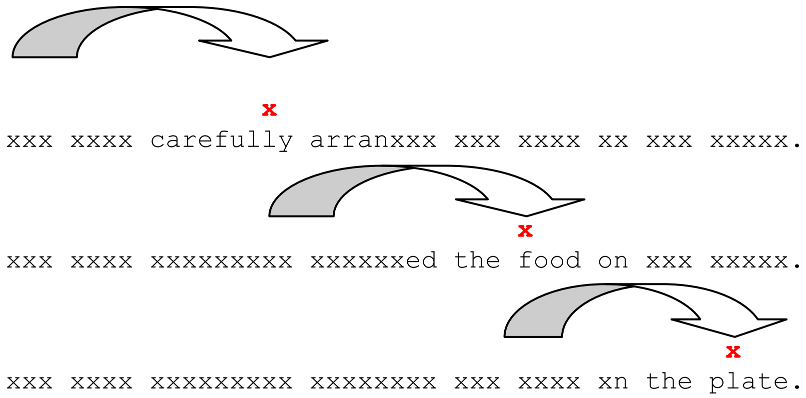
Previous eye movement research has demonstrated that information acquired to the right of fixation during reading (i.e., parafoveally) is not only beneficial to the reader, but is necessary for reading to occur at a normal rate (Rayner, 1998). *Parafoveal preview benefit* is defined as the fixation time advantage on a target word when the parafoveal information associated with that target (obtained from the prior fixation) is valid versus invalid. Parafoveal preview is typically manipulated by employing a gaze-contingent display change paradigm during reading. For example, in the "boundary" paradigm, participants parafoveally view either valid or invalid information of the (eventual) target, which then changes to the target when the reader crosses a pre-specified invisible boundary (Rayner, 1975a; see Figure 1.3). An alternative task is the "moving window" technique: a pre-specified number of characters to the left and right of fixation are displayed normally within a window, the position of which is contingent on participants' fixation location, with text outwith the left and right boundaries of this window being replaced by a string of *x*s (McConkie & Rayner, 1975; Rayner, 1975b; See Figure 1.4).

Figure 1.3. An example of a "boundary change" technique.



Note. The '**x**' represents the location of the participant's fixation. The arrows represent the direction of the participant's saccadic eye movement. The ¦ symbol represents the invisible boundary.

Figure 1.4. An example of a "moving window" technique.



Note In this example, a 15-character window is depicted, symmetrical around the fixation location. The 'x' represents the location of the participant's fixation. The arrows represent the direction of the participant's saccadic eye movement.

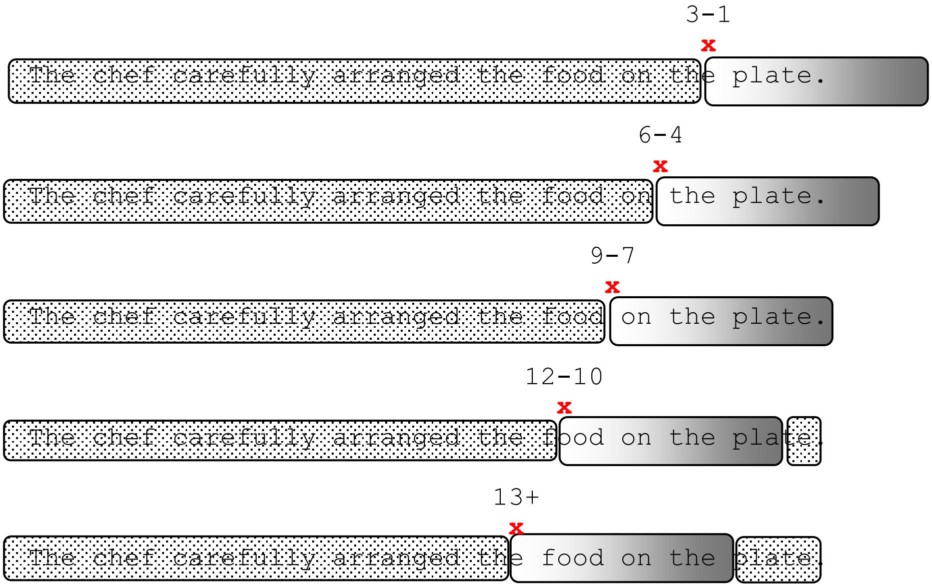
By manipulating the size of the window, researchers can determine the minimum window size required for reading to proceed at a normal rate. "Moving window" studies (McConkie & Rayner, 1975; Miellet, O'Donnell, & Sereno, 2009) have been used to functionally approximate the *perceptual span* in reading. The perceptual span is defined as that region of text from which useful information can be extracted (i.e., reading is slowed when text within the span is altered). For readers of English, it is estimated to extend from 3 characters to the left of fixation (approximately the beginning of the fixated word) to about 14 characters to the right of fixation. The span's asymmetry is taken to reflect attentional demands linked to reading direction (e.g., in English, new information is always located to the right; in Hebrew, the asymmetry of the span is reversed to reflect the fact that new information is located to the left of fixation). Although the span encompasses a significant number of letters to the right of fixation, the level of analysis drops off substantially from the fovea – from recognising words to identifying letters to merely determining the length of the upcoming parafoveal word(s). The *word identification span* – the area from which readers can identify words during a particular fixation – is smaller than the perceptual span, typically extending only to around 7 characters to the right of fixation (McConkie & Zola, 1987; Rayner, Well, Pollatsek, & Bertera, 1982).

Prior fixation location as a measure of parafoveal preview benefit

The use of boundary change and moving window techniques have proved invaluable in determining the nature and amount of information that can be acquired parafoveally during reading. However, a possible limitation of these studies is that both involve non-natural presentation of text. The "boundary" paradigm manipulates parafoveal preview typically in a binary way (i.e., valid or invalid), although it must be noted that participants are very rarely aware of the display change (White, Rayner, & Liversedge, 2005). Non-foveal (i.e., parafoveal and peripheral) information is altered to varying degrees in a moving window experiment (N.B., the replacement of text outwith the boundary of the window is, in effect, a form of invalid preview).

The present thesis investigates an alternative approach to measuring parafoveal preview information, based on the established knowledge that visual acuity drops off as a function of retinal eccentricity (see Figure 1.5). Assuming that the amount of parafoveal preview obtained is largely related to the pre-target launch distance – with greater distances giving rise to lesser previews – then target word processing as a function of launch distance should represent a more continuous, although necessarily *post-hoc*, assessment of parafoveal processing. It is proposed that the greatest strength in using launch distance as a metric of parafoveal preview is that all text – foveal and non-foveal – can be displayed without manipulation. There is evidence that the complexity of the pre-target word influences the amount of parafoveal processing on the subsequent target (e.g., Henderson & Ferreira, 1990), such effects should also be modulated by visual acuity as gauged by launch distance.

Figure 1.5. Acquisition of non-foveal information as a function of launch distance.



Note. The x represents the location of the participant's fixation. 3-1, 6-4, 9-7, 12-10, 13+: number of characters from the beginning of the target word. Lighter shading indicates higher visual acuity, darker shading lower visual acuity. Dotted areas indicate text outwith readers' word identification span.

Examining prior launch site in order to assess parafoveal preview benefit is not a novel concept. Several previous studies have utilised launch distance information (e.g., Kennison & Clifton, 1995; Lavigne, Vitu, & d'Ydewalle, 2000; Rayner, 1975b; Rayner, Binder, Ashby, & Pollatsek, 2001; White & Liversedge, 2006, White, 2008). However, in the experimental chapters included in this thesis, launch distance is used in order to examine the possible changes in interactions between variables known to influence eye movement behaviour during reading.

Word skipping during reading

Readers do not always saccade from fixated word n to word n+1; instead readers often *skip* word n+1 and progress to word n+2 (or very occasionally, to a further word n+x). Just as word length strongly influences fixation times during reading, it also influences the likelihood of skipping a word. Shorter words are much more likely to be skipped than longer words. Short function words (e.g., "*if*", "*of*", "*the*") are skipped approximately 65% of the time, whereas longer content words (e.g., nouns) are skipped approximately 15% of the time (Carpenter & Just, 1983; Rayner & Duffy, 1988). The effect of word frequency on word skipping is not altogether clear. This is due in part to the strong correlation between word length and word frequency, with shorter words being much more frequent than longer ones. Evidence to suggest an effect of word frequency on word skipping when word length is controlled has been reported – Rayner et al. (1996) reported that HF target words were skipped more often than LF target words. However, this effect was limited to trials where the fixation prior to the target word was 3-4 characters away from the beginning of the target word – typically, word skipping behaviour is confined to such instances, regardless of the frequency of the target word (Rayner et al., 1996; Rayner, Binder, Ashby & Pollatsek, 2001). The effect of contextual predictability on word skipping is much clearer – HP words are skipped more often than LP words (Balota et al., 1985; Drieghe, Brysbaert, Desmet, & De Baecke, 2004; Ehrlich & Rayner, 1981; Rayner et al., 2004; Rayner & Well, 1996).

The effect of word length on fixation probability has been examined in studies which have required participants to make saccadic eye movements across string of letter *z*s. Vitu, O'Regan, Inhoff, and Topolski (1995) found that, as in normal reading, participants were more likely to skip shorter *z*-strings, are fixation probability increased as the length of the *z*-string increased. From this, Vitu et al. (1995) concluded that predetermined oculomotor strategies are an important determinant of eye movement control during reading. Drieghe, Brysbaert, and Desmet (2005) questioned these results, demonstrating that experimental manipulations can influence the skipping of *z*-strings and normal words. Drieghe et al. (2005) observed that inserting an extra blank space after a *z*-string significantly increased the probability of fixating that string by up to 10%. However, the same manipulation had no effect on the probability of fixating an actual word. Drieghe et al. (2005) question strongly whether findings on skipping from *z*-string scanning studies can be generalised to normal reading behaviour.

Brysbaert, Drieghe, and Vitu (2005) conducted a meta-analysis of skipping studies which manipulated processing difficulty of words and also reported word lengths of critical words. The first group of studies examined by Brysbaert et al. (2005) featured those which manipulated the processing difficulty of critical words in terms of critical word characteristics (e.g., word frequency). The second group of studies examined manipulated processing difficulty in terms of the critical word's contextual predictability. Brysbaert et al. (2005) found a 5% difference in skipping rates between linguistically easier and more difficult words in the first group of studies. This effect was dwarfed by the effect of word length on skipping in these studies – a non-significant 2% skipping rate was found for nine-letter words, whereas an enormous 50% effects was found for two-letter words. The second group of studies examined by Brysbaert et al. (2005) demonstrated an average predictability effect on skipping of 8%; the length effect was highly comparable to the first group of studies. From the relative magnitudes of the linguistic and visual effects on skipping, Brysbaert et al. (2005) concluded that in order to predict the likelihood of skipping a word, it is more informative to know the length of the word, rather than how difficult it is to access or integrate.

Research into eye movements during reading has allowed computational models of eye movement control during reading to be established. These models can be separated into three broad categories (Engbert, Longtin, & Kliegl, 2002): *sequential attention shift* (SAS) models, *guidance by attentional gradient* (GAG) models, and *primary oculomotor control* (POC) models (see **Chapter 2**, Discussion for a detailed description of these models; also see Reichle, Rayner, & Pollatsek, 2003 for a comparison of these models). One common feature of all three types of models is the prediction that short, high-frequency, and highly predictable words will be skipped more often than longer, lower-frequency, and low predictability words. Although all three types of model share the prediction that short, high-frequency, and highly predictable words will be most likely to be skipped, one fundamental difference between these types of model is the prediction of these types of model with regard to fixation durations before the skipping of a word.

Experimental studies of fixation durations prior to skipping a word have yielded inconsistent results, with fixations prior to skips being reported between 26 ms shorter and 84 ms longer (Kliegl & Engbert, 2005). Obtaining a conclusive answer to the question of the effects of words skipping on fixation durations during reading has important consequences for models of eye movement control during reading and for theories of language processing.

<u>Word-initial letter constraint effects</u>

"Boundary" experiments have varied the visual, phonological, and semantic similarity between the foveated target and its initial parafoveal preview and have generally shown that orthographic and phonological, but not semantic, information is extracted parafoveally (e.g., Balota et al., 1985; McConkie & Zola, 1979; Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, McConkie, & Zola, 1980).

Rayner et al. (1982) found that the when the first three letters (i.e., word-initial trigram) of the parafoveal preview were identical to those of the (eventual) target word and when the remaining letters of the preview were replaced by letters that were visually similar to the target, reading rate was only slightly impaired compared to when the preview was completely identical to the target (i.e., the valid preview condition). The implication is that the identification of word-initial letters is fundamental to obtaining a parafoveal preview benefit. Given that the first few letters of the parafoveal word are nearest the fovea and that the space before the parafoveal word serves to decrease lateral masking of its beginning letters, such findings are not unexpected.

If the identification of the word-initial trigram facilitates reading, as evidenced by parafoveal preview benefit, the question arises whether the level of lexical constraint conferred by the trigram can affect word identification. Within the auditory word recognition literature, the homologous issue of word beginnings and their role in spoken word identification has been the topic of innumerable studies. Marslen-Wilson and Welsh (1978; see also Marslen-Wilson, 1987) proposed the *cohort model* of spoken word recognition. In this model, the initial acoustic information activates a large number of candidate words (i.e., a cohort) in parallel, but as further evidence accumulates, the activation of words that are no longer compatible with the input decays until a single candidate remains (the point in a spoken word which delivers a single candidate is called the *uniqueness point*). Although the signal is produced and processed in a more continuous and sequential way in the auditory compared to the visual domain, parafoveal preview nevertheless gives emphasis to the initial letters of an upcoming word. Thus, it is reasonable to expect similar activation and selection processes to occur in visual word recognition during fluent reading. High-constraint (HC) initial trigrams rarely appear in words whereas low-constraint (LC) initial trigrams often do. For example, the HC trigram *dwa-* includes very few words in its cohort (e.g., *dwarf*, *dwarves*); in contrast, the LC trigram *clo-* has many words in its cohort (e.g., *clown*, *close*, *clock*, *cloud*, *cloth*, *cloak*, *clone*, *clout*, *clove*, *clog*, *cloy*, *clothes*, *clover*, *closet*, *cloister*, *clobber*; N.B., this excludes morphologically-related suffixed words).

White (2008) conducted an eye movement reading study examining the effects of orthographic familiarity and word frequency. This study attempted to examine word frequency effects while controlling for the effects of orthographic familiarity – frequent words are argued to be necessarily familiar, however, less frequent words may be orthographically unfamiliar. White (2008) makes the important distinction between type frequency and token frequency as a measure of orthographic familiarity. Type frequency – typically used in previous studies of orthographic familiarity (Bertram & Hyönä, 2003; Rayner & Duffy, 1986) – is the count of the number of words containing a particular bigram or trigram. This measure can be seen as a measure of lexical informativeness – the trigram "*pne*", when positioned at the beginning of a word has a very low type frequency and is highly informative to the reader. However, White (2008) argues that type frequency does not reflect letter sequence familiarity, as a number of words share the initial trigram "*irr*". However, very few of these words are high frequency words, thus, although "*irr*" has a high type frequency, it has a low orthographic familiarity. White argues that an improved measure of orthographic familiarity is token frequency – the sum of the frequencies of words containing a particular letter sequence. White (2008) observed shorter fixation durations on orthographically familiar words compared to unfamiliar words across standard measures of fixation duration. White (2008) showed clear effects of word frequency, independent of the effects of orthographic familiarity. These results demonstrated that the lexical processing of words influences saccadic programming, as indexed by fixation durations on target words. It is argued thus, that models of eye movement control during reading should include a Saccade programming mechanism which is sensitive to the lexical processing of word frequency.

Models of visual word recognition

Many studies involving recognition of words in isolation have shown that the coding of letter position is somewhat flexible. Nonwords created by transposing two adjacent letters (e.g., "*dveil*" from the base word "*devil*") are recognised more easily than nonwords created by substituting two adjacent letters from a legitimate word in order to invalidate that word (e.g., "*dcnil*"). This finding has been observed in tasks such as naming (Christianson, Johnson, & Rayner, 2005) and lexical decision (Chambers, 1979; Forster, Davis, Schoknecht, & Carter, 1987; O'Connor & Forster, 1981; Perea & Lupker, 2003a, 2003b, 2004).

Five different theoretical accounts have been proposed to explain letter coding during lexical processing (Davis & Bowers, 2006). Davis and Bowers (2006) identified these as: (a) slot coding, (b) Wickelcoding, (c) continuous open bigram coding, (d) discrete open bigram coding, and (e) spatial coding. Slot coding assumes that a separate slot is required for each letter of a word, and has been incorporated into traditional models of lexical identification, including McLelland and Rumelhart's (1981) interactive activation model, the dual route cascaded model of Coltheart and colleagues (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), and the activation-verification model (Paap, Johansen, Chun, & Vonnahme, 2000). Wickelcoding is similar to slot coding, wherein letter positions are encoded in relation to their local letter context (e.g., the letter "*x*" in "*taxes*" would be coded as having and a to its left, and an e to its right). Wickelcoding has been adopted by a number of connectionist models of lexical processing (Seidenberg & McClelland, 1989).

Both continuous open bigram coding (Whitney, 2001; Whitney & Lavidor, 2005) and discrete open bigram coding (e.g., Granger & van Heuven, 2003) require encoding the constituent letters of a word in terms of all ordered bigram pairs that can be formed from the word. The distinguishing feature between these two types of coding, is that under the discrete system, bigram activation can only be at 0 or 1. Alternatively, under continuous bigram coding, activation of bigrams can exist at values including and between 0 and 1. The SERIOL model (Whitney, 2001; Whitney & Lavidor, 2005) argues that word beginning letters are activated earlier and to a greater extent. The level of activation associated with a bigram is higher if the letter inputs are more highly activated and if the component letters are closely spaced.

The SOLAR model of lexical identification (Davis, 1999, 2006; Davis & Bowers, 2004) involves the spatial coding of letters. This approach involves letter nodes within the processing system being activated by the constituent letters of a word, regardless of their position within the word. Letter node activation diminishes as a function of its position in a word, from left to right. Different words generate different spatial patterns of activation across letter nodes.

Research investigating isolated word recognition demonstrates that any system of leter encoding must involve a degree of flexibility which exceeds the earliest and simplest of accounts.

In terms of eye movements during reading, Rayner and Kaiser (1975) examined the effects of letter substitution with visually similar or dissimilar letters at the beginning, middle and end positions of words. Replacements with dissimilar letters resulted in greater processing difficulty than replacements with similar letters. Furthermore, replacements at the beginnings of words were substantially more disruptive to reading behaviour than replacements made at middle and ending positions. This finding by Rayner and Kaiser highlights the importance of word-initial letters in word identification, compared with letters further into words. White, Johnson, Liversedge, and Rayner (2008) investigated the effects of word-initial and word-final transpositions on eye movement behaviour during reading. Additionally, they manipulated the externality-internality of the transpositions, and the frequency of the critical words. It is argued by the authors that differences in processing difficulty between transposition conditions reflects the importance of letter position in word recognition. White et al. (2008) found that transposed text was read only slightly more slowly than normally presented text, therefore the language processing system can comprehend such texts in a relatively short space of time. Reading of transposed letter materials was considerably less disrupted than reading of letter-substituted texts (Rayner & Kaiser, 1975). Thus, the specific letters of a word are crucially important for its identification, and readers cannot rely entirely on context to enable comprehension. White et al. (2008) found that infrequent words which had been transposed were more difficult to resolve than frequent words which had been transposed, implying that words which are difficult to process may be more reliant on correct letter position information (White et al., 2008).

White et al.'s (2008) results also indicate that certain letter position transpositions were more disruptive than others. Their results generally showed that external letters are more important for recognition than internal letters, and more importantly, the position of the word-initial letter appears to be most crucial overall. It may be that external letters could be more important for word identification due to either visual or linguistic reasons. It may be that this advantage arises due to the fact that external letters suffer from less lateral masking than internal letters (Bouma, 1973). Alternatively, external letters, perhaps in addition to word length information, may be enough to allow rapid identification of some words (Clark & O'Regan, 1999).

A possible explanation for why word-initial letters are apparently more critical for successful word recognition is because letters within words are processed serially, rather than in parallel, certainly for early stages of word processing. Kwantes and Mewhort's (1999) orthographic uniqueness point effects support this view, therefore letters at the beginning of a word are important for narrowing down the possible candidate set of words. However, Kwantes and Mewhort (1999) used a naming task, and their results were not replicated in an eye movement reading study by Miller, Juhasz and Rayner (2006).

Present thesis

Table 1.1. presents a summary of each experiment, detailing the factors that were manipulated, and which experimental technique was employed.

Table 1.1. Summary of experimental studies by factor and technique

	Experimental Factors				**Experimental Technique**	
Experiment	**Frequency**	**Predictability**	**WILC**	**Launch**	**LD**	**EM**
1	✓	✓		✓		✓
2a	✓	✓		✓		✓
2b	✓	✓		✓		✓
3	✓	✓		✓		✓
4a	✓		✓		✓	
4b	✓	✓	✓	✓		✓

Note. Frequency = word frequency; Predictability = contextual predictability; WILC = word-initial letter constraint; Launch = parafoveal preview benefit as indexed by launch distance to beginning of target word; LD = visual lexical decision; EM = eye movement recording.

Experiments 1, *2a* and *2b* (**Chapters 2** and **3**) considers the relationship between word frequency and contextual predictability on eye movements during reading, specifically investigating whether these factors demonstrate an additive or interactive pattern of effects on fixation duration measures and on the likelihood of fixating a target word. Furthermore, the relationship between word frequency and contextual predictability will be considered as a function of parafoveal preview benefit, as indexed by launch distance to the beginning of target words in sentences.

Experiment 3 (**Chapter 4**) investigates fixation durations prior to skipping a target word versus fixation durations prior to fixating target words. The word frequency and contextual predictability of target words in this study is manipulated in order to investigate whether fixation durations prior to skipping / fixating are target words differs as a function of target word frequency and predictability.

Experiments 4a and *4b* (**Chapter 5**) test the importance of word-initial letter constraint (WILC) on the processing of words in isolation and in context, respectively. *Experiment 4a* employs a visual lexical decision technique to determine whether WILC influences the processing of words in isolation. Additionally, the target words in *Experiment 4a* will be manipulated with respect to their word frequency, in order to examine the simultaneous effects of WILC and word frequency on word identification times. Experiment 4b investigates the simultaneous effects of WILC, word frequency and contextual predictability on eye movements in reading. The aim of Experiment 4b is to establish what (if any) effects WILC has on eye movement behaviour during reading, and whether any observed effects of WILC are modulated by the frequency and/or predictability of the word.

Chapter 2

The effect of parafoveal preview benefit on the combined effects of word frequency and contextual predictability

Introduction

Two key variables that influence the amount of time a reader spends fixating a word in reading are its frequency of occurrence and its predictability from the prior text. Past research has been somewhat equivocal on whether these two factors are additive or interactive. *Experiment 1* explores the relationship between frequency and predictability effects on eye movement behaviour during normal reading. In contrast to prior studies examining these variables simultaneously, the effect of launch site, that is, the distance between the target word and the location of the pre-target fixation, is additionally examined. Launch distance can determine how much information is obtained from the target parafoveally, prior to its subsequent fixation (see **Chapter 1**, Figure 1.5). It is argued that this approach will provide a more dynamic account of how frequency and predictability interact as a function of the reader's initial viewing distance.

The effects of contextual predictability on eye movements during reading are well-documented (Balota et al., 1985; Carroll & Slowiaczek, 1986; Ehrlich & Rayner, 1981; Kliegl et al., 2004, 2006; McDonald & Shillcock, 2003a, 2003b; Morris, 1994; Rayner et al., 2004; Rayner & Well, 1996; Zola, 1984). The precise time-course of context effects remains a topic of debate: does context affect early, lexical processing or only later, post-lexical processing? The answer to this question has often been pursued within the lexical ambiguity literature in determining whether the contextually appropriate meaning of a homograph can be selected during its lexical access, or whether all meanings are nonetheless accessed with the appropriate meaning only selected postlexically as a consequence of its semantic integration (see, e.g., Sereno et al., 2006). An alternative approach has gauged the temporal course of contextual predictability effects by whether such effects interact with word frequency (e.g., Sternberg, 1969). The presence of word frequency effects is generally considered an index of lexical access (e.g., Balota, 1990; Sereno & Rayner, 2003). Frequency effects have been reliably demonstrated "early" in processing both in eye movement and electrophysiological paradigms. For example, Sereno and Rayner (2000) found frequency effects in the initial fixation on words whose parafoveal preview (from the prior fixation) consisted of a non-word letter string that was visually unrelated to the subsequent target. Additionally, in measuring event-related potentials (ERPs) during single word presentation, Sereno and colleagues have consistently found frequency effects in the N1 component (i.e., first negative-going wave) beginning around 130 ms post-stimulus (Scott, O'Donnell, Leuthold, & Sereno, 2009; Sereno, Brewer, & O'Donnell, 2003; Sereno, Rayner, & Posner, 1998; see also Dien, Frishkoff, Cerbone, & Tucker, 2003; Hauk & Pulvermüller, 2004; Neville, Mills, & Lawson, 1992; Nobre & McCarthy, 1994; Pulvermüller, Assadollahi, & Elbert, 2001). An observed interaction between frequency and predictability would suggest that these variables share the same processing stage, supporting an early, lexical locus of contextual processing. Alternatively, additive effects of frequency and predictability would suggest that the temporal locus of contextual processing is relatively delayed.

Interactive findings

Early behavioural reaction-time (RT) experiments examined the joint effects of word frequency and contextual predictability. The majority of these studies typically reported an interactive pattern of effects (but cf. Schuberth & Eimas, 1977). For example, across several experiments, Stanovich and West (1981; 1983) examined context effects in pronunciation latencies on end-of-sentence HF and LF words. In addition to main effects of frequency and predictability, they reported a significant interaction, in which the processing of LF words is facilitated more by predictable contexts than HF words. West and Stanovich (1982) observed the same pattern of effects using lexical decision. Taken together, these results provide considerable evidence that context interacts with the variable (word frequency) that otherwise determines how rapidly a word can be identified. However, there are certain aspects of these studies limiting the extent to which their findings can be generalised. First, delays often occurred between offset of the context and onset of the target. Such delays could induce strategic processing. Second, the contexts were quite short and often contained intralexical primes (e.g., Forster, 1979). Thus, it is possible to argue that associative priming drives the observed pattern of contextual facilitation rather than top-down effects from higher-order levels of discourse representation. Third, comparisons were often made between a contextually congruous condition that was highly predictable and an incongruous condition that was highly anomalous. A more representative contrast might be to compare high predictable with less predictable (but not anomalous) targets. Finally, as mentioned earlier, the response measures of naming and lexical decision may involve the recruitment and application of strategies not found in normal reading.

In an early eye movement reading study, Inhoff (1984) investigated frequency and predictability effects. Similar to the RT studies, Inhoff found an interaction in gaze duration (i.e., the sum of all consecutive fixations made on a word). Inhoff's results, however, represented the combined data from a normal reading condition and a degraded stimulus condition in which there was a 3-character mask that moved in synchrony with the eyes and that significantly slowed fixation times. In addition, the experimental passages were excerpts from *Alice in Wonderland*; as such, target words were selected opportunistically and word length (which covaries with frequency) was not formally controlled.

In an ERP study, Sereno et al. (2003) presented sentences word-by-word and examined end-of-sentence HF and LF targets in neutral and biasing contexts. They also obtained an interactive pattern of frequency and predictability in terms of the voltage amplitude of the N1 component, from 132-192 ms post-stimulus. That is, while there was no context effect for HF words, LF words were facilitated in a biasing context. As this effect occurred in the same time window in which word frequency effects had been demonstrated, they argued that top-down processing modulated early lexical processing. However, the presentation rate was relatively slow compared to normal reading (~500 ms per word), and the predictability contrast for LF words was statistically marginal.

Additive findings

Despite the enormous amount of research into the individual effects of frequency and predictability on eye movements during reading, surprisingly few eye movement studies have included manipulations that orthogonally vary target word frequency and predictability. Four previous eye movement studies included manipulations of frequency and predictability of target words in sentences (Altaribba, Kroll, Sholl & Rayner, 1996; Ashby, Rayner, & Clifton, 2005; Lavigne, Vitu & d'Ydewalle, 2000; Rayner et al., 2001). These studies consistently found main effects of frequency and predictability on fixation times, but all failed to find a significant interaction. It is important to note that the interaction between these two variables was not the principal focus of any of these studies. Lavigne et al. (2000) and Rayner et al. (2001) investigated the effects of predictability on landing positions in words, and Altaribba et al. (1996) dealt with cross-language priming. Ashby et al. (2005) compared reading behaviour of highly skilled and average readers. Although they reported differential effects of frequency and predictability between participant group, they found no frequency-predictability interaction.

Three recent eye movement studies did explicitly investigate the interaction between word frequency and contextual predictability. In a study conducted in French, Miellet, Sparrow, and Sereno (2007) selected a subset of words from a passage that varied in frequency and predictability, and only differed minimally in length. They observed additive effects of frequency and predictability and were able to account for the pattern of data by modifying a version (extended, additive version 7; Rayner et al., 2004) of the E-Z Reader model of eye movement control (Reichle et al., 2003). The only methodological drawback of this study was in terms of the modest number of data points acquired. There were only five items in each of the four conditions, obtained by crossing frequency (HF, LF) with predictability (high, low), that were read by a total of 15 participants.

Kliegl et al. (2004) examined the effects of word length, frequency, and contextual predictability on various measures of eye movement behaviour during reading of the Potsdam Sentence Corpus (144 individual German sentences ranging from 5-11 words each, with an average length of 7.9 words). Analyses of the eye movement data revealed reliable independent effects of word length, frequency, and predictability on the probability of fixation. In fixation duration measures which did not include regressions to words (i.e., first fixation duration, single fixation duration, and gaze duration), a non-significant tendency of predictability was obtained when the effects of length and word frequency were controlled. The effect of predictability on the corpus data, however, became significant when regressions to words were included (i.e., total fixation time).

Upon analysing a subset of target words from the corpus, Kliegl et al. only found significant predictability effects in single fixation duration (i.e., the duration of first-and-only fixations) as well as gaze duration measures. They argued that *a priori* selection of target words yielded a benefit to the reliability of predictability effects in measures of first-pass reading. Kliegl et al. also examined multiplicative interactions between their variables, but in terms of frequency and predictability, the multiplicative interaction did not add significantly to the amount of variance explained by a linear expression of the effects of these variables. However, it was acknowledged by the authors that the regression lines obtained in their analyses were suggestive of higher-order terms.

Finally, an eye movement reading study that directly investigated the frequency × predictability interaction was carried out by Rayner et al. (2004). Participants read a series of single-line sentences, each containing a target word that was either HF or LF and either predictable or unpredictable from the prior context. In their design, this was achieved by switching targets across contexts. That is, for half of the sentences, HF targets were predictable while their length-matched LF targets were unpredictable; for the other half, LF targets were predictable while HF targets were unpredictable (participants only read one version of each sentence). Fixation time data showed an additive pattern, with main effects of frequency and predictability. While Rayner et al. found no statistical interaction, they stated that the numerical pattern of their effects were suggestive of an interaction with larger word frequency differences in their unpredictable condition (i.e., larger predictability effects for LF words). Rayner et al. did find a reliable interaction, however, in how often target words were skipped, with HF predictable targets skipped more often than any of the other three conditions (which did not differ from each other).

Although this study directly examined the frequency × predictability interaction, it was perceived to have certain limitations. First, there were only 8 items that each participant read in each experimental condition. It could be argued that having few items per condition may result in a pattern of effects reflecting idiosyncrasies of the stimuli used, and such a pattern of effects may not be observed using a wider range of materials. Second, target words were embedded near the middle of a single sentence. For context effects to develop more fully, it may be more appropriate to employ longer contexts preceding target words. Another concern relates to the content of their contexts. Some materials were "anecdotal," relying upon target words fulfilling certain contextual conventions. Example materials from Rayner et al.'s (2004) study are shown in Table 2.1.

Table 2.1. Example Materials from Rayner et al. (2004)

<u>HF-HP or LF-LP</u>

Most cowboys know how to ride a *horse|camel* if necessary.
June Cleaver always serves meat and *potatoes|carrots* for dinner.
While away at war, Fred mailed his mother a *letter|compass* from China.
The teacher kept the class quiet as she read a *story|diary* at the end of the day.

<u>LF-HP or HF-LP</u>

In the desert, many Arabs ride a *camel|horse* to get around.
Bugs Bunny eats lots of *carrots|potatoes* to stay healthy.
The lost hiker carefully checked his *compass|watch* to figure out the way
After writing down her private thoughts, Sally hides her *diary|story* in the closet.

Note. HF = high frequency; LF = low frequency; HP = high-predictable; LP = low-predictable. Target words are in italics. Each sentence can accommodate either an HF-HP or LF-LP target (upper set of materials) or an LF-HP or HF-LP target (lower set of materials).

Interactive or additive?

It is unclear why there is discrepancy between the results of the earlier RT studies and eye movement research in terms of the relationship between the effects of word frequency and contextual predictability. It may be that the frequency × predictability interaction is an elusive effect that does not manifest itself in the eye movement record. Alternatively, an interaction *may* exist, and by employing a more robust experimental design, an interactive pattern of frequency and predictability effects may be observed, not only on the probability of fixating target words, as has been reported, but also on fixation duration measures. Accurately determining the precise relationship between the effects of word frequency and contextual predictability is important for models of language processing. A modular architecture maintains that higher-order discourse context can only operate on the output of the lexical processor (e.g., Fodor, 1983; Forster, 1979). Conversely, an interactive model asserts that prior context can directly influence lexical access, itself (e.g., McClelland, 1987; Morton, 1969). The presence of additive or interactive effects would lend support to either a modular or interactive account of lexical processing, respectively.

Parafoveal effects of frequency and predictability

The perceptual span is defined as that region of text from which useful information can be extracted (i.e., reading is slowed when text within the span is altered). The perceptual span has been functionally approximated from "moving window" studies (McConkie & Rayner, 1975; Miellet et al., 2009; see **Chapter 1**, Figure 1.4). For English, it is estimated to extend from 3 characters to the left of fixation (approx. the beginning of the fixated word) to about 14 characters to the right of fixation. The span's asymmetry is taken to reflect attentional demands linked to reading direction (e.g., in English, new information is always located to the right). Research has demonstrated that the ability of the reader to extract information from the parafovea is influenced both by the frequency and the contextual predictability of that parafoveal word. When parafoveal previews are valid, subsequent target fixation time is significantly shorter when that word is an HF versus an LF word (Inhoff & Rayner, 1986), and when that word is a contextually predictable versus an unpredictable word (Balota et al., 1985).

Experiment 1 was carried out to investigate whether simultaneously varying the frequency and predictability of target words in short texts yielded additive or interactive effects on eye movement behaviour in reading. This study was principally designed to address the perceived limitations of Rayner et al. (2004). However, it also served to accumulate a large body of eye movement data to allow for the *post-hoc* analysis of the additional effects of parafoveal preview benefit, as indexed by the distance between the beginning of the target word and the location of the prior fixation. The present study used a 2 (Frequency: HF, LF) × 2 (Predictability: HP, LP) design with 22 items per condition. Each experimental item extended over two lines of text, with longer contexts preceding target words than those used in Rayner et al. (2004). The factor of parafoveal preview was implemented *post-hoc* with three levels of launch distance: Near (1-3 characters), Middle (4-6 characters), and Far (7-9 characters). Data were analysed across several standard eye movement measures, first in the 2 × 2 and then in the 2 × 2 × 3 designs outlined above.

It was predicted that, in the 2 × 2 design, an interactive pattern of findings might emerge, with larger predictability effects for LF than HF words. The changes and augmentations implemented in *Experiment 1*, in comparison to the Rayner et al. (2004) design, would provide more advantageous circumstances for observing such effects. In the 2 × 2 × 3 design, it was predicted that a launch distance effect would be observed, with longer target fixations associated with greater launch distances, replicating prior research (e.g. McConkie et al., 1988; Sereno, 1992). The effect that launch distance would have on the frequency × predictability interaction is less certain. Although it may be that effects would be reduced with greater launch distances, it is not certain whether the attenuation would equally affect frequency, predictability, and their interaction.

Method

Participants

Sixty-four members of the University of Glasgow community (47 females; mean age 22 years old) were paid £6 or given course credit for their participation. All were native English speakers with normal or corrected-to-normal vision and had not been diagnosed with any reading disorder.

Apparatus

Participants' eye movements were monitored via a Fourward Technologies (Buena Vista, VA) Dual-Purkinje Eyetracker (Generation 5.5). The eyetracker's resolution is less than 10 min of arc, and its signal was sampled every millisecond by a 386 computer. Although viewing was binocular, eye movements were recorded from the right eye. Passages were displayed over two lines on a ViewSonic 17GS CRT in a 14-point non-proportional font (light cyan on a black background) and were limited to the central 60 characters of an 80-character line. Participants were seated approximately 86 cm from the monitor, and 4 characters of text subtended 1^{o} of visual angle. The room was dimly lit and display brightness was adjusted to a comfortable level.

Design

A 2 (Frequency: HF, LF) × 2 (Predictability: HP, LP) design was used. HF and LF targets appeared in short, two-line passages (one per passage) in which each target was considered either contextually predictable (HP) or not (LP). Each passage was designed to accommodate both an HF and LF target (one each in two versions of each passage). For half of the passages, the HF target was HP while the LF target was LP; for the other half of passages, the LF target was HP while the HF target was LP. Because there were two possible targets for each passage, the materials were divided into two sets to be read by two different participant groups. Group 1 read half of the HF/LF target pairs in HP contexts and half in LP contexts. Group 2 read the HF/LF target pairs in the opposite context conditions as Group 1. With 44 pairs of HF/LF targets appearing in either HP or LP contexts, there was a total of 176 passages. Because each participant group was only presented with half (88) of the possible passages (to avoid repetition of targets or contexts), each participant received 22 items in each of the 4 experimental conditions (HF-HP, HF-LP, LF-HP, LF-LP). Example experimental items are presented in Table 2.2.; all passages and corresponding targets are listed in **Appendix I**. Target words were always positioned near the middle of a line and were never sentence initial or final. Experimental passages were presented in a different random order to each participant.

Materials

The mean specifications of HF-HP, HF-LP, LF-HP, and LF-LP targets are presented in Table 2.3. Word frequencies were acquired from the British National Corpus (BNC), a database of 90 million written word tokens (http://www.natcorp.ox.ac.uk). Mean frequency values for HF (range: 52-512 per million) and LF (range: 0-10 per million) words are listed in Table 2.3, word frequencies of individual target words are presented in **Appendix II**.

Table 2.2. Example Materials

HF-HP or LF-LP

On holiday for a week, Jill and Harry decided to redecorate [lb]
some rooms in their **house** | **motel** that they felt needed making over.

The gifted students were selected to receive extra lessons [lb]
at the local **school** | **circus** during weekends and holidays.

LF-HP or HF-LP

Exhausted from driving, and lost on the dusty highway, [lb]
Tony decided to stop at the first **motel** | **house** to get directions.

All the children were thoroughly amused by the clowns that [lb]
came once a year to the **circus** | **school** in their village.

Note. HF = high frequency; LF = low frequency; HP = high-predictability target; LP = low-predictability target. Target words are in **bold**. Each sentence can accommodate either an HF-HP or LF-LP target (upper set of materials) or an LF-HP or HF-LP target (lower set of materials). [lb] denotes how materials were split across the two lines of display.

Table 2.3. Specifications of Target Stimuli

Condition	Length	Frequency	Predictability	Cloze
HF-HP	5.89 (1)	144 (104)	6.20 (0.42)	0.60 (0.31)
HF-LP	5.89 (1)	144 (104)	4.07 (1.17)	0.02 (0.06)
LF-HP	5.89 (1)	5 (3)	6.05 (0.51)	0.53 (0.31)
LF-LP	5.89 (1)	5 (3)	3.69 (1.16)	0.02 (0.06)

Note. Mean values are shown with standard deviations in parentheses. Units of measurement are as follows: Length in number of letters; Frequency in occurrences per million; Predictability rating range is 1 (highly unpredictable) to 7 (highly predictable). HF = high frequency, LF = low frequency, HP = high predictable, and LP = low predictable.

Word length was matched exactly on a pairwise basis, and average word length was 5.89 characters (range: 5-8 characters). The pre-target context length of 15.5 words on average was twice that of the 7.7 words on average used in Rayner et al.'s (2004) materials and allowed more time for a contextual representation to develop. Contextual predictability was determined on the basis of the results from two norming tasks: word predictability rating and Cloze probability.

Predictability task

The materials were divided into two sets and were presented to two different participant groups (to avoid target word or context repetition). Two groups of 10 participants (none of whom participated in either the experiment or Cloze task) were presented passages with the target word presented in bold font. Participants were asked to indicate how predictable they considered the target word to be on a scale of 1 (highly unpredictable) to 7 (highly predictable). The same targets (across participants) were always rated higher in HP contexts, even when targets in LP contexts were rated above 4 (i.e., on the predictable end of the scale). It is important to note that the relatively high ratings of LP targets reflected the fact that they were designed to be *less* predictable (and not implausible or anomalous) compared to HP targets in a given context. And, although HP contexts were constructed to be predictive of their targets, they were not intended to be exclusively predictive. Finally, an effort was made to avoid intralexical priming of the target by the immediately preceding context (e.g., Forster, 1979). Mean predictability ratings are listed in Table 2.3 and are comparable to Rayner et al.'s (2004) values of 6.6, 4.4, 6.3, and 4.6 for their analogous HF-HP, HF-LP, LF-HP, and LF-LP conditions, respectively. Predictability ratings for individual target words are presented in **Appendix II**.

Cloze task

A single group of 20 participants (none of whom participated in either the experiment or word-rating task) were given each experimental item up to, but not including, the target word (only one set of materials was administered because the target word was absent). Participants were asked to generate the next word in the sentence (i.e., the missing target). Responses were scored as "1" if the target was correctly identified and "0" for all other guesses. Mean Cloze probabilities (correct responses) across the experimental conditions are listed in Table 2.3. Rayner et al. (2004) reported Cloze values of 0.78 for HP and less than 0.01 for LP words (averaging across HF and LF conditions). In comparison, our Cloze probabilities were lower for HP (0.57) and slightly higher for LP words (0.02). Cloze values for individual target words are presented in **Appendix II**.

Procedure

Participants were given written and verbal instructions about the eyetracking task. A bite bar was prepared to minimize head movements. Participants were instructed to read normally for comprehension, as they would read a story. They were told that yes-no questions followed half the passages to ensure they were paying attention.

The experiment involved initial calibration of the eyetracking system, reading 10 practice passages, recalibration, and reading the 88 experimental passages. A calibration display appeared before every trial and comprised a series of calibration points extending over the maximal horizontal and vertical range in which passages were presented. During this display, the calculated position of the eye was visible, allowing the experimenter to check the accuracy of the calibration and recalibrate if necessary.

Each trial began with the calibration display. When participants were fixating the upper left-most calibration point (corresponding to the first character of text), a passage was presented. After reading each passage, participants fixated on a small box, below and to the right of the last word, and pressed a key to clear the screen. The calibration screen reappeared either immediately or after they had answered a yes-no question by pressing corresponding response keys. Participants had no difficulty in answering the questions (average over 90% correct).

Results

The target region comprised the space before the target word and the target itself. Lower and upper cut-off values for individual fixations were 100 and 750 ms, respectively. Data were additionally eliminated if there was a blink or track loss on the target, or if the fixation on the target was either the first or last fixation on a line. Overall, 6.1% of the data were excluded for these reasons. In this study, the percentages of data for single fixation, immediate refixation, and skipping of the target were 62.8, 12.4, and 18.7%, respectively.

The resulting data were analysed over a number of standard fixation time measures on the target word: (a) first fixation duration (FFD; the duration of the initial fixation, regardless of whether the word was refixated); (b) single fixation duration (SFD; fixation time when the word is only fixated once); (c) gaze duration (GD; the sum of all consecutive fixations before the eyes move to another word); and (d) total fixation time (TT; the sum of all fixations, including later regressions made to that word). FFD, SFD, and GD represent first-pass, more immediate measures of processing. For reasons of comparison with Rayner et al. (2004), the probability of making a first-pass fixation (PrF) on the target was examined in the initial analysis. Analyses of variance (ANOVAs) were conducted both by participants (F_1) and by items (F_2) and are reported below, first for the Frequency × Predictability, and then for the Frequency × Predictability × Preview design. Table 2.4 reports the number of data points across all conditions used in these analyses. Following these main analyses, supplementary findings regarding the position of the target fixation (landing position) are reported, as well as effects on the fixation immediately preceding the target fixation (parafoveal-on-foveal effects).

Table 2.4. Profile of Data Points for Analyses

		Launch Distance (characters)						
		1-3	4-6	7-9	10+	Skip	Reject	Total
FFD								
	HF-HP	220	323	262	200	318	85	1408
	HF-LP	219	347	331	180	262	69	1408
	LF-HP	222	358	314	201	232	81	1408
	LF-LP	255	331	250	223	242	107	1408
SFD								
	HF-HP	212	288	220	155			
	HF-LP	203	309	278	118			
	LF-HP	206	299	261	136			
	LF-LP	233	276	198	146			

Note. The total number of data points across the experiment is 5632, resulting from 64 participants with 22 items in each of 4 conditions. FFD = first fixation duration; SFD = single fixation duration; HF = high frequency; LF = low frequency; HP = high predictable; LP = low predictable.

Frequency × Predictability analyses

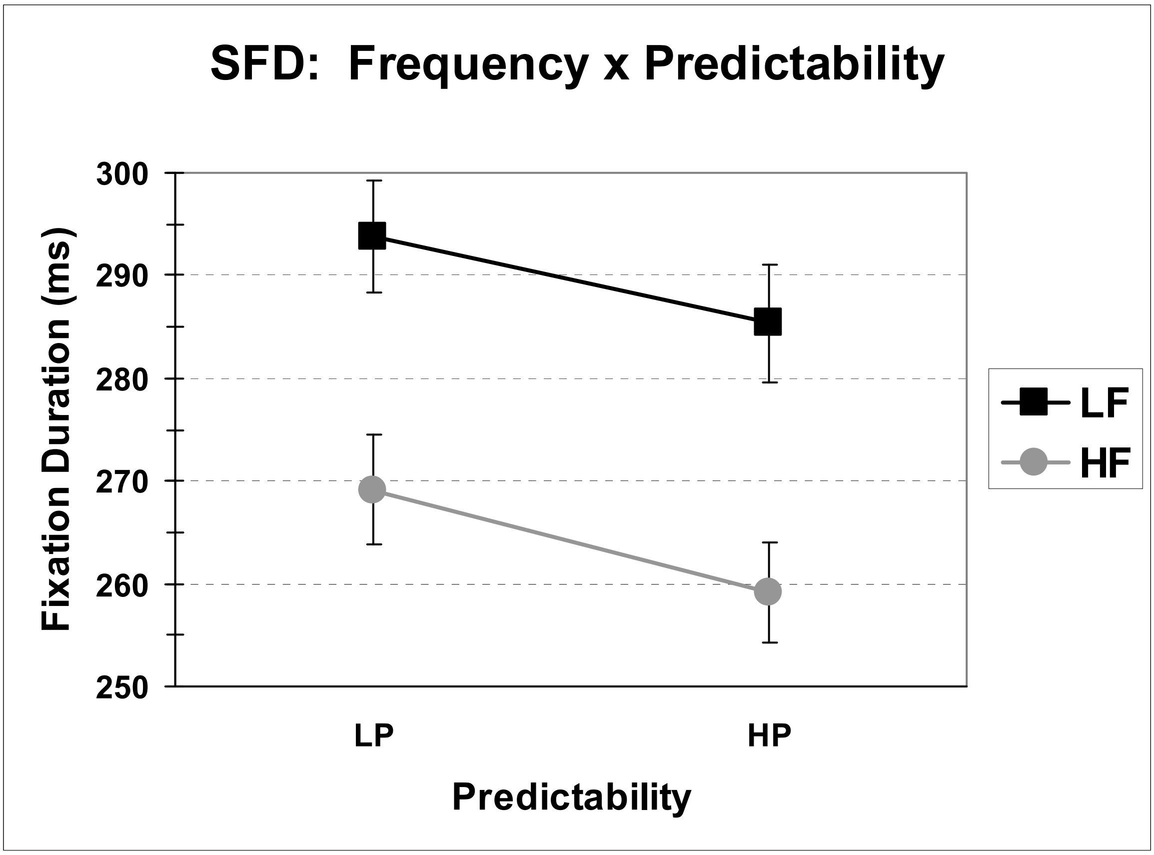
The means for FFD, SFD, GD, TT, and PrF measures across experimental conditions are shown in Table 2.5. As SFD accounts for the majority of first-pass fixation time data on the target (83.5%), these means, including standard error bars, are displayed in Figure 2.1.

Table 2.5. Average Fixation Time (ms) and Fixation Probability across Target Measures

	HF		LF	
	HP	LP	HP	LP
FFD	256	264	279	289
SFD	259	269	285	294
GD	273	286	306	318
TT	297	328	334	380
PrF	0.77	0.81	0.83	0.82

Note. HF = high frequency; LF = low frequency; HP = high predictable; LP = low predictable; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; PrF = probability of fixation.

Figure 2.1. Average single fixation duration (SFD) on target words (with standard error bars) as a function of word frequency and contextual predictability.



Note. HF = high frequency; LF = low frequency; HP = high predictability; LP = low predictability.

FFD, SFD, and GD. The main effect of Frequency was significant in the FFD, SFD, and GD measures [$F_1(1,63)$: F-values 82.01-104.09, *MSE*s 399-810, all ps<.001; $F_2(1,43)$: F-values 89.28-147.46, *MSE*s 190-568, all ps<.001]. HF words were fixated for less time than LF words (260 vs. 284 ms for FFD, 264 vs. 290 ms for SFD, and 279 vs. 312 ms for GD, respectively). Predictability was also significant in FFD, SFD, and GD [$F_1(1,63)$: F-values 13.76-16.87, *MSE*s 309-618, all ps<.001; $F_2(1,43)$: F-values 12.05-14.36, *MSE*s 337-626, all ps<.01]. HP words were fixated for less time than LP words (267 vs. 276 ms for FFD, 272 vs. 281 ms for SFD, and 289 vs. 302 ms for GD, respectively). The Frequency × Predictability interaction was not significant [all Fs<1].

TT. The pattern of effects was similar in the TT measure. There was a main effect of Frequency, with shorter fixation times on HF (312 ms) than on LF (357 ms) words [$F_1(1,63)=71.04$, $MSE=1793$, $p<.001$; $F_2(1,43)=51.65$, $MSE=1768$, $p<.001$]. There was also a main effect of Predictability, with shorter fixations on HP (315 ms) than on LP (354 ms) words [$F_1(1,63)=55.93$, $MSE=1675$, $p<.001$; $F_2(1,43)=37.07$, $MSE=1899$, $p<.001$]. The interaction was marginal by participants, but non-significant by items [$F_1(1,63)=2.86$, $MSE=1261$, $p=.096$; $F_2<1$].

PrF. The PrF was calculated on the basis of the whether a trial received a fixation, given that that trial was included in the analysis (i.e., PrF is based on ~94% of the data, after rejected trials were excluded). The main effect of Frequency was significant [$F_1(1,63)=9.72$, $MSE=.008$, $p<.01$; $F_2(1,43)=10.74$, $MSE=.005$, $p<.01$]. The probability of fixating HF words (.79) was less than that for LF words (.82). Unlike the fixation time data, the effect of Predictability did not reach significance [$F_1(1,63)=1.85$, $MSE=.006$, $p>.15$; $F_2(1,43)=2.54$, $MSE=.006$, $p=.118$]. Also in contrast to the fixation time data, the Frequency × Predictability interaction was significant, although this effect was marginal by items [$F_1(1,63)=7.71$, $MSE=.006$, $p<01$; $F_2(1,43)=3.63$, $MSE=.009$, $p=.064$]. Follow-up contrasts for HF words showed that HF-HP words were less likely to be fixated than HF-LP words [$F_1=8.67$, $p<.01$; $F_2=4.94$, $p<.05$]. For LF words, however, the equivalent comparison (LF-HP vs. LF-LP) was not significant [all Fs<1]. Follow-up contrasts for HP words showed that HF-HP words were less likely to be fixated than LF-HP words [$F_1=20.37$, $p<.001$; $F_2=9.17$, $p<.01$]. For LP words, however, the equivalent comparison (HF-LP vs. LF-LP words) was not significant [all Fs<1]. Overall, HF-HP words were less likely to be fixated than words in other conditions.

Summary. In general, the pattern of results from the Frequency × Predictability analyses replicated those of Rayner et al. (2004). In first-pass measures (FFD, SFD, and GD), there were significant effects of Frequency and Predictability with no interaction. Rayner et al. found an identical pattern of first-pass results. For TT in the current study, the main effects were again significant, and there was only a hint of an interaction (marginal by participants, but non-significant by items). Rayner et al. only found reliable main effects. Rayner et al., however, did find a significant interaction in the PrF measure: words in their analogous HF-HP condition were skipped more often than any of their other three conditions (analogous HF-LP, LF-HP, and LF-LP conditions). Their main effect of Frequency for PrF was only significant by items and their main effect of Predictability was not significant. The results of *Experiment 1* were quite similar. Frequency was statistically significant in both participants and items analyses, but Predictability was not. The interaction, although marginal by items, was in all other ways identical to that found in Rayner et al.: HF-HP words were skipped more often than words in the other conditions.

Frequency × Predictability × Preview analyses

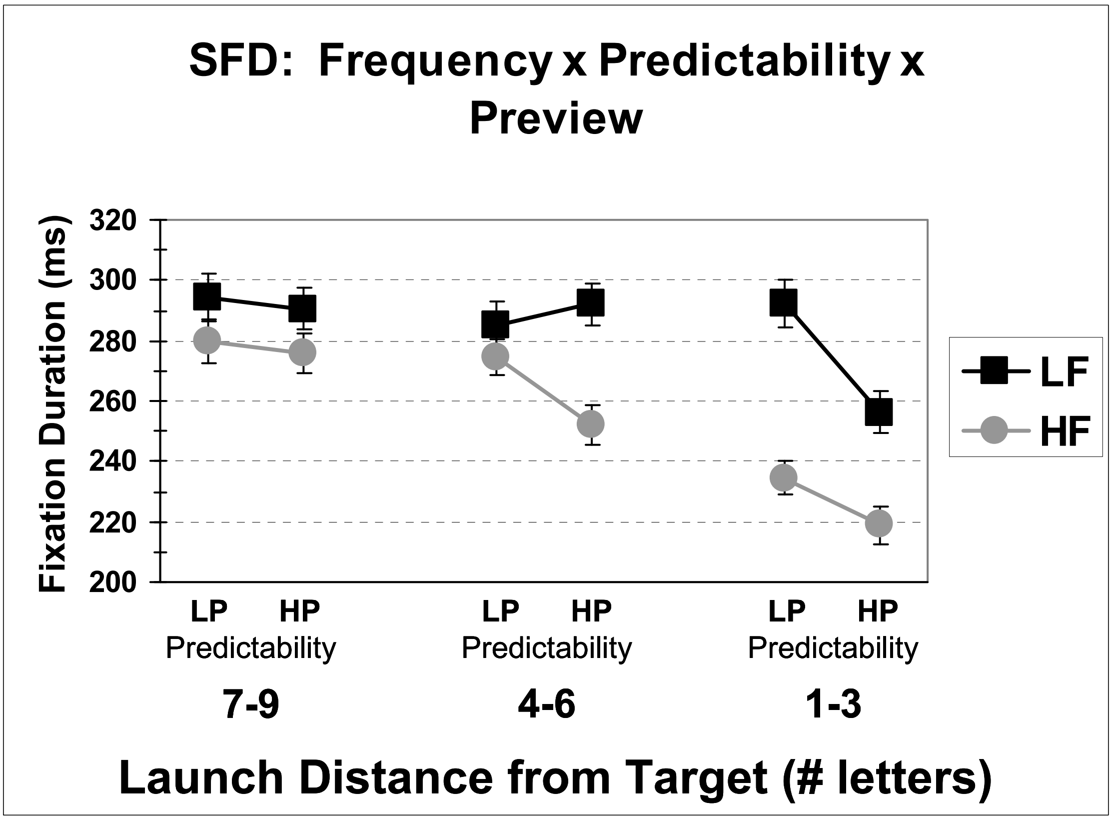
The first-pass target fixation time data used in the analyses above were conditionalised *post-hoc* in terms of launch distance as a metric of parafoveal preview. It was of specific interest to assess the first-pass data because it corresponds to the earliest measures of processing. Launch distance was measured as the distance from the beginning of the target (i.e., the space before the target) to the location of the immediately preceding pre-target fixation. There were three levels of this Preview factor: Near (1-3 characters), Middle (4-6 characters), and Far (7-9 characters). Fixations initiated from launch sites of 10 or more characters only accounted for 14.3% of the total data (9.5% from 10-12 characters, 4.8% from 13+ characters). In addition, these fixations were spread out over an 11 character window (10-21 characters). In the conditionalised data, the percentages of the total data for each Preview condition for single fixation and immediate refixation were as follows: 15.2 and 1.1% for Near; 20.8 and 3.3% for Middle; and 17.0 and 3.6% for Far, respectively. Conditionalised fixation time data accounted for 81.0% of the initial fixation time data. The mean data for FFD, SFD, and GD measures across Frequency, Predictability, and Preview conditions are displayed in Table 2.6. As in the overall analysis, because SFD comprised the majority of the first-pass conditionalised data (86.9%), these means, including standard error bars, are shown in Figure 2.2. In the 2 × 2 × 3 analyses, FFD, SFD, and GD produced highly similar patterns of results, including levels of significance. Accordingly, presentation of results below is limited to SFD data.

Table 2.6. Average Fixation Time (ms) as a Function of Launch Distance (characters) across Target Measures

	HF		LF	
	HP	LP	HP	LP
Near: 1-3 characters				
FFD	218	233	256	295
SFD	219	234	256	293
GD	220	244	264	315
Middle: 4-6 characters				
FFD	250	269	282	280
SFD	252	274	292	285
GD	265	286	308	308
Far: 7-9 characters				
FFD	268	273	283	283
SFD	276	280	291	294
GD	297	305	317	318

Note: HF = high frequency; LF = low frequency; HP = high predictable; LP = low predictable; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration.

Figure 2.2. Average single fixation duration (SFD) on target words (with standard error bars) as a function of word frequency, contextual predictability, and parafoveal preview as indexed by launch distance.



Note. HF = high frequency; LF = low frequency; HP = high predictability; LP = low predictability.

<u>Main effects</u>. All three main effects were significant. First, there was a main effect of Preview [$F_1(2,126)=50.03$, $MSE=1634$, $p<.001$; $F_2(2,86)=32.15$, $MSE=1303$, $p<.001$]. Follow-up contrasts, in general, revealed significant differences between target fixations launched from Near (251 ms), Middle (276 ms), and Far (285 ms) positions, with faster fixation times associated with closer launch distances [Near vs. Middle: *F*s>40, *p*s<.001; Near vs. Far: *F*s>55, *p*s<.001; Middle vs. Far: $F_1=6.62$, $p<.05$, and $F_2=1.22$, $p>.25$]. Second, there was a significant main effect of Frequency [$F_1(1,63)=77.64$, $MSE=2111$, $p<.001$; $F_2(1,43)=106.46$, $MSE=1099$, $p<.001$]. As in the initial analysis, HF words (256 ms) were fixated for less time than LF words (285 ms). Finally, the main effect of Predictability was also significant [$F_1(1,63)=19.02$,

MSE=1546, p<.001; F_2(1,43)=13.68, *MSE*=2125, p<.001]. As in the initial analysis, HP words (264 ms) were fixated for less time than LP words (277 ms).

Interactions. All interactions were significant except for Frequency × Predictability [all *F*s<1]. Frequency × Preview was significant [F_1(2,126)=9.36, *MSE*=1939, p<.001; F_2(2,86)=7.71, *MSE*=1905, p<.001], as was Predictability × Preview [F_1(2,126)=5.72, *MSE*=1570, p<.01; F_2(2,86)=5.57, *MSE*=1453, p<.01]. Because the 3-way interaction was also significant [F_1(2,126)=7.19, *MSE*=1425, p<.01; F_2(2,86)=7.49, *MSE*=1212, p<.01], and for reasons of clarity, separate Frequency × Predictability ANOVAs for Near, Middle, and Far Preview conditions were performed. Condition means relevant to these analyses are shown in Table 2.6.

Near (1-3 characters) analysis. There were significant main effects of Frequency and Predictability [all *F*s>15, all *p*s<.001]. As in the prior analyses, HF and HP words elicited shorter fixations than LF and LP words, respectively. There was also a Frequency × Predictability interaction [all *F*s>4, all *p*s<.05]. As can be seen in Figure 2.2, the Predictability effect was greater for LF than HF words. The HF-HP vs. HF-LP contrast was significant by participants, but marginal by items [F_1=4.71, p<.05; F_2=3.60, p=.065]. The other three contrasts – LF-HP vs. LF-LP, HF-HP vs. LF-HP, and HF-LP vs. LF-LP – were all highly significant [all *F*s>18, all *p*s<.001].

Middle (4-6 characters) analysis. The pattern of effects in this analysis differed somewhat from the Near analysis. As before, there was a main effect of Frequency, with HF words eliciting shorter fixations than LF words [all *F*s>18, all *p*s<.001]. The Predictability effect, however, was only trend by participants and marginal by items [F_1(1,63)=2.77, p=.101; F_2(1,43)=3.28, p=.077]. Although the interaction was significant [all *F*s>5, all *p*s<.05], the pattern of contrasts differed. As shown in Figure 2.2, unlike the Near pattern, the Predictability effect was greater for HF than LF words in the Middle condition. That is, in comparison to the Near analysis, the HF-HP vs. HF-LP contrast was significant [all *F*s>7, all *p*s<.01], while neither the LF-HP vs. LF-LP contrast [F_1=1.16, *p*>.25; F_2<1] nor the HF-LP vs. LF-LP contrast [F_1=2.41, *p*=.126; F_2=2.06, *p*>.15] reached significance. The HF-HP vs. LF-HP contrast, as before, was significant [all *F*s>22, all *p*s<.001].

Far (7-9 character) analysis. The pattern of effects in this analysis differed substantially from the other two analyses. The only effect that was significant, as seen in Figure 2.2, was Frequency [all *F*s>5, all *p*s<.05]. Neither Predictability nor the interaction were significant [all *F*s<1].

Summary. The Frequency × Predictability × Preview analyses demonstrated several effects. First, as in the 2-way analysis, Frequency and Predictability were significant but their interaction was not. Second, the main effect of Preview was not only significant, but all interactions involving Preview were also significant (Frequency × Preview, Predictability × Preview, and Frequency × Predictability × Preview). In general, shorter launch distances led to greater parafoveal previews and, subsequently, shorter fixation times on the target. To better understand the 3-way interaction, separate 2-way analyses were performed at each level of Preview (Near, Middle, Far), each of which produced a distinct pattern of results. The Near analysis of Frequency × Predictability revealed reliable main effects and an interaction in which LF words showed a larger Predictability effect than HF words. The only main effect in the Middle analysis was Frequency; Predictability was trend by participants and marginal by items. Although the interaction was significant, the pattern was opposite to that of the Near analysis: HF words showed a larger Predictability effect than LF words. Finally, the Far analysis only showed a significant effect of Frequency. From these analyses, it appears that the original additive effects of Frequency and Predictability on fixation time (as measured without regard to launch site) was the result of a combination of three differing patterns of results, two of which were interactive.

Landing position analyses

One concern regarding the launch site analyses involves the location of readers' target word fixations in terms of character position. It is well-established that the landing position in a target depends on the launch distance (e.g., McConkie et al., 1988; Radach & Kempe, 1993; Radach & McConkie 1998; Rayner et al., 1996). As launch distance increases, landing position shifts further to the left within the target and becomes more variable. Moreover, target fixation time varies as a function of landing position, with longer fixation times associated with more eccentric landing positions. This U-shaped function tends not to be symmetrical. The most efficient viewing position in normal reading is one situated halfway between the beginning and middle of a word ("*preferred viewing location*"; Rayner, 1979) and is less central than that found in single word identification ("*optimal viewing position*"; O'Regan & Jacobs, 1992).

As in the prior analyses with fixation duration, landing position was examined by 3-way (Frequency × Predictability × Preview) ANOVAs by participants and items. A significant main effect of Preview (i.e., launch distance) was observed [$F_1(2,126)=202.08$, $MSE=1.04$, $p<.001$; $F_2(2,86)=183.75$, $MSE=.55$, $p<.001$]. Follow-up contrasts showed that the landing position from each launch distance (Near, Middle, or Far) differed significantly from every other launch distance condition [F_1s>92.40, ps<.001; F_2s>77.00, ps<.001]. That is, Near launch sites gave rise to average landing positions (4.52 characters) that were located further into the target than landing positions associated with Middle launch sites (3.57 characters), and both of these were further right than landing positions from Far launch sites (2.71 characters). It is interesting to note that, although launch sites were distributed across 9 characters, the ensuing average landing positions comprised a range of less than 2 characters.

Other effects of landing position were, overall, not significant. The main effect of Frequency, although statistically suggestive, was not reliable, with only a small numerical difference between landing position on HF versus LF words (3.65 vs. 3.54 characters, respectively) [$F_1(1,63)=3.07$, $MSE=.76$, $p=.085$; $F_2(1,43)=2.40$, $MSE=.57$, $p=.129$]. Similarly, the main effect of Predictability was not significant [$F_1<1$; $F_2(1,43)=2.80$, $MSE=.44$, $p=.102$]. Finally, none of the 2- and 3-way interactions were significant [all Fs<1.25, ps>.30].

Recall, a significant main effect of Preview in SFD was found, with shorter fixation times associated with closer launch distances. It is suggested that a closer launch distance gave rise to better parafoveal preview, reducing subsequent target fixation time. Results from the current landing position analyses, however, suggest that there might be a complex trade-off between preview benefit and landing position. That is, although close launch sites provide a clearer preview of the target, the succeeding saccade will land further into the target, hence resulting in a non-preferred or less-than-optimal viewing position which would serve to increase target recognition time. Far launch sites, in contrast, not only provide a poor preview, but also tend to undershoot the preferred viewing location, again leading to increased fixation time. Medium launch sites, which occurred most frequently in our data, may represent the “just right” situation – in which a certain degree of parafoveal preview can still be obtained without adversely affecting the subsequent preferred landing (or processing) position on the target.

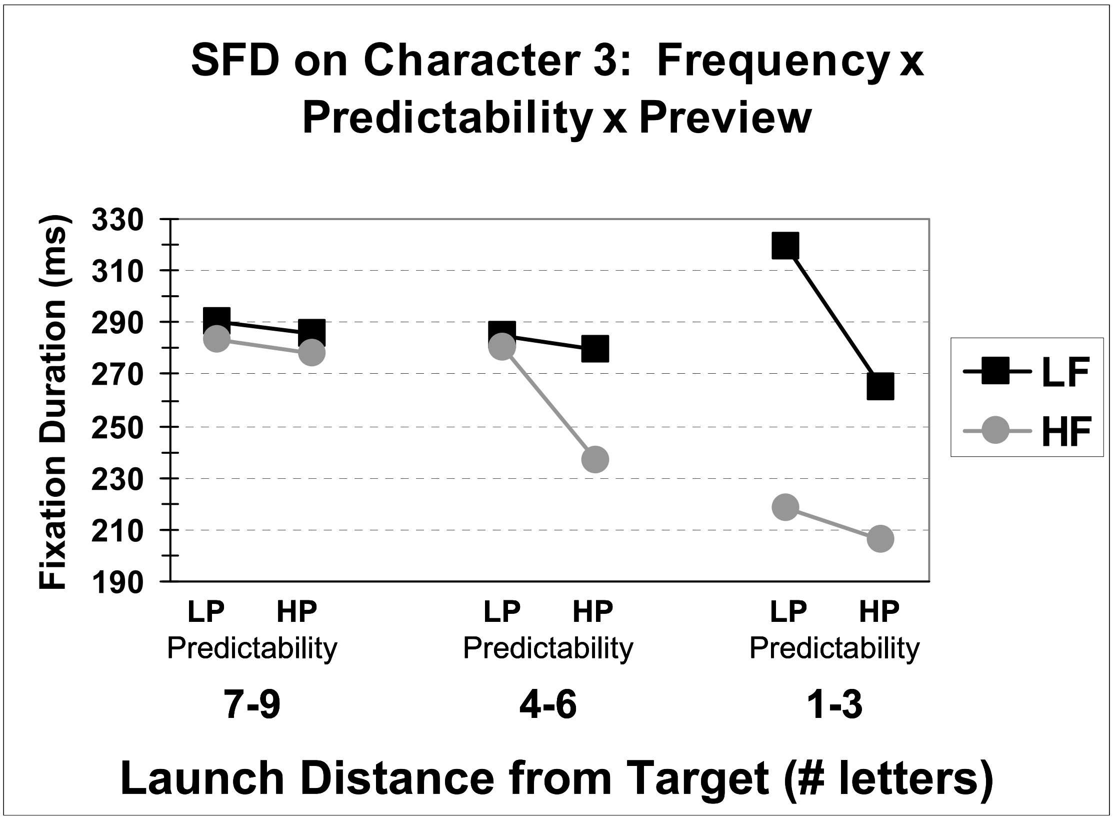
To address these issues, SFD *only* in cases when the landing position was on character 3 of the target were examined, enabling the consideration of the effects of launch distance without variability in landing position. It was not possible to conduct ANOVAs on this data as there were too few cases in the dataset. The percentage of data points per condition are reported in Table 2.7 (mean = 62, range: 32-100). Overall, SFD data from character 3 represented 25% of the SFD data conditionalised on launch site, and only 13% of the total possible data points. Average SFDs on character 3 of the target across Frequency, Predictability, and Preview conditions are shown in Figure 2.3. The pattern of means was quite similar to that obtained in the 3-way SFD design (Figure 2.3). For the main pattern to emerge, it must have been maintained in the remaining 75% of the conditionalised SFD data having landing positions other than character 3 (based on the average target word length of ~6 characters, there were 6 other possible landing positions – the space or character 0, and characters 1, 2, 4, 5, and 6). Taken together, this seems to tentatively demonstrate that the pattern of effects in the 3-way SFD data was not, in fact, driven by the processing consequences of systematic differences in landing position, but by differences in the amount of parafoveal preview.

Table 2.7. Percentage of SFD Data Points on Character 3 by Launch Distance

	HF		LF	
	HP	LP	HP	LP
Near: 1-3 characters	18	30	30	28
Middle: 4-6 characters	15	20	20	36
Far: 7-9 characters	32	35	18	16

Note. SFD = single fixation duration; HF = high frequency; LF = low frequency; HP = high predictable; LP = low predictable.

Figure 2.3. Average single fixation duration (SFD) on character 3 of target words as a function of word frequency, contextual predictability, and parafoveal preview as indexed by launch distance.



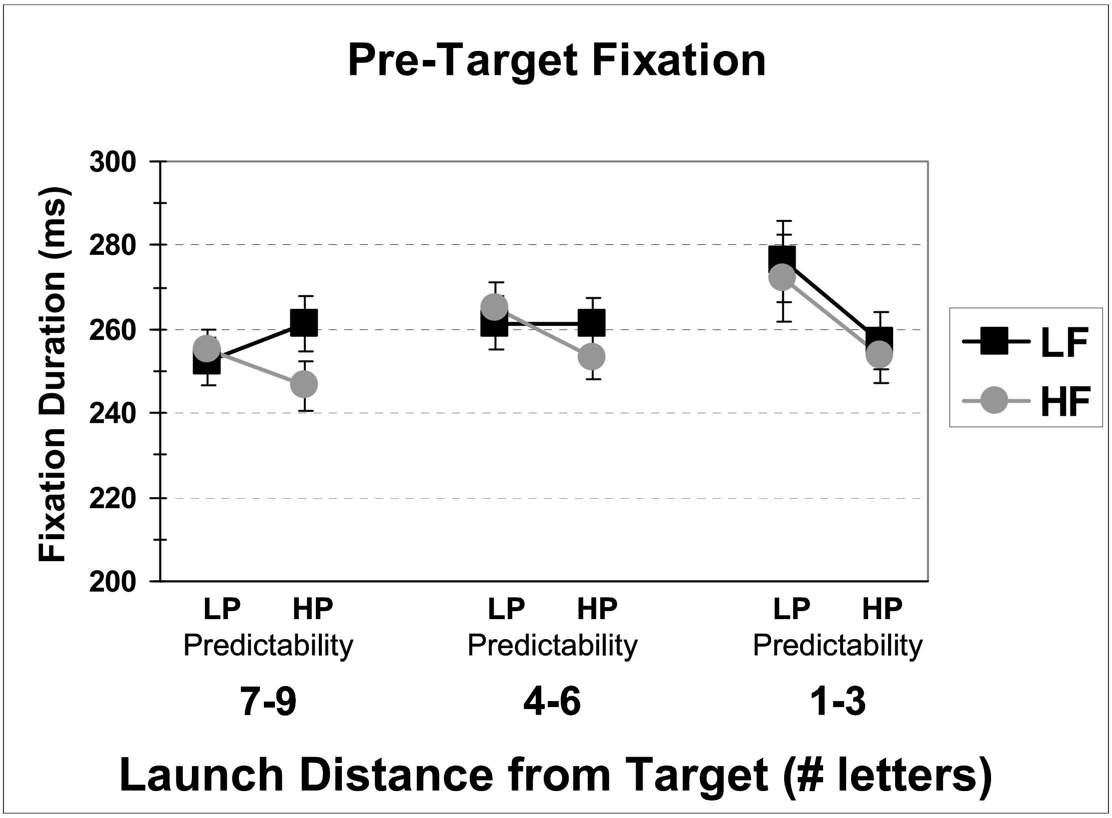
Note. HF = high frequency; LF = low frequency; HP = high predictability; LP = low predictability.

<u>Pre-target fixation analyses</u>

The duration of the launch site fixation, itself, was examined as a function of target word condition. The goal was to determine whether aspects of the target word affected the duration of the pre-target fixation. Such effects are termed "parafoveal-on-foveal" (PoF) effects because the ease or difficulty of processing a target can begin to emerge on the prior fixation, when the target is located in parafoveal vision. While the mechanisms underlying PoF effects are disputed (see, e.g., Miellet et al., 2009), these effects, in general, tend to be quite small and are often difficult to demonstrate reliably (Kliegl, 2009).

Three-way (Frequency × Predictability × Preview) ANOVAs on the fixation before the target were conducted by participants and by items. Pre-target fixations were included in the analyses only if they were immediately followed by a fixation on the target. Cases were excluded in which the target was skipped for several reasons. Fixations preceding skips occur only in a minority of the data and are typically inflated in duration. Additionally, skips are more likely to occur in certain conditions (Table 2.5). The pre-target fixation data are displayed in Figure 2.4. The only effect that was significant in both participants and items analyses was a main effect of Predictability [$F_1(1,63)=9.73$, $MSE=1304$, $p<.01$; $F_2(1,43)=4.81$, $MSE=1271$, $p<.05$]. Fixations occurring before HP words (256 ms) were reliably faster than those occurring before LP words (264 ms), supporting the presence of PoF effects.

Figure 2.4. Average pre-target fixation duration (with standard error bars) as a function of word frequency, contextual predictability, and parafoveal preview as indexed by launch distance.



Note. HF = high frequency; LF = low frequency; HP = high predictability; LP = low predictability.

The remaining effects were either not significant or were only significant by either participants or by items (but not both). As such, our interpretations are fairly tentative. The main effect of Frequency was not significant [$F_1(1,63)=1.74$, $MSE=1731$, $p>.15$; $F_2(1,43)=1.39$, $MSE=1340$, $p>.20$]. The main effect of Preview was only significant by participants [$F_1(2,126)=3.08$, $MSE=2579$, $p<.05$; $F_2(2,86)=2.03$, $MSE=1103$, $p=.137$]. Pre-target fixation times tended to be longer with closer launch sites (265, 260, and 254 ms for Near, Middle, and Far launch distances, respectively). Frequency × Preview was not significant by participants and only marginal by items [$F_1<1$; $F_2(2,86)=2.36$, $MSE=966$, $p=.100$]. Predictability × Preview, however, was significant, but only by participants [$F_1(2,126)=3.36$, $MSE=1817$, $p<.05$; $F_2(2,86)=2.13$, $MSE=1021$, $p=.125$]. The greatest difference between HP and LP conditions (collapsed across Frequency) on the pre-target fixation arose from Near (LP–HP=19 ms) in comparison to Middle (LP–HP=6 ms) or Far (LP–HP=0 ms) launch sites. The Frequency × Predictability interaction was marginal [$F_1(1,63)=2.71$, $MSE=1591$, $p=.104$; $F_2(1,43)=3.34$, $MSE=2525$, $p=.075$]. The numerical pattern of means showed that pre-target fixations were fastest for HF-HP targets (251 ms) compared to any other target condition (264, 260, and 263 ms for HF-LP, LF-HP, and LF-LP conditions, respectively). Finally, Frequency × Predictability × Preview was not significant [$F_1<1$; $F_2(2,86)=1.47$, $MSE=1324$, $p>.20$].

In sum, PoF effects did emerge, but only in limited circumstances. Pre-target fixations were speeded when the parafoveal target was HP versus LP. Although the interactions were generally of marginal significance, these showed that the PoF effect of predictability was mediated, to a degree, both by launch distance (with greater predictability differences the closer the launch site) and by frequency (with greater differences when the target was HF).

Discussion

Experiment 1 examined the interaction between word frequency and contextual predictability on target words in short passages of text while readers' eye movements were monitored. While past RT studies have generally demonstrated interactive effects of frequency and predictability, eye movement reading studies have typically reported additive effects. It is suggested that several possible methodological limitations were associated with both the RT and eye movement studies. *Experiment 1* attempted to address these limitations, using more experimental items per condition in carefully controlled contexts, and by avoiding anomaly in conditions of low predictability. Because the processing of some level of frequency and predictability begins on the prior fixation, as evidenced by the parafoveal preview benefit associated with these variables, target fixation times were additionally examined as a function of the pre-target launch distance. In this way, the amount of parafoveal preview achieved on the prior fixation varies (from high to low) as a result of launch distance (from near to far). Prior research manipulating parafoveal preview has typically used letter strings that are visually different from target words in their "no preview" condition (e.g., Sereno & Rayner, 2000; for a review, see Balota & Rayner, 1991). When the boundary is crossed, the preview is replaced by the target. While an invalid preview ensures foveal-only processing of a target, it also introduces an incorrect stimulus, which may be perceived in greater or lesser detail depending on the location of the pre-target fixation. Analysing target word processing as a function of launch distance should provide a more ecologically valid assessment of parafoveal processing. By testing a relatively high number of items per condition (*N*=22) across a high number of participants (*N*=64), it was possible to perform reliable *post-hoc* analyses on the data by launch distance to target.

Frequency (HF, LF) × Predictability (HP, LP) effects on target words irrespective of prior launch site were first analysed. Fixation time measures that reflect more immediate, first-pass processing of the target – FFD, SFD, and GD – showed reliable effects of Frequency and Predictability but no interaction, replicating the results from identical measures in Rayner et al. (2004). HF and HP words received shorter fixations than their LF and LP counterparts. TT results (which include later regressions made to the target) also replicated those of Rayner et al., showing main effects and no interaction (N.B., our interaction was marginal by participants). Finally, as in Rayner et al., a reliable interaction was observed in the PrF measure. HF-HP words were skipped more often (i.e., had a lower probability of fixation) than the other conditions (HF-LP, LF-HP, and LF-LP). It was predicted that the "upgraded" specifications of the materials used in *Experiment 1*, in relation to those used in Rayner et al., might lead to interactive fixation time findings. This did not occur. The implications of these results, however, cannot be discussed without reference to findings in which launch distance was used as an additional factor in the analysis.

The Frequency × Predictability × Preview (Near, Middle, Far) analyses were performed while maintaining a relatively high number of data points within each sub-condition (average=249 for SFD). As in the original analysis, reliable effects of Frequency and Predictability were found but no interaction of these two factors. As predicted, the main effect of Preview was also significant, with longer target fixation times associated with greater launch distances. Additionally, all interactions involving Preview were significant, including the 3-way interaction. Thus, separate Frequency × Predictability analyses at each level of Preview (Near, Middle, and Far) were performed. Frequency was significant in all three analyses. While LF words were consistently fixated for longer durations than HF words, this difference was greater for nearer launch sites (SFD differences: 48, 25, and 14 ms for Near, Middle, and Far launch sites, respectively). Predictability was significant in the Near analysis, trend by participants and marginal by items in the Middle analysis, and non-significant in the Far analysis. Again, the advantage for HP words over LP words decreased with launch distance (SFD differences: 26, 8, and 4 ms for Near, Middle, and Far launch sites, respectively). In terms of the Frequency × Predictability interaction, three distinct patterns emerged across Preview condition. The interaction was significant in both the Near and Middle analyses, but in different ways. In the Near analysis, although both HF and LF words showed reliable Predictability effects, this effect was larger for LF words. In the Middle analysis, Predictability was only significant for HF words. Finally, in the Far analysis, the interaction was non-significant. In general, the overall pattern of launch site findings demonstrated, as predicted, an attenuation of effects with greater launch distance (i.e., less effective parafoveal preview).

Two further supplementary analyses of the present data set were performed. The first of these analyses examines how target landing position was affected by launch site. Past research has demonstrated that greater launch distances yield landing positions that are both further to the left within the target (word-beginning) and more variable. Moreover, landing position, itself, influences the ease or difficulty of processing of the target as reflected in fixation time, with more eccentric positions (word-beginning or word-end) giving rise to longer fixations. In line with prior research, it was found that average landing position did vary systematically as a function of launch distance: fixation location moved toward the left with increased launch distance. Thus, it was possible that the pattern of fixation time results was not solely due to differences in the amount of parafoveal preview available from the prior fixation (as gauged by launch distance), but was instead due to associated differences in fixation location on the target, itself. Fixation location was held constant by only considering SFDs whose landing position was character 3 of the target word. While these data represented a relatively large proportion (25%) of the SFD data (i.e., assuming an even distribution, each of the 7 possible landing positions should comprise ~14% of the data), the data were too sparse to perform meaningful analyses. The numeric pattern of means, however, generally mirrored that of the complete dataset. It is suggested that, although landing position was influenced by launch distance, the resulting effects on fixation time were more a consequence of the relative amount of parafoveal preview of the target (i.e., launch site) rather than the location of the fixation on the target.

The second ancillary analysis concerned the duration of the pre-target fixation, namely, whether there was any evidence of PoF processing, when target word effects begin to appear before its subsequent fixation. It was found that the pre-target fixation was faster when the parafoveal target was HP versus LP. Although the remaining effects produced a variable pattern of statistical significance, they were suggestive that the PoF effect of predictability was influenced, in part, by launch distance to the target and target frequency, with larger PoF predictability effects with closer launch sites and HF targets, respectively.

All of these additional analyses inject complexity to the initial findings of additive Frequency × Predictability target word effects and provide a more dynamic account of events. In terms of the pre-target fixation, closer launch sites tended to give rise to longer (pre-target) fixations. However, closer launch sites also led to greater parafoveal pre-processing of the target, specifically in terms of its predictability, particularly when the target was HF. Although the pre-target launch site systematically affected the subsequent location of the fixation on the target (leading to more or less preferred viewing locations), differences in target fixation location did not result in any significant target fixation time effects. For example, when saccades were made from the Near location, although the landing position was further into the target (in a less-preferred location), target fixation times were, nevertheless, fastest in this condition. Thus, it seems that the increased parafoveal pre-processing of the target acquired from a close launch site was sufficient to offset any cost associated with a non-optimal fixation location. Moreover, when landing position was limited to the third character of the target, the basic pattern of target effects remained. From these analyses, it appears that at least some portion of target word Frequency and Predictability effects begin to emerge prior to its fixation. This suggestion of lexical-level pre-processing is substantiated by the differential pattern of Frequency × Predictability effects demonstrated on the target, itself, which are dependent on launch distance (i.e., the amount of parafoveal preview). Further evidence for a degree of lexical pre-processing is derived from the pattern of target word skipping, in which HF-HP words were more likely to be skipped than words in any other condition.

Floors and ceilings

The present analyses showed that the apparent additive effects were the product of frequency effects at all launch distances and two opposing interactions related to predictability at the Middle and Near launch sites. As can be seen in Figure 2.2, with Middle preview, the HF predictability effect was greater than a (non-significant) LF predictability effect, while with Near preview, the LF predictability effect was greater than a (significant) HF predictability effect. At least superficially, the range of fixation times across conditions seems to suggest possible floor and ceiling effects. On the "floor" end, it can be argued that there is a lower limit for the duration of single fixations on words in reading – that is, due to oculomotor constraints, fixation times, on average, just cannot get any faster. On this view, it is possible that HF-HP words in the Near condition *should* be fixated for less time but are not. While there is evidence that first fixations of immediately refixated words are faster than first-and-only (single) fixations (e.g., Sereno, 1992), this is often attributed to lower-level aspects of eye movement behaviour (Rayner, 1979). That is, an awkward location of the initial fixation (e.g., landing on external vs. more central letters of a word) can lead to an immediate refixation in order to optimize the viewing position. In addition, first fixations of refixated words are also faster because there is no associated cost of shifting attention to another word as would be the case with single fixations (Sereno, 1992). The most compelling evidence for a floor effect in the present data, however, is demonstrated by comparing first-pass measures for HF-HP words at the Near launch site. As seen in Table 2.6, this condition has associated means of 218, 219, and 220 ms for FFD, SFD, and GD measures, respectively. For all three measures to be equivalent, targets would have to be fixated only once almost all of the time. Thus, a single fixation was sufficient in duration, and possibly excessive, to process such words at the closest launch site.

On the "ceiling" end, the average longest duration of single fixations was around 290 ms. As seen in Figure 2.2, all LF conditions (excluding LF-HP words at the Near launch site) received similar SFDs (means were within 9 ms of each other). The notion of a fixation deadline in reading has been previously proposed and is able to account for certain aspects of eye movement behaviour (e.g., Henderson & Ferreira, 1990; Sereno, 1992). If a criterion level of processing on the current word has not been completed (reaching the criterion would normally trigger an eye movement to the next word), a deadline will be reached whereby an eye movement will nonetheless be made. The saccade target (intra or extraword) depends on the relative timing and progress of cognitive and oculomotor variables. If there is a fixation deadline, the question remains as to *when* the processing occurs in more difficult conditions (e.g., LF-LP words at the Far launch site). To this end, the number of immediate first-pass refixations, as well as the number of second-pass fixations across all Frequency, Predictability, and Preview conditions were examined. Across these conditions, there are a total of 385 refixations and 430 second-pass fixations. This data is somewhat obscured in fixation time measures: although GD includes first-pass refixations and TT includes second-pass fixations, such fixations only account for a small percentage of the data. As noted earlier, each cell of the 3-way design attracted a different number of fixations (see Table 2.4). For example, there were more target fixations that originated from Middle versus Near or Far launch distances. To control for this uneven distribution, the percentage of refixations and second-pass fixations in any given cell based on the total possible number of data points in that cell was calculated (see Table 2.8). On average, there were more of these fixations in the LF (27%) than in the HF (20%) condition, in the LP (28%) than in the HP (19%) condition, and in the Far (28%) or Middle (25%) than in the Near (18%) condition. This pattern lends support to the idea of a deadline, with more fixations (immediate or returning) made to those conditions which were more difficult.

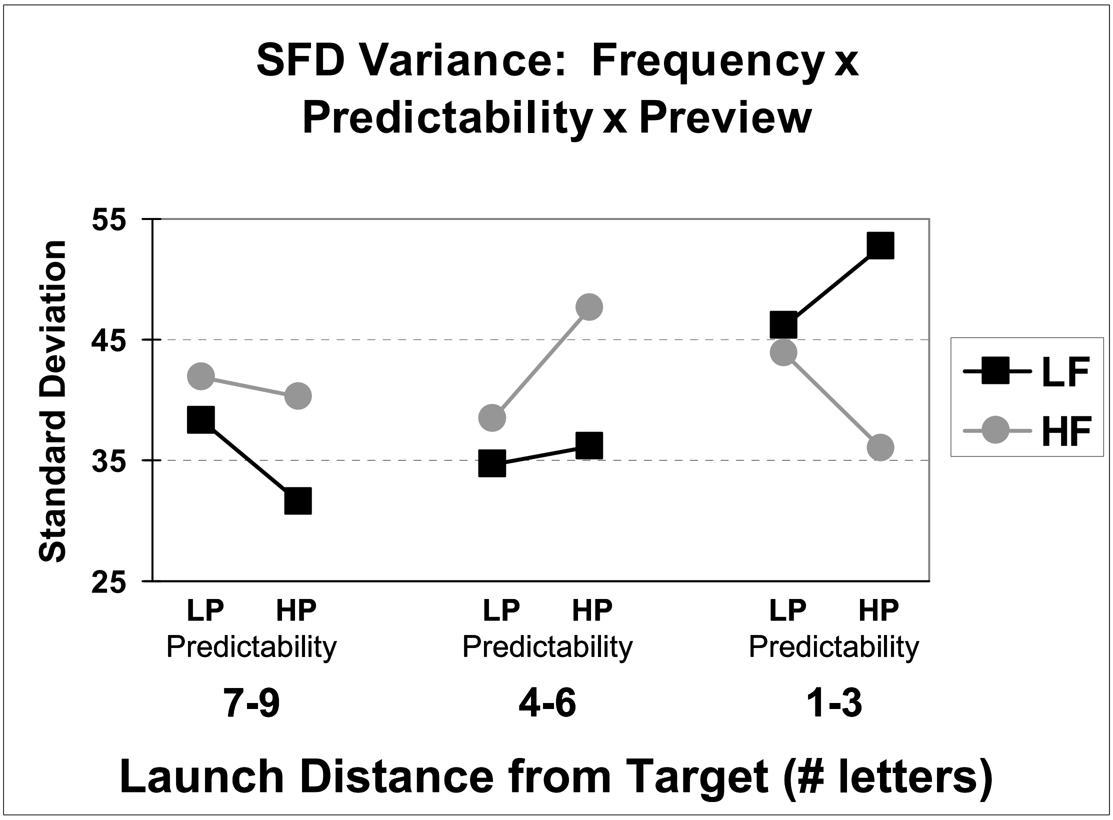
Table 2.8. Percentage of Refixations and Second-Pass Fixations as a Function of Launch Distance (characters) across Conditions

	HF		LF	
	HP	LP	HP	LP
Near: 1-3 characters	9	18	15	28
Middle: 4-6 characters	18	23	23	34
Far: 7-9 characters	23	30	23	35

Note: HF = high frequency; LF = low frequency; HP = high predictable; LP = low predictable.

One further assessment of the data was performed to substantiate the occurrence of floor and ceiling effects, and that was that the variance across all conditions was calculated. If floors and ceilings were operating in certain conditions, then there should be relatively less variance in these conditions. The average standard deviations across all conditions are shown in Figure 2.5. The standard deviations, however, were highly variable. In addition, as some of the participant and item means in any given condition were only represented by a single data point, standard deviations could not be obtained, giving rise to missing cells. Thus, although the numerical pattern of results generally confirmed the above conjectures, statistical proof of such effects could not be provided.

Figure 2.5. Average single fixation duration (SFD) variance on target words as a function of word frequency, contextual predictability, and parafoveal preview as indexed by launch distance.



Note. HF = high frequency; LF = low frequency; HP = high predictability; LP = low predictability.

In sum, the qualitative assessments of the data lend some support to the notion of a floor affecting the HF-HP/Near condition and a ceiling affecting all LF conditions except the LF-HP/Near condition. However, it cannot be definitively shown that such effects exist. If floor and ceiling effects were, in fact, operative, it becomes somewhat problematic to interpret the results. For example, if the HF-HP/Near condition had not been artificially slowed by a putative floor, the pattern of Frequency and Predictability effects in the Near Preview condition may have been additive. None of the HF conditions, however, were affected by a ceiling, as evidenced by reliable Frequency effects across all Predictability and Preview conditions. HF conditions also showed, when unconstrained by either a floor or ceiling, an attenuation of Predictability effects from the Middle to Far launch distances. In contrast, LF-HP/Near was the only condition *not* affected by a putative ceiling. It is possible, for example, that if fixation times in the remaining LF conditions were unimpeded, then Frequency × Predictability may have been additive in the Middle Preview condition and interactive in the Far Preview conditions (with extended fixations selectively for LF-LP words). Such scenarios at this point, however, are purely speculative. Despite the limitations imposed by the potential existence of such effects, an attempt to offer plausible interpretations of these findings with respect to models of lexical processing and current models of eye movement control is provided below.

<u>Models of lexical processing</u>

The approach adopted from the outset of this chapter had been to frame Frequency × Predictability within the modularity-interactive debate by determining whether the data exhibited additive or interactive effects. Within the additive-factors approach, additive or interactive statistical findings are generally used to infer either serial processing over discrete stages or multiple activations affecting each other within a common stage, respectively. Although this approach is still widely used within the literature related to mental chronometry, it has long been subjected to a variety of critical assessments (see, e.g., Townsend, 1984; Yap & Balota, 2007). Given the complex connectivity of the neural substrates associated with, for example, language processing, the notion of isolated, non-overlapping processing stages seems implausible. Nevertheless, additive-factors has provided a productive framework that has helped reveal the relative timing of lexical variables. Temporally precise techniques such as measuring electrophysiological responses can then be used to confirm the onset and duration of different aspects of processing.

Within an additive-factors framework, the original (2-way) Frequency × Predictability results, when examined in isolation, demonstrated additive effects and seem, at first glance, to support a modular account of lexical processing. That is, context does not directly affect lexical access, but influences a later, post-lexical integration stage of processing. Given that this additive pattern was maintained in all fixation time measures (FFD, SFD, GD, and TT), this view would have to assume that both lexical and post-lexical stages are reflected in the earliest FFD measure and are not modulated by additional processing that occurs in the temporally later GD or TT measures. As a corollary, it would also assume that the processing cost of integrating LF or LP meanings is equivalent to that associated with HF or HP meanings. An interactive account, on the other hand, would have to posit that the apparent additive pattern of effects was a consequence of differential access and integration processes that happen to offset each other. During lexical access, a biasing context would confer greater benefit to LF than HF words. In terms of semantic integration, however, an interactive account would have to assume that an initial advantage gained during access is offset by a cost in integration (depending on the specific frequency-predictability activation profile), masking underlying interactive lexical effects. These opposing effects would begin in FFD and continue into later measures. Because additional suppositions are required from both models to explain why the pattern of fixation times does not differ across measures, at present, neither account seems wholly tenable. The issue remains of how to account for the different Frequency × Predictability sub-patterns when Preview is included as a factor.

It is clear from the 3-way analysis above that past eye movement findings (including the initial analysis in this chapter) demonstrating additive effects of frequency and predictability conceal sub-patterns (some interactive) which vary with launch distance. Analyses across the different launch sites in the present study indicated a dynamic complexity – the nature of the interaction reversed from Near to Middle sites and became insignificant at Far sites. The potential presence of apparent floor and ceiling effects, however, severely constrains attempts to offer a definitive interpretation. At a superficial level, at least, there is clear evidence that the additive pattern of results does not hold when launch site is considered. Given these circumstances, it does not seem prudent to speculate about what modular and interactive models might suggest in order to account for the additional factors of launch distance and fixation time limits. A more productive approach is to discuss the present findings in relation to current models of eye movement control.

Models of eye movement control

Recently, several models of eye movement control in reading have emerged which attempt to capture the temporal dynamics of reading by parameterising lower-level, perceptual to higher-level, cognitive contingencies of reading behaviour. The assumption that on-going cognitive processing is the main determinant of eye movement control (Rayner et al., 1996) is a key feature of such models. Specifically, fixation time (i.e., when to move the eyes) is mainly determined by the status of on-line language processing, while fixation position (i.e., where to move the eyes) depends on the combined influence of linguistic, visual, and oculomotor factors. There are two main categories of eye movement control models that differ in how visual attention is thought to be allocated in reading. In "sequential attention shift" models, parafoveal preview benefit is due to a covert, serial movement of attention towards the parafoveal word preceding the eye movement to that word (e.g., Morrison, 1984; E-Z Reader of Reichle et al., 2003). In "guidance by attentional gradient" models, the preview benefit is explained by parallel processing of several words within the perceptual span (e.g., SWIFT of Engbert, Nuthmann, Richter, & Kliegl, 2005; Mr. Chips of Legge, Hooven, Klitz, Mansfield, & Tjan, 2002; Glenmore of Reilly & Radach, 2003). Our discussion will be limited to E-Z Reader and SWIFT as these are the most prominent models.

In E-Z Reader (e.g., Reichle et al, 2003), lexical access occurs over two stages. Completion of the first stage of lexical access ("familiarity check") signals saccadic programming to begin, and completion of the second ("completion of lexical access") signals the attentional "spotlight" to shift to the next word. The main factors affecting both stages of access are word frequency and contextual predictability. The model can and has simulated either an additive or a multiplicative interaction of frequency and predictability. In its original instantiation, E-Z Reader adopted a multiplicative function (Reichle et al., 2003). To accommodate the data of Rayner et al. (2004), this function was changed to an additive one (detailed in the same paper).

The SWIFT model (e.g., Engbert et al., 2005) assumes that processing is spatially distributed within an "activation field" which decreases with the distance from fixation location. The activation of a given word increases with the degree of lexical access, but then rapidly declines when the word is fully comprehended. Consequently, most words to the left of the foveal target will have minimal activation unless they have not been fully accessed. Words to the right generally have a higher level of activation, although this decreases with degree of eccentricity. Lexical access time is a function of both frequency and predictability. The parallel processing of words leads to predictions regarding the processing difficulty of target word *n* both on word *n+1* and word *n-1* (Kliegl et al., 2006).

E-Z Reader and SWIFT can be discriminated by the absence or presence, respectively, of pervasive PoF effects, in which lexical characteristics of the parafoveal word are reflected in fixation time on the foveal word. Pervasive PoF effects are considered to be damaging to strictly serial models of eye movement control such as E-Z Reader. A central assumption of this model is that the cognitive processes involved in processing the currently *foveated* word are the motivating force behind eye movements in reading. The recognition of words is instantiated as a serial process, with the word contained within the reader's attentional beam being the only word processed lexically (Drieghe, Rayner, & Pollatsek, 2007). The E-Z Reader model, as mentioned previously, proposes two stages of word recognition. Termination of the first phase of processing word *n* prompts the reader's oculomotor system to begin programming of a saccade to word *n* +1. Termination of the second phase causes the reader's attentional beam to shift to word *n*+1. Recent versions of the E-Z Reader model (Reichle, Pollatsek, & Rayner, 2007) propose that both stages are related to obtaining word meaning – the first stage indicating a point where meaning activation has crossed a lower threshold than the second threshold required to trigger a shift of attention. Because parafoveal processing can only start after saccadic programming has started – and because the duration of saccadic programming is independent of parafoveal processing – it is assumed that models such as E-Z Reader cannot account for robust PoF effects. Models such as SWIFT incorporate the parallel processing of both foveal and parafoveal words during reading. One could argue from a such a parallel point of view of processing that PoF effects are naturally predicted, if a parallel method of foveal and parafoveal processing were in operation.

Recently, proponents of E-Z Reader have suggested that PoF effects can arise from "mislocated" fixations – that is, ones resulting from saccadic undershoots of the parafoveal word which land, instead, on the foveal word (Drieghe, Rayner, & Pollatsek, 2008). This claim, however, has been challenged by those who argue for parallel processing of adjacent words (e.g., Kennedy, 2008). The present data on the pre-target fixation are somewhat equivocal on this issue. On one hand, a significant main effect of Predictability is shown (i.e., collapsed across Near, Middle, and Far pre-target fixation locations), supporting a parallel processing approach. On the other, statistically weaker effects are found, in which the pre-target Predictability effect is modulated by proximity of the pre-target fixation to the target, supporting a serial account in conjunction with mislocated fixations. Of more relevance to the current findings, however, is each model's theoretical stance on how frequency and predictability interact. E-Z Reader is theoretically silent on the additive versus multiplicative nature of the interaction. SWIFT identifies a different temporal profile for each function. That is, frequency only becomes relevant when the word comes into view. Word predictability is independent of visual input and can, therefore, occur earlier than frequency. This process dissociation in SWIFT, however, produces neither a strictly additive nor multiplicative interaction.

The results of *Experiment 1* show both additive and multiplicative patterns of frequency and predictability. The nature of the interaction seems to depend not only on launch site, but also on possible floor and ceiling effects. If these conjectures are valid, then it becomes a computationally empirical question whether implementing a preview function along with certain fixation ranges in E-Z Reader (additive or multiplicative versions) or SWIFT would generate simulated data replicating the findings of *Experiment 1*. Both models discuss launch site, but only in relation to its effect on the accuracy and distribution of landing sites. In both models, landing sites can influence fixation duration. For example, close and far launch sites to short and long words, respectively, can give rise to non-optimal landing positions (overshoots and undershoots, respectively), and increase fixation duration. As such, launch distance is potentially confounded with a word's optimal viewing location as a function of its length. Although word length and frequency in general tend to be negatively correlated, these variables were manipulated orthogonally in *Experiment 1*. In any case, the quality of the preview is not directly addressed in either model. In terms of fixation limits, Reichle et al. (2003) specifically argued against the concept of a deadline. They reasoned that if it were present, then first fixations of refixated words should always be longer than single-and-only fixations (i.e., the deadline would always be reached if a word required a second fixation). This account, however, fails to recognise the additional demands in single fixations associated with shifting attention to a new word versus, in refixations, simply maintaining attention on the current word (Sereno, 1992). A benefit of implementing a preview function and fixation limits might be that a single rule could be used to characterize the activation functions of frequency and predictability. Thus, an additive or interactive pattern of effects would not be hard-wired into the model, but instead emerge as a consequence of other constraints

Conclusion

Experiment 1 explored the nature of the interaction between word frequency and contextual predictability in fixation times on words during normal reading. In general, RT research has found interactive effects of these variables while eye movement research has found additive effects. The design of *Experiment 1* attempted to improve on various methodological aspects of previous studies. The role of parafoveal preview, as indexed by launch distance, was also examined. When only frequency and predictability were considered, the results replicated past eye movement research demonstrating additive effects. When launch distance was taken into account, however, interactive as well as additive patterns were observed within the data. These patterns were suggestive of the operation of concurrent floor and ceiling effects. A methodological drawback of *Experiment 1* was that, although there was a relatively large amount of data points per condition within the post-hoc analysis of launch distance, it was not enough to definitively demonstrate the existence of fixation time limits. As a result, the interpretation of these findings in terms of models of language processing can only be speculative. The data, however, do have implications for current models of eye movement control. The quality of parafoveal preview and the notion of fixation time limits are factors that, if incorporated into eye movement models, could provide insight into the underlying processing that occurs while reading. In sum, it is believed that *Experiment 1* provides a worthwhile approach to validate models of word recognition and eye movement control in reading.

Chapter 3

Re-examining the frequency × predictability interaction on fixation durations in normal reading

Introduction

Global analyses of fixation duration data in *Experiment 1* yielded additive effects of word frequency and contextual predictability. However, conditionalised analyses, contingent on the location of the fixation prior to the target word revealed that the simultaneous effects of frequency and predictability are modulated by parafoveal preview benefit. When parafoveal preview was highest (i.e., the Near launch distance condition), word frequency and contextual predictability yielded interactive effects on fixation duration, such that the processing of LF words was greater facilitated by a supportive context than was the processing of an HF word. This same pattern of effects was not replicated at Middle and Far launch distances, producing an overall additive pattern of effects.

The ability to extract information from a parafoveal word is influenced not only by the proximity of the prior fixation to that word, but also by the features of the upcoming word itself. It may be the case that the interactive pattern of effects observed in the Near launch site of *Experiment 1* can be replicated in global analyses by more strongly manipulating the lexical and contextual aspects of target words. As mentioned previously, the amount of information a reader can extract about an upcoming parafoveal word is influenced by that word's frequency and contextual predictability (Balota et al., 1985; Inhoff & Rayner, 1986).

Experiment 2a was designed to address two related concerns with regard to *Experiment 1*: i) the Cloze value of HP words in *Experiment 1* were not sufficiently high; and ii) the range of Cloze values included in both LP and HP conditions were too widely distributed. In *Experiment 1*, although the mean contextual predictability of LP words was .02, the Cloze predictability of individual items ranged from .00 to .30 with a standard deviation of .06. The mean contextual predictability of what were termed HP words was only .57, with a range of .00 to 1.00 and a standard deviation of .32. It may be the case that the search for interactive effects of predictability and frequency in *Experiment 1* was undermined by having a poorly controlled manipulation of predictability. In *Experiment 2a*, a new set of materials will be tested in order to examine the difference between very high predictability (VHP) and very low predictability (VLP) words. The mean Cloze values of VHP and VLP materials in *Experiment 2a* will be higher and lower (respectively) than the Cloze values of HP and LP targets in *Experiment 1*. Also, the Cloze probabilities of individual items will be maintained within a much stricter range than the values of the target words in *Experiment 1*.

The experimental materials used in *Experiment 2a* will be of a different structure to those used in *Experiment 1* (see Table 3.1). The motivation for positioning each target in a unique passage was to address methodological concerns arising from *Experiment 1*. Target words will be displayed towards the middle of the second line of a 2-line passage. Each line of text will display a maximum of 80 characters, an expansion from the 60 character maxima in *Experiment 1*. Furthermore, each target word in *Experiment 2a* will have its own unique contextual frame. In *Experiment 1*, each passage was designed to accommodate *either* an HF or LF target (see Table 3.1). For half of the passages, the HF target was HP while the LF target was LP; for the other half of passages, the LF target was HP while the HF target was LP. This meant that two groups of participants were required so that each target word could be viewed in each of its predictability conditions, without repetition of target words. In *Experiment 2a*, unique frames will be used for each target word across predictability conditions (See Table 3.1). In *Experiment 1*, pairs of length-matched HF and LF words were generated. Contexts were constructed to be supportive of one member of this pair, with the other being a less predictable alternative. However, this approach is not conducive to well-controlled LP items. It may be more appropriate to generate specific LP items, rather than generate an HP context for one word, then bluntly swap that word for an alternative.

Table 3.1. Example Materials – *Experiments 1* and *2a*

Experiment 1

HF-HP or LF-LP

The gifted students were selected to receive extra lessons [lb]
at the local **school** | **circus** during weekends and holidays.

LF-HP or HF-LP

All the children were thoroughly amused by the clowns that [lb]
came once a year to the **circus** | **school** in their village.

Experiment 2a

HF-VHP

The night after her day at the zoo, Natalie fell into a deep sleep. [lb]
However, she had a very unusual **dream** about being chased by a chimp.

HF-VLP

The burglar was quiet and efficient as he stole the valuables. [lb]
He quickly ran to the **house** across the street and robbed it too.

LF-VHP

After his morning jog, Gregor was happy to take a long, hot shower. [lb]
When he stepped out, he reached for his **towel** but it wasn't there.

LF-VLP

The house hunters had a very good idea of what they were looking for. [lb]
They wanted a house with a large **attic** to convert into a home office.

Note. HF = high frequency; LF = low frequency; (V)HP = (very) high-predictability target; (V)LP = (very) low-predictability target. Target words are in **bold**. [lb] denotes how materials were split across the two lines of display. Experiment 1: Each sentence can accommodate either an HF-HP or LF-LP target (upper set of materials) or an LF-HP or HF-LP target (lower set of materials).

A further advantage of generating unique passages for each target word is that each subject can see every target word in its specifically-designed context. In *Experiment 1*, because each member of and HF-LF word pair could be seen in only its HP or LP form, two separate subject groups were required, and each target word was seen in *only* its HP *or* LP form. By generating a unique context for each target word, there is no need for separate subject groups, allowing more observations per item with the same number of participants.

It is hypothesised that a stronger, more carefully-controlled manipulation of contextual predictability will allow readers to extract more information parafoveally from target words in *Experiment 2a* than in *Experiment 1*. It is hypothesised that the results of *Experiment 2a* will demonstrate an interactive pattern of frequency and predictability effects in global fixation duration analyses. It is predicted that this pattern of this interaction will be such that the processing of LF words is facilitated more so by a supportive context than the processing of an HF word. This is in contrast to the results of *Experiment 1*, wherein such an interactive pattern of effects was confined to cases where participants had received a high level of parafoveal preview benefit (i.e., their eyes had been located near to the beginning of the target word on prior fixation).

Experiment 2a

Method

Participants

Forty members of the University of Glasgow community (22 females; mean age 23 years old) were paid £6 or given course credit for their participation. All were native English speakers with normal or corrected-to-normal vision and had not been diagnosed with any reading disorder.

Apparatus

Eye movements were monitored via an SR Research Desktop-Mount EyeLink 2K eyetracker, with a chin/forehead rest. The eyetracker has a spatial resolution of 0.01^{o} and eye position was sampled at 1000 Hz using corneal reflection and pupil tracking. Text (black letters on a white background, using 14-point Bitstream Vera Sans Mono, a non-proportional font) was presented on a Dell P1130 19" flat screen CRT (1024 × 768 resolution; 100 Hz). At a viewing distance of 72 cm, approximately 4 characters of text subtended 1^{o} of visual angle. Viewing was binocular with eye movements recorded from the right eye.

Design and Materials

A 2 (Frequency: HF, LF) × 2 (Context: VHP, VLP) design was used. With a total of 120 experimental items, there were 30 items in each of the 4 conditions. All experimental items are listed in **Appendix III**. An example set of materials, showing all 4 target conditions, is presented in Table 3.1. Target words were always positioned near the middle of the second line of a passage. Experimental items were presented in a different random order to each participant.

Table 3.2. Specifications of Target Stimuli

Condition	Length	Frequency	Predictability	Cloze
HF-VHP	5.87 (1)	172 (106)	2.29 (0.24)	0.97 (0.04)
HF-VLP	5.87 (1)	172 (131)	0.52 (0.70)	0.01 (0.02)
LF-VHP	5.87 (1)	7 (4)	2.25 (0.33)	0.96 (0.05)
LF-VLP	5.87 (1)	7 (4)	0.35 (0.68)	0.01 (0.02)

Note. Mean values are shown with standard deviations in parentheses. Units of measurement are as follows: Length in number of letters; Frequency in occurrences per million; Predictability rating range is -3 (highly unpredictable) to 3 (highly predictable). HF = high frequency, LF = low frequency, VHP = very high predictable, VLP = very low predictable.

Frequency. Half of the targets were HF and half were LF words. Word frequencies were obtained using the 90-million written word BNC (http://www.natcorp.ox.ac.uk). Mean frequencies were 172 occurrences per million for HF targets (range 36-727 per million) and 7 occurrences per million for LF targets (range <1-16 per million; see Table 3.2). The frequency of the target words in the current experiment are highly comparable to those used in *Experiment 1* (166 and 5 occurrences per million for HF and LF conditions, respectively).

Predictability. Half of the targets were presented in a VLP context and half in a VHP context. The level of contextual predictability was determined by two norming tasks – a Cloze probability task and a predictability rating task. In the Cloze task, 20 participants (none of whom participated in the main experiment or the predictability rating task) were given each experimental item up to but not including the target word. Their task was to generate the next word in the sentence. Items were scored as "1" for correct responses and "0" for all other responses. The manipulation of predictability in the present experiment was found to be much stronger than in *Experiment 1*. The mean Cloze predictability of VHP target words was .96 (opposed to a mere .57 in *Experiment 1*), and the mean Cloze predictability of target words in VLP conditions was .01 (as opposed to .03 in *Experiment 1*) .Furthermore, the range of Cloze values of individual items in each condition was much better controlled in the present experiment than in *Experiment 1* (VHP range .85-1.00 vs. HP range .00-1.00; VLP range .00-.05 vs. LP range .00-.30). A 2 (Frequency: HF, LF) × 2 (Context: VHP, VLP) ANOVA on Cloze probabilities by items (F_2) revealed a main effect of Context, with more targets generated in VHP (.96) than in VLP (.01) contexts (see Table 3.2) [$F_2(1,29)=25262$, $MSE=.001$, $p<.001$]. No other main effects or interactions were significant [all $F_2\text{s}<1$].

In the predictability rating task, 20 participants (again, none of whom participated in the main experiment or Cloze task) were presented with each item in its entirety with the target word underlined. Ten percent of the materials were non-experimental filler items (two-line texts) that were clearly anomalous. The participants' task was to indicate how predictable they considered the target word to be on a 7-point scale from -3 (highly unpredictable) to 3 (highly predictable). A 2 (Frequency: HF, LF) × 2 (Context: VHP, VLP) ANOVA on predictability ratings by items (F_2) revealed, as expected, a main effect of Context, with targets rated more predictable in VHP (2.27) than in VLP (0.43) contexts (see Table 3.2) [$F_2(1,29)=500.33$, $MSE=.202$, $p<.001$]. No other main effects or interactions were significant [all F_2s<1].

Procedure

Participants were given written and verbal instructions about the eyetracking task. They were told to read for comprehension, as they would normally, and that questions would appear after half of the trials to ensure they were paying attention.

The experiment involved the initial calibration of the eyetracking system, reading 10 practice passages, recalibration, then reading the 120 experimental passages. The 9-point calibration display comprised a series of calibration points extending over the maximal horizontal and vertical range of the display. After participants fixated each point in a random order, the accuracy of the calibration was checked (validation). The experiment proceeded only when the calibration was highly accurate (average error $<.30^{o}$; maximal error on any one point $<.50^{o}$). If necessary, participants could be recalibrated at any time during the experiment.

Each trial began with a black square which corresponded to the position of the first letter of the experimental item. An accurately calibrated fixation at this location triggered the presentation of the item. After reading each item, participants moved their eyes to the lower, right corner of the screen and pressed a button to clear the screen. On half of the trials, a Yes-No comprehension question followed. Participants had no difficulty in answering these questions correctly (average over 94% correct). Prior to each new trial, participants were required to fixate a central point allowing the experimenter to implement a drift-correction routine.

Results

The target region comprised the space before the target word and the target itself. Lower and upper cut-off values for individual fixations were 100 and 750 ms, respectively. Data were additionally eliminated if there was a blink or track loss on the target, or if the fixation on the target was either the first or last fixation on a line. Overall, 7.4% of the data were excluded for these reasons. In reading, most content words are generally fixated once – sometimes words are immediately refixated, sometimes they are skipped altogether. In the present study, the percentages of data for single fixation, immediate refixation, and skipping of the target were 61.3, 5.8, and 24.8%, respectively. The number of data points included and excluded across conditions is presented in Table 3.3. The resulting data were analyzed over a number of standard fixation time measures on the target word: (a) FFD; (b) SFD; (c) GD; and (d) TT. The probability of making a first-pass fixation on the target (PrF) was also examined. The average values across all measures are presented in Table 3.4.

Table 3.3. Number of Data Points for Analyses

			Skip	Reject	Total
FFD					
	HF-VHP	760	361	79	1200
	HF-VLP	810	295	93	1200
	LF-VHP	815	294	91	1200
	LF-VLP	866	242	92	1200
SFD					
	HF-VHP	472			
	HF-VLP	504			
	LF-VHP	504			
	LF-VLP	537			

Note. The total number of data points across the experiment is 4800, resulting from 40 participants with 30 items in each of 4 conditions. FFD = first fixation duration; SFD = single fixation duration; HF = high frequency; LF = low frequency; VHP = high predictable; VLP = low predictable.

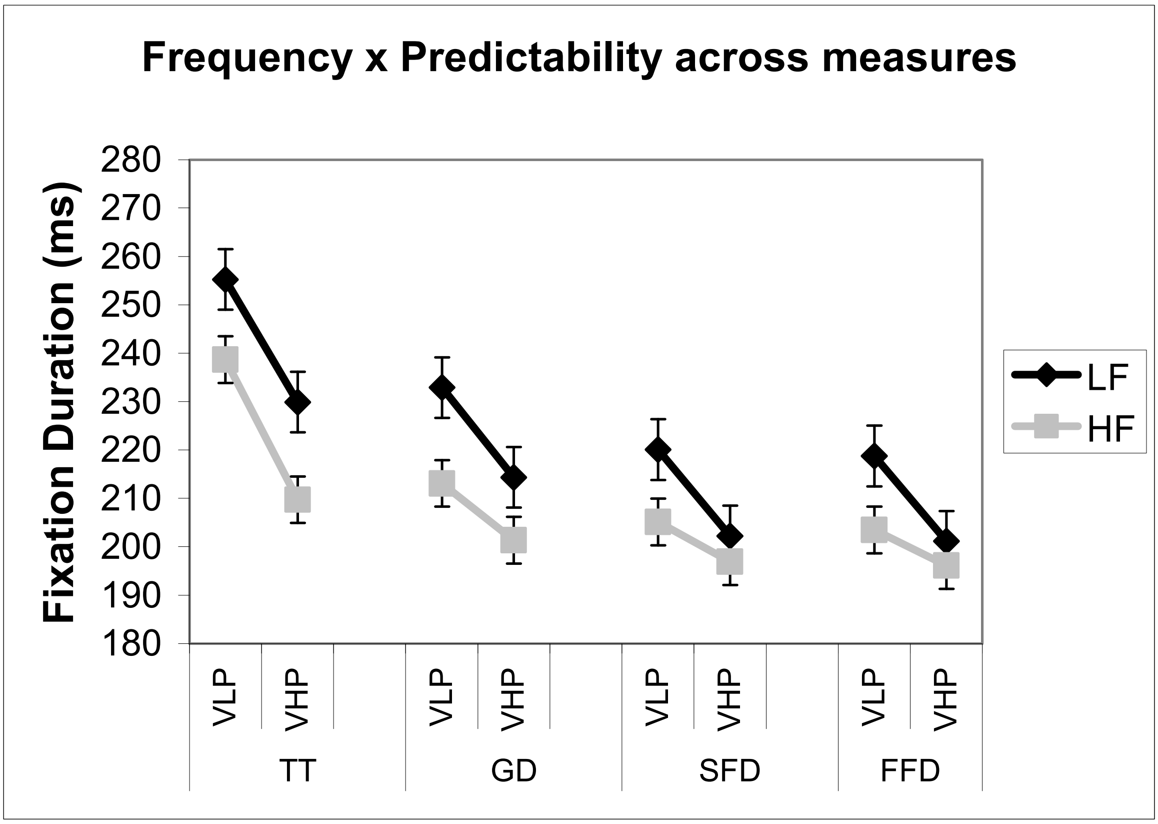
Table 3.4 Average Fixation Time (ms) and Fixation Probability across Target Measures

	HF		LF	
	VHP	VLP	VHP	VLP
FFD	196	203	201	219
SFD	197	205	202	220
GD	201	213	214	233
TT	210	239	230	255
PrF	.68	.74	.73	.77

Note. HF = high frequency; LF = low frequency; VHP = high predictable; VLP = low predictable; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time; PrF = probability of fixation.

Condition means across measures, including standard error bars, are displayed in Figure 3.1. For all measures, 2 (Frequency: HF, LF) × 2 (Context: VHP, VLP) ANOVAs were conducted both by participants (F_1) and items (F_2) sources of variance.

Figure 3.1. Average fixation durations on target words across measures as a function of word frequency and contextual predictability.



Note. Fixation durations in milliseconds (ms). HF = high frequency; LF = low frequency; VHP = high predictable; VLP = low predictable; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total fixation time.

Main effects of Frequency and Predictability

The main effects observed in the global analyses were highly similar to those observed in the global analyses of *Experiment 1*. Analyses revealed a significant main effect of word frequency across all fixation duration measures [$F_1(1,39)$: F-values 21.36-54.30, *MSE*s 247-543, all *p*s<.001; $F_2(1,29)$: F-values 21.29-36.46, *MSE*s 158-570, all *p*s<.001]. HF words were fixated for less time than LF words (200 vs. 210 ms for FFD, 201 vs. 211 ms for SFD, 207 vs. 224 ms for GD, and 224 vs. 243 ms for TT, respectively). Predictability was also significant in FFD, SFD, GD and TT [$F_1(1,39)$: F-values 24.92-31.25, *MSE*s 135-544, all *p*s<.001; $F_2(1,29)$: F-values 8.63-13.75, *MSE*s 266-799, all *p*s<.01]. HP words were fixated for less time than LP words (199 vs. 211

ms for FFD, 200 vs. 213 ms for SFD, 208 vs. 223 ms for GD, and 220 vs. 247 for TT, respectively).

Significant main effects of frequency and predictability were also found on the PrF. Participants were more likely to fixate LF words (.75) than HF words (.71) [$F_1(1,39)=10.42$, $MSE=82.54$, $p<.01$; $F_2(1,29)=16.52$, $MSE=38.10$, $p<.001$]. Participants were also more likely to fixate VLP words (.75) than VHP words (.71) [$F_1(1,39)=7.05$, $MSE=103.94$, $p<.05$; $F_2(1,29)=8.18$, $MSE=85.45$, $p<.01$].

Frequency × Predictability

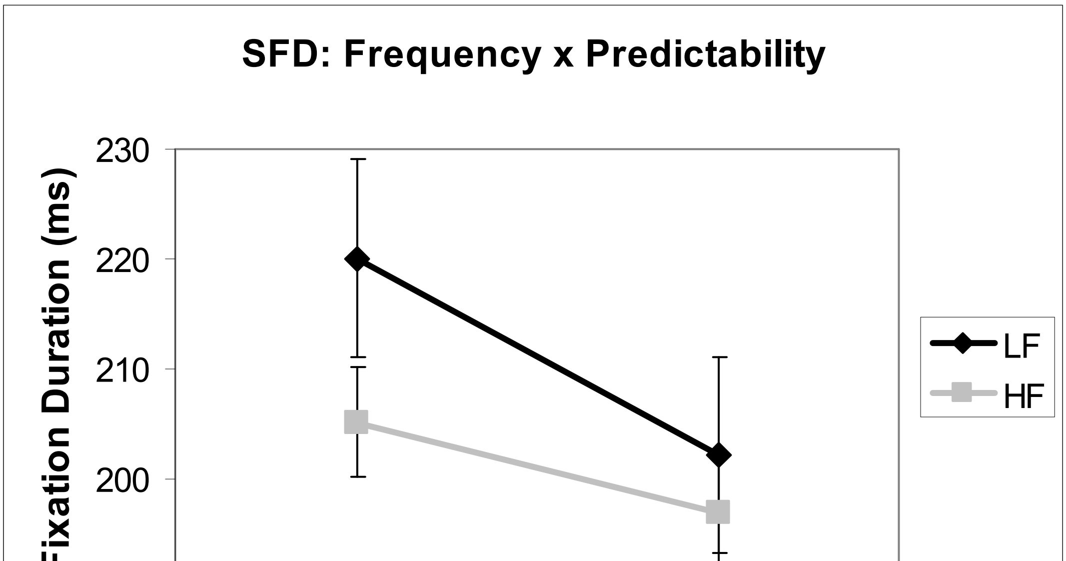
Figure 3.1 demonstrates the effect patterns across fixation duration measures. Contrary to the results of *Experiment 1*, the global analyses of the *Experiment 2a* revealed an interaction between word frequency and contextual predictability effects. This interaction was significant by participants analyses in both FFD and SFD data, but only trend and marginally significant in items analyses, respectively [FFD: $F_1(1,39)=7.22$, $MSE=147.44$, $p<.05$; $F_2(1,29)=2.45$, $MSE=315.56$, $p=.128$; SFD: $F_1(1,39)=6.71$, $MSE=139.44$, $p<.05$; $F_2(1,29)=3.05$, $MSE=333.69$, $p=.091$] but was non-significant in GD and TT measures [GD: $F_1(1,39)=1.41$, $MSE=327.58$, $p>.20$; $F_2<1$; TT: both Fs<1]. Follow-up comparisons revealed that for VLP words, fixation durations were 16 and 15 ms longer on LF words than HF in FFD and SFD measures respectively [all $ps<.001$]. Fixation durations on VHP were longer on LF words than HF, but this difference was much smaller in magnitude – 5 ms in both FFD and SFD [FFD: $p_1=.07$; $p_2=.08$; SFD: $p_1<.05$; $p_2=.11$]. Follow up-comparisons also revealed that for LF words, VLP words were fixated for longer than VHP words – 18 ms in both FFD and SFD [all ps<.01]. For HF words, VLP words were fixated for longer than VHP words, but this difference was much smaller than for LF words – 7 ms and 8 ms in FFD and SFD respectively [FFD:

p_1=.06; p_2>.35; SFD: p_1=.05; p_2>.45]. Figure 3.2 demonstrates the interactive pattern of frequency and predictability effects on SFD data (including standard error bars).

The results of FFD and SFD analyses suggest that word frequency and contextual predictability exert an interactive pattern of effects on fixation durations. The nature of the interaction is such that a VHP context provides a greater processing benefit to LF than HF target words.

With respect to the PrF analyses, the qualitative pattern of effects of observed in the present experiment was highly similar to that observed in *Experiment 1*: the benefit of a VHP context was greater to HF than LF words (.05 vs. .03 less likely to be fixated);

Figure 3.2. Average single fixation duration (SFD) on target words (with standard error bars) as a function of word frequency and contextual predictability.



Note. Fixation durations in milliseconds (ms). HF = high frequency; LF = low frequency; VHP = high predictable; VLP = low predictable.

however, this pattern of effects did not differ significantly from additivity [both *F*s<1].

It has been argued earlier in this chapter that VHP contexts allow for sufficient extraction of parafoveal preview information that an interactive pattern of frequency and predictability effects are observed in global analyses. Participants are able to extract so much information parafoveally in the case of VHP contexts that the interactive pattern of effects is not confined to Near launch sites. It may be the case that an interactive pattern of effects, wherein the processing of LF words is more facilitated by a supportive context than the processing of HF words, may be observed at Middle or possibly even Far launch distances when examining VLP and VHP contexts. In order to test this, the data from the original global VHP vs. VLP analyses (which yielded an overall interactive pattern) was conditionalised on launch distance from the target on prior fixation. It is hypothesized that a non-significant three-way interaction between the effects of word frequency, contextual predictability and parafoveal preview benefit, as indexed by launch distance, will be observed. Unlike VLP vs. MP materials, it is argued that an interactive pattern of frequency and predictability effects will be observed outwith the Near launch site group, thus removing the statistical significance of the three-way interaction.

Preview × Frequency × Predictability

The SFD data used in the analyses above were conditionalised *post-hoc* in terms of launch distance as a metric of parafoveal preview. These data correspond to the earliest measures of processing, and are therefore of greatest interest for further analysis. Launch distance was measured as the distance from the beginning of the target (i.e., the space before the target) to the location of the immediately preceding pre-target fixation.

There were three levels of this Preview factor: Near (1-3 characters), Middle (4-6 characters), and Far (7-9 characters).

The number of data points per experimental condition per launch site is included in Table 3.5. Fixations initiated from launch sites of 10 or more characters accounted for 19.9% of the total data (11.9% from 10-12 characters, 8.0% from 13+ characters). Additionally, these fixations were spread out over a 13-character window (10-22 characters). Conditionalised fixation time data accounted for 72.8% of the initial fixation time data. As in the overall analysis, SFD comprised the majority of the first-pass conditionalised data (62%). The mean data for SFD measures across Frequency, Predictability, and Preview conditions are displayed in Table 3.6 and Figure 3.3. Due to SFD data representing the majority of viable trials, and for reasons of brevity, only the results of the 3 (Launch site: Near, Middle, Far) × 2 (Frequency: HF, LF) × 2 (Predictability: VHP, VLP) ANOVA on SFD data are presented below.

Table 3.5. Number of Data Points for Conditionalised Analyses

		Launch Distance (characters)						
		1-3	4-6	7-9	10+	Skip	Reject	Total
FFD								
	HF-VHP	116	198	238	208	361	79	1200
	HF-VLP	155	225	210	222	295	93	1200
	LF-VHP	133	247	228	207	294	91	1200
	LF-VLP	156	236	226	248	242	92	1200
SFD								
	HF-VHP	72	123	148	129			
	HF-VLP	96	140	130	138			
	LF-VHP	82	153	141	128			
	LF-VLP	97	146	140	154			

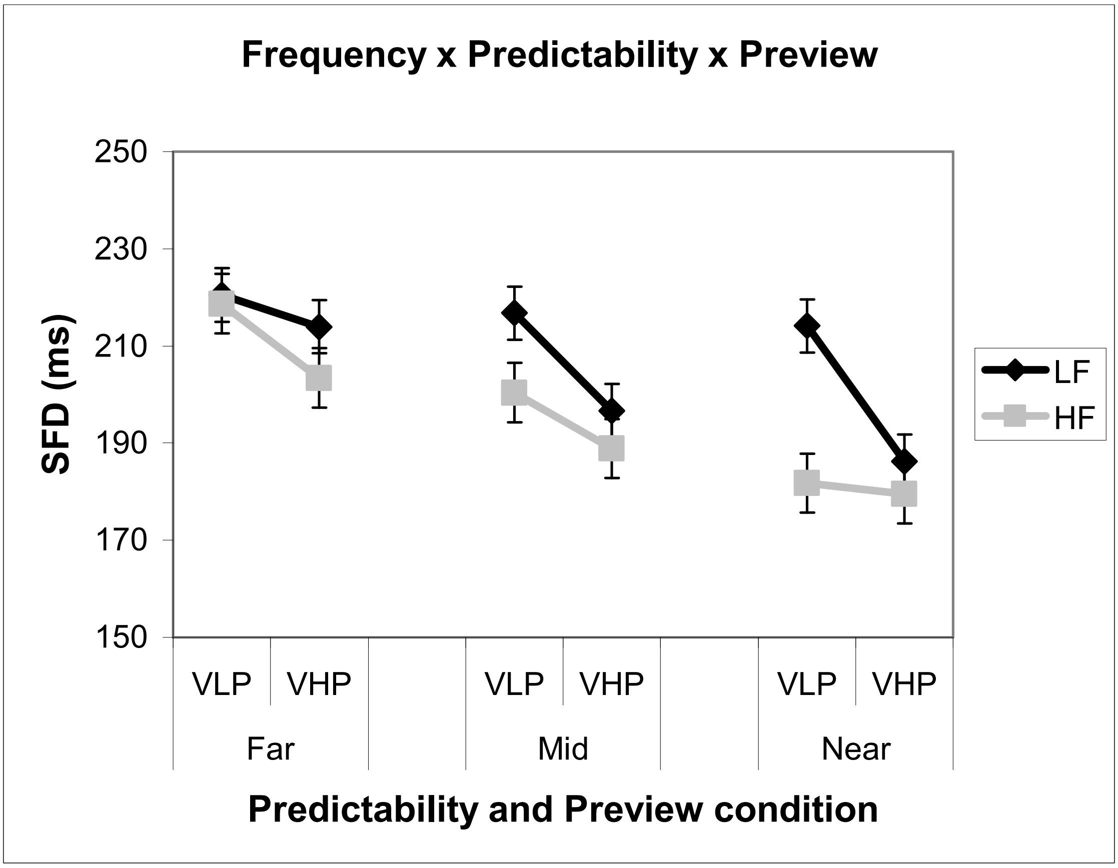
Note. Total number of data points across the experiment is 4800, resulting from 40 participants with 30 items in each of 4 conditions. FFD = first fixation duration; SFD = single fixation duration; HF / LF = high / low frequency; VHP / VLP = very high predictable / low predictable.

Table 3.6 Mean Single Fixation Durations across frequency, predictability and preview conditions: *Experiment 2a*.

		Launch Distance (characters)		
		1-3	4-6	7-9
SFD				
	HF-VHP	179	189	203
	HF-VLP	182	200	219
	LF-VHP	186	197	214
	LF-VLP	214	217	221

Note. Fixation durations in milliseconds (ms). HF = high frequency; LF = low frequency; MP = medium predictable; VLP = low predictable.

Figure 3.3. Three-way interaction between frequency, predictability, and preview benefit on SFD data: *Experiment 2a*



Note. Fixation durations in milliseconds (ms). HF = high frequency; LF = low frequency; VHP = medium predictable; VLP = low predictable. Near / Mid / Far = 1-3 / 4-6 / 7-9 characters form beginning of target word on prior fixation respectively

Analyses on the conditionalised data revealed significant main effects of frequency , predictability and preview on SFDs. Mean target SFDs for Near, Middle and Far launch distances were 190, 201, and 214 ms, respectively [$F_1(2,39)=13.00$, $MSE=1744$, $p<.001$; $F_2(2,29)=17.92$, $MSE=1014$, $p<.001$]. Planned follow-up comparisons revealed that the 11 ms difference between Near and Middle launch distances was significant (both *p*s<.05); the 24 ms difference between Near and Far launch distances was significant (both ps<.001); and the 13 ms difference between Middle and Far launch distances was also significant (both ps<.01). Analyses on the conditionalised data set revealed that LF words were fixated for longer durations than HF words (208 ms vs. 195 ms; $F_1(1,39)=29.71$, $MSE=662$, $p<.001$; $F_2(1,29)=8.88$, $MSE=1596$, $p<.01$). Analyses also revealed that VLP words were fixated for longer durations than VHP words (209 ms vs. 197 ms; $F_1(1,39)=23.03$, $MSE=1010$, $p<.001$; $F_2(1,29)=19.28$, $MSE=1085$, $p<.001$).

As in the global analyses of VLP vs. VHP data, the conditionalised analyses revealed a significant interaction between frequency and predictability [$F_1(1,39)=5.01$, $MSE=601$, $p<.05$; $F_2(1,29)=4.96$, $MSE=588$, $p<.05$]. The remaining two-way interactions (frequency × launch distance, predictability × launch distance) were non-significant (all *F*s<1). As suggested above, conditionalised analyses on VLP vs. VHP data yielded a non-significant three-way interaction between the effects of word frequency, contextual predictability, and parafoveal preview benefit, as indexed by launch distance to the target [see Figure 3.3; both *F*s<1]. It was suggested that no three-way interaction would be observed due to significant two-way interactions between the effects of word frequency and contextual predictability at Near and Middle launch distances. In order to explore this contention, separate, exploratory 2 (frequency: HF, LF) × 2 (predictability: VLP, VHP) ANOVAs were carried out by both participants and items for data at each preview condition. The results of these analyses are presented in Table 3.7

Table 3.7. Exploratory frequency × predictability analyses at each launch distance – *Experiment 2a*

		Launch Distance (characters)		
		1-3	4-6	7-9
SFD				
Freq		19 ms	12 ms	6 ms
	F_1	<.001	<.001	=.10
	F_2	<.05	<.01	<.05
Pred		15 ms	16 ms	11 ms
	F_1	<.01	<.01	<.05
	F_2	<.05	<.01	<.05
Freq × Pred				
	F_1	<.01	<.05	*NS*
	F_2	<.01	=.08	*NS*
HF-VLP vs. HF-VHP		2 ms	11 ms	*NA*
	p_1	>.70	<.05	
	p_2	>.70	<.05	
LF-VLP vs. LF-VHP		28 ms	20 ms	*NA*
	p_1	<.001	<.001	
	p_2	<.001	<.001	

Note. Fixation durations in milliseconds (ms). HF = high frequency; LF = low frequency; VHP = very high predictable; VLP = low predictable. Freq = frequency effect – positive integers reflect longer fixation durations on LF words than HF words; Pred = predictability effect – positive integers reflect longer fixation durations on VLP words than VHP words; HF-VLP vs. HF-VHP = simple main effect of predictability for HF words – positive integers reflect longer fixation durations on VLP words than VHP words; LF-VLP vs. LF-VHP = simple main effect of predictability for LF words – positive integers reflect longer fixation durations on VLP words than VHP words. NS = $F<1$.

Significant effects of frequency and predictability were observed at all launch distances. The interaction between frequency and predictability was found to be significant at Near and Middle launch distances. It is argued that the materials termed HP in *Experiment 1* were in fact *medium predictability* (MP) items. The global additive effect observed in *Experiment 1* was found to be composed of both interactive and additive patterns of effects, dependant on the amount of information the reader could extract parafoveally. In *Experiment 1*, interactive effects were confined to Near launch distances *only*. The ability to extract information from a parafoveal word is influenced by its contextual predictability (Balota et al., 1985). The results of *Experiment 2a* suggest that when the contextual predictability of HF and LF words is sufficiently high, a global interactive pattern of effects will be observed on fixation durations, due to the occurrence of interactive effects which are not confined to Near launch distances.

In order to explore this contention, a further experiment was conducted. *Experiment 2b* involved the presentation of 60 specifically-designed MP items, half containing LF target words, and half containing HF target words. It was hypothesised that analyses involving VLP and MP items would demonstrate an additive pattern of frequency and predictability effects, replicating the global analyses of *Experiment 1*.

Experiment 2b

Method

Participants

See *Experiment 2a*.

Apparatus

See Experiment 2a.

Design and Materials

A 2 (Frequency: HF, LF) × 2 (Context: MP, VLP) design was used. With a total of 120 experimental items, there were 30 items in each of the 4 conditions. All experimental items are listed in **Appendix III**. An example set of MP materials is presented in Table 3.8. Target words were always positioned near the middle of the second line of a passage. Experimental items were presented in a different random order to each participant. Mean stimulus specifications across conditions are presented in Table 3.9, specifications for individual target words are presented in **Appendix IV**.

Table 3.8. Example medium-predictability items

<u>HF-MP</u>

Edgar was worried about getting burgled when he went out at night. [lb]
He usually left a **light** on to make it look as if someone was home.

<u>LF-MP</u>

When preparing a turkey, you do not have to throw away the giblets. [lb]
These can be used to make **gravy** to be served with the roasted bird.

Note. HF = high frequency; LF = low frequency; MP = medium-predictability target. Target words are in **bold**. [lb] denotes how materials were split across the two lines of display.

Table 3.9. Specifications of Target Stimuli: *Experiment 2b*

Condition	Length	Frequency	Predictability	Cloze
HF-MP	5.87 (1)	172 (160)	1.84 (0.67)	0.56 (0.16)
HF-VLP	5.87 (1)	172 (131)	0.52 (0.70)	0.01 (0.02)
LF-MP	5.87 (1)	7 (4)	1.57 (0.66)	0.54 (0.16)
LF-VLP	5.87 (1)	7 (4)	0.35 (0.68)	0.01 (0.02)

Note. Mean values are shown with standard deviations in parentheses. Units of measurement are as follows: Length in number of letters; Frequency in occurrences per million; Predictability rating range is -3 (highly unpredictable) to 3 (highly predictable). HF = high frequency, LF = low frequency, MP / VLP = medium / very low predictable.

<u>Frequency</u>. Half of targets were HF and half were LF words. Word frequencies were obtained using the 90-million written word BNC (http://www.natcorp.ox.ac.uk). Mean frequencies were 172 occurrences per million for HF targets (range 36-727 per million) and 7 occurrences per million for LF targets (range <1-16 per million; see Table 3.9). The frequency of target words in the current experiment are comparable to those used in *Experiment 1* (166 and 5 occurrences per million for HF and LF conditions, respectively).

<u>Predictability</u>. Half of targets were presented in a VLP context and half in an MP context. Contextual predictability was determined by two norming tasks – a Cloze

probability task and a predictability rating task. In the Cloze task, 20 participants (none of whom participated in the main experiment or the predictability rating task) were given experimental items up to but not including the target word. Their task was to generate the next word in the sentence. Items were scored as "1" for correct responses and "0" for all other responses. The manipulation of predictability in the *Experiment 2b* was found to be comparable to *Experiment 1*. The mean Cloze predictability of MP targets was .54 (.57 in *Experiment 1*), and the mean Cloze predictability of targets in VLP conditions was .01 (.03 in *Experiment 1*). A 2 (Frequency: HF, LF) × 2 (Context: MP, VLP) ANOVA on Cloze probabilities by items (F_2) revealed a main effect of Context, with more targets generated in MP (.54) than in VLP (.01) contexts (see Table 3.9) [$F_2(1,29)=502.60$, $MSE=.017$, $p<.001$]. No other main effects or interactions were significant [all F_2s<1]. In the predictability rating task, 20 participants (again, none of whom participated in the main experiment or Cloze task) were presented with each item in its entirety with the target word underlined. Ten percent of the materials were non-experimental filler items (two-line texts) that were clearly anomalous. The participants' task was to indicate how predictable they considered the target word to be on a 7-point scale from -3 (highly unpredictable) to 3 (highly predictable). A 2 (Frequency: HF, LF) × 2 (Context: VHP, VLP) ANOVA on predictability ratings by items (F_2) revealed, as expected, a main effect of Context, with targets rated more predictable in MP (1.71) than in VLP (0.43) contexts (see Table 3.9) [$F_2(1,29)=134.82$, $MSE=.354$, $p<.001$]. No other main effects or interactions were significant [all F_2s<1].

Procedure

See *Experiment 2a.*

Results

The eye movement data collected was subject to the same inclusion / exclusion criteria as that in the main analyses. 8.9% of MP data points were excluded. The number of data points included and excluded across conditions and measures are presented in Table 3.10. Mean fixation durations across measures and conditions are presented in Table 3.11. As targets receiving single fixations represented the majority of the viable trials, and for reasons of brevity, only data from SFD analyses are presented below.

Table 3.10. Number of Data Points for Analyses: *Experiment 2b*

			Skip	Reject	Total
FFD					
	HF-MP	761	328	111	1200
	HF-VLP	812	295	93	1200
	LF-MP	810	288	102	1200
	LF-VLP	866	242	92	1200
SFD					
	HF-MP	464			
	HF-VLP	504			
	LF-MP	494			
	LF-VLP	537			

Note. Total number of data points across the experiment is 4800, resulting from 40 participants with 30 items in each of 4 conditions. FFD = first fixation duration; SFD = single fixation duration; HF / LF = high / low frequency; MP / VLP = medium / low predictable.

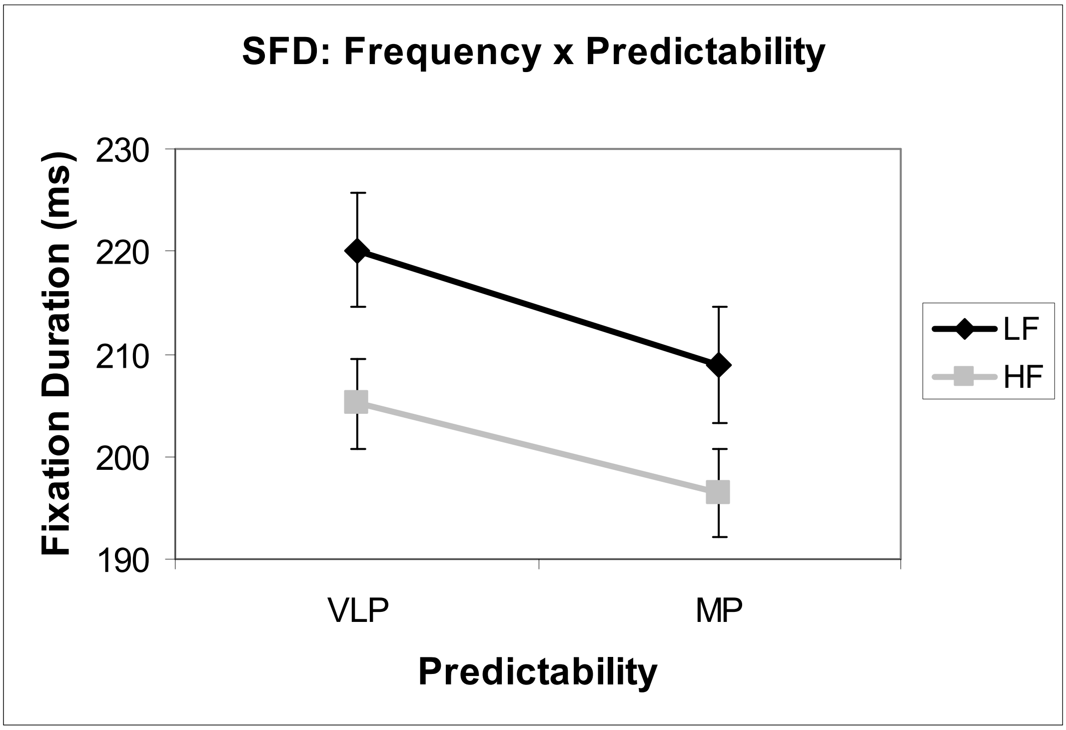
Table 3.11. Mean Single Fixation Durations across conditions

HF			LF		
VHP	MP	VLP	VHP	MP	VLP
197	199	205	202	210	220

Note. HF / LF = high / low frequency; VHP / MP / VLP = very high / medium / very low predictable

SFD condition means are presented in Figure 3.4. Analyses revealed a significant main effect of word frequency on SFDs – LF words were fixated for longer durations than HF words (215 vs. 202 ms respectively). This effect was shown to be significant by both participants and items [$F_1(1,39)=47.44$, $MSE=157.86$, $p<.001$; $F_2(1,29)=20.51$, $MSE=292.88$, $p<.001$]. A significant main effect of contextual predictability was also observed – VLP words were fixated for longer durations than MP words (213 vs. 202 ms respectively). This effect was also shown to be significant by both participants and items [$F_1(1,39)=22.50$, $MSE=174.01$, $p<.001$; $F_2(1,29)=11.29$, $MSE=230.73$, $p<.01$].

Figure 3.4. Average single fixation duration (SFD) with standard error bars) as a function of frequency and predictability: *Experiment 2b*.



Note. Fixation durations in milliseconds (ms). HF / LF = high / low frequency; MP / VLP = medium / very low predictable.

Analyses of the interaction between frequency and predictability effects on SFD data was shown to be non-significant by both participants and items [both *F*s<1]. This pattern of effects supports the hypothesis that word frequency and contextual predictability will exert additive effects on fixation durations when the manipulation of contextual predictability compares MP to VLP passages. It is argued that when presented with an MP context, participants are unable to extract enough in formation parafoveally from target words, and an additive pattern of effects on fixation duration measures is observed.

It may be the case that a three-way interaction between parafoveal preview benefit (as indexed by launch distance to the beginning of the target word from prior fixation), frequency and predictability may be observed in the MP vs. VLP data set. It is hypothesized that an interactive pattern of frequency and predictability will be observed only in cases where participants' prior fixation had been close to the beginning of the target word on prior fixation (i.e., the highest parafoveal preview condition).

<u>Preview × Frequency × Predictability – *Experiment 2b*</u>

SFD data used in the analyses above were conditionalised *post-hoc* in terms of launch distance as a metric of parafoveal preview. This process was identical to that used in *Experiment 2a*. The number of data points per experimental condition per launch site is included in Table 3.12. Fixations initiated from launch sites of 10 or more characters accounted for 18.4% of the total data (10.9% from 10-12 characters, 7.5% from 13+ characters). Additionally, these fixations were spread out over a 13 character window (10-22 characters). Conditionalised fixation time data accounted for 81.6% of the initial fixation time data. As in the overall analysis, SFD comprised the majority of the first-pass conditionalised data (62%). The mean SFDs across Frequency, Predictability, and

Preview conditions are displayed in Table 3.13 and Figure 3.5. Due to SFD data representing the majority of viable trials, and for reasons of brevity, only the results of the 3 (Launch site: Near, Middle, Far) × 2 (Frequency: HF, LF) × 2 (Predictability: MP, VLP) ANOVAs on SFD data are presented below.

Table 3.12. Number of Data Points for Conditionalised Analyses: *Experiment 2b*

		Launch Distance (characters)						
		1-3	4-6	7-9	10+	Skip	Reject	Total
FFD								
	HF-MP	131	212	190	228	328	111	1200
	HF-VLP	155	225	210	222	295	93	1200
	LF-MP	134	236	227	213	288	102	1200
	LF-VLP	156	236	226	248	242	92	1200
SFD								
	HF-MP	80	129	116	139			
	HF-VLP	96	140	130	138			
	LF-MP	82	144	138	130			
	LF-VLP	97	146	140	154			

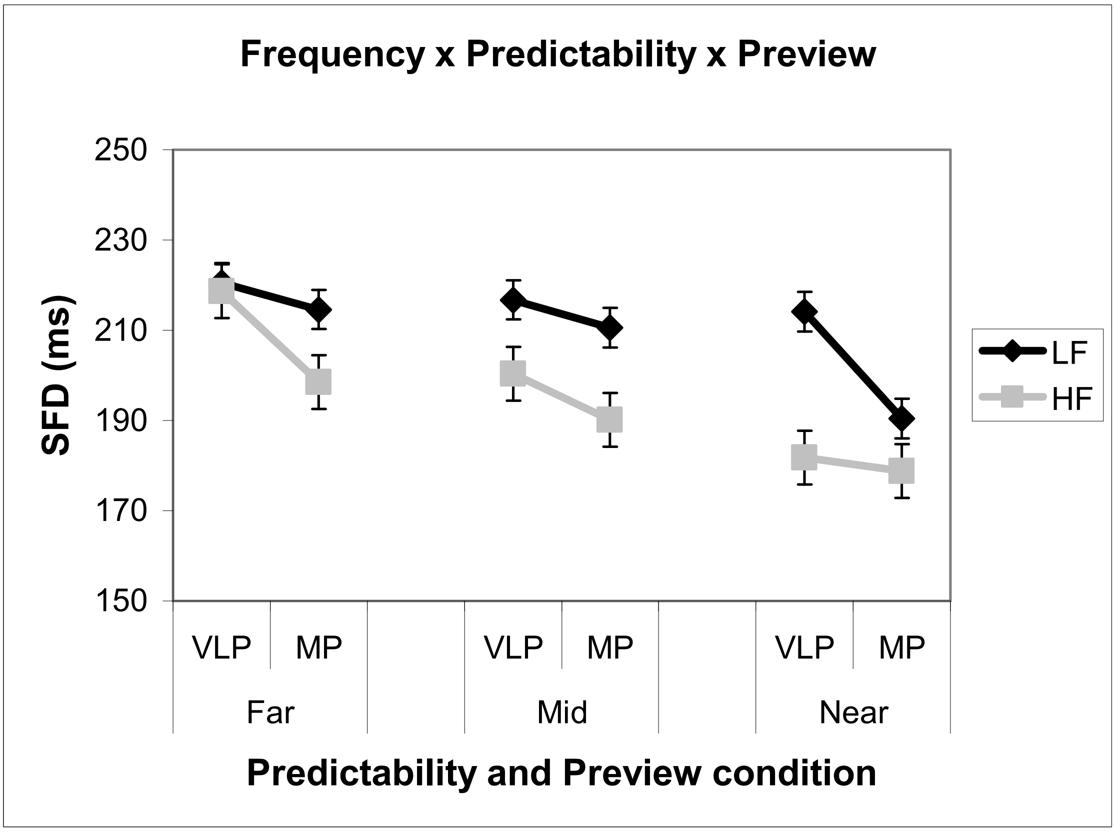
Note. Total number of data points across the experiment is 4800, resulting from 40 participants with 30 items in each of 4 conditions. FFD = first fixation duration; SFD = single fixation duration; HF / LF = high / low frequency; MP / VLP = medium / low predictable.

Table 3.13. Mean Single Fixation Durations (SFD) across frequency, predictability and preview conditions

		Launch Distance (characters)		
		1-3	4-6	7-9
SFD				
	HF-MP	179	190	199
	HF-VLP	182	200	219
	LF-MP	190	211	215
	LF-VLP	214	217	221

Note. Fixation durations in milliseconds (ms). HF / LF= high / low frequency; MP / VLP = medium / very low predictable

Figure 3.5. Three-way interaction between frequency, predictability, and preview benefit on SFD data: *Experiment 2b*.



Note. Fixation durations in milliseconds (ms). HF = high frequency; LF = low frequency; MP = medium predictable; VLP = low predictable. Near / Mid / Far = 1-3 / 4-6 / 7-9 characters form beginning of target word on prior fixation respectively

Analyses on the conditionalised data revealed significant main effects of frequency , predictability and preview on SFDs. Mean target SFDs for Near, Mid and Far launch distances were 191, 204, and 213 ms, respectively [$F_1(2,39)=18.70$, $MSE=2038$, $p<.001$; $F_2(2,29)=18.036$, $MSE=2237$, $p<.001$]. Planned follow-up comparisons revealed that the 13 ms difference between Near and Mid launch distances was significant (both ps<.001); the 22 ms difference between Near and Far launch distances was significant (both ps<.001); and the 9 ms difference between Mid and Far launch distances was also significant (both ps<.05). Analyses on the conditionalised data set revealed that LF words were fixated for longer durations than HF words (211 ms vs. 195 ms; $F_1(1,39)=32.53$, $MSE=995$, $p<.001$; $F_2(1,29)=6.37$, $MSE=1207$, $p<.05$). Analyses also revealed that VLP words were fixated for longer durations than MP words (209 ms vs. 197 ms; $F_1(1,39)=14.46$, $MSE=1099$, $p<.001$; $F_2(1,29)=17.10$, $MSE=1404$, $p<.001$).

As in the global analyses of VLP vs. MP data, the conditionalised analyses revealed a non-significant interaction between frequency and predictability [both Fs<1]. The remaining two-way interactions (frequency × launch distance, predictability × launch distance) were also non-significant (all Fs<1). However, as in the global analyses in *Experiment 1*, conditionalised analyses on VLP vs. MP data yielded a significant three-way interaction between the effects of word frequency, contextual predictability, and parafoveal preview benefit, as indexed by launch distance to the target [see Figure 3.4; $F_1(2,78)=3.07$, $MSE=666$, $p=.08$; $F_2(2,58)=3.01$, $MSE=678$, $p=.10$]. In order to explore this three-way interaction in a clear fashion, separate 2 (frequency: HF, LF) × 2 (predictability: VLP, MP) ANOVAs were carried out by both participants and items.

<u>Near (1-3 character) analyses</u>

Analyses of Near launch site data revealed that LF words were fixated for significantly longer durations than HF words (202 ms vs. 181 ms; $F_1(1,39)=22.53$, $MSE=858$, $p<.001$; $F_2(1,29)=16.36$, $MSE=711$, $p<.001$). Words presented in VLP contexts were fixated for longer durations than those in MP conditions (198 ms vs. 185 ms; $F_1(1,39)=6.00$, $MSE=1183$, $p<.05$; $F_2(1,29)=5.01$, $MSE=959$, $p<.05$). The interaction between word frequency and contextual predictability at Near launch distances was shown to be marginally significant [$F_1(1,39)=2.95$, $MSE=1466$, $p=.09$; $F_2<1$].

Planned follow-up comparisons revealed that for HF words, the 2.93 ms effect of predictability was non-significant ($p_1>.70$, $p_2>.45$), whereas for LF words, the 23.7 ms effect of predictability was found to be highly significant ($p_1<.01$, $p2<.05$)

Middle (4-6 character) analyses

Analyses of Mid launch site data revealed that LF words were fixated for significantly longer durations than HF words (214 ms vs. 195 ms; $F_1(1,39)=24.65$, $MSE=548$, $p<.001$; $F_2(1,29)=5.27$, $MSE=1292$, $p<.05$). Words presented in VLP contexts were fixated for longer durations than those in MP conditions (209 ms vs. 196 ms; $F_1(1,39)=3.13$, $MSE=857$, $p=.08$; $F_2<1$). The interaction between word frequency and contextual predictability at Near launch distances was shown to be non-significant [both Fs<1].

Far (7-9 character) analyses

Analyses of Far launch site data revealed that LF words were fixated for significantly longer durations than HF words (218 ms vs. 209 ms; $F_1(1,39)=2.39$, $MSE=1328$, $p=.13$; $F_2(1,29)=4.79$, $MSE=1280$, $p<.05$). Words presented in VLP contexts were fixated for longer durations than those in MP conditions (220 ms vs. 207 ms; $F_1(1,39)=6.56$, $MSE=1031$, $p<.05$; $F_2(1,29)=4.71$, $MSE=722$, $p<.05$). The interaction between word frequency and contextual predictability at Near launch distances was shown to be non-significant [both Fs<1].

The results of the conditionalised analyses of VLP vs. MP data replicates the results of *Experiment 1*. The overall additive pattern of frequency and predictability effects disguised the fact that when parafoveal preview benefit is highest (i.e., Near launch distances), word frequency and contextual predictability exert an interactive effect on fixation durations. Additive patterns of frequency and predictability effects were observed in conditions here preview information was diminished (i.e., Middle and Far launch distances). These results suggest that not only is the relationship between word frequency and predictability effects modulated by parafoveal preview benefit, but strongly implies that when readers are able to extract high amounts of information about a parafoveal target word, eventual fixation time on that word will be modulated by an interactive effect of word frequency and contextual predictability.

It appears that for VLP vs. MP contexts, an interactive pattern of frequency and predictability effects can only be observed when participants fixate close to the beginning of target words on prior fixation

Discussion

Experiment 2a was conducted in order to address concerns about the manipulation of contextual predictability in *Experiment 1*. In *Experiment 2a*, the mean Cloze value of VHP words was .96 compared to .57 for HP words in *Experiment 1*. Furthermore, the range of individual VHP items' Cloze values in *Experiment 2a* was .85-1.00 as opposed to .00-1.00 in *Experiment 1*. Cloze values for VLP words in *Experiment 2a* had a mean value of .01 as opposed to .03 in *Experiment 1*, and the range of individual VLP Cloze values in *Experiment 2a* were .00-.05, compared to .00-.30 in *Experiment 1*. It is argued that this stronger, and better controlled, manipulation of contextual predictability allows for more information to be extracted from the target word parafoveally. Thus, the global analyses of *Experiment 2a* may replicate the interactive pattern of frequency and predictability effects observed in the Near launch site analyses of *Experiment 1*. Significant main effects of word frequency and contextual predictability were observed in *Experiment 2a*. Global analyses of measures taken to reflect early, lexical processing of a word (FFD and SFD), did indeed reveal an interactive pattern of frequency and predictability effects, however statistical support for this interaction was stronger in participants analyses than in items analyses (see above).

Experiments 2a and 2b were designed to investigate the simultaneous effects of word frequency and contextual predictability on eye movements during reading. Although this had also been the focus of *Experiment 1*, these experiments were designed to address some concerns about *Experiment 1* – principally, that the materials used in *Experiment 1* did not provide a strong enough, or well-controlled enough manipulation of contextual predictability. To overcome these perceived limitations, a new set of materials were constructed. In contrast to the materials used in *Experiment 1*, the materials used in *Experiments 2a* and *2b* were designed such that each target word was presented in a unique short context, in contrast to the passages used in *Experiment 1*, which contained one member of a predictable-unpredictable target word pair. Furthermore, it is argued that what were termed HP materials in *Experiment 1* were in fact MP – the mean Cloze predictability values of HP targets in *Experiment 1* was only .57. This in contrast to previous research which typically report HP materials as having mean Cloze values of above .70. Another concern was that the range of values for both HP and LP materials in *Experiment 1* was too widespread: HP materials ranged from .00 to 1.00 in Cloze values, and LP materials ranged from .00 to .30. The VHP materials used in *Experiment 2a* had a mean Cloze value of .96, with a very tight range of .85-1.00. VLP materials in *Experiment 2a* had a mean Cloze value of .02, with a range from .00-.05.

In *Experiment 1*, and interactive pattern of effects was observed between word frequency and contextual predictability, wherein LF words experience a greater processing advantage in a supportive context than do HF words, but only when parafoveal preview benefit was high (i.e., participants' eyes had been located close to the beginning of the target word on prior fixation). Prior research has demonstrated that the ability to extract information parafoveally is not only governed by visual acuity, but can be influenced by the frequency and predictability of a parafoveal word (Balota et al., 1985, Inhoff & Rayner, 1986). It was hoped that by super-charging the predictability of target words in *Experiment 2a*, that the interactive pattern of frequency and predictability observed in high preview conditions in *Experiment 1* may be replicated in global analyses in *Experiment 2a*. Global analyses did indeed reveal an interactive pattern of frequency and predictability effects on measures of eye movement behaviour taken to reflect "early", lexical measures of processing (FFD, SFD). The nature of this interaction was such that the processing of LF target words was greater facilitated by a VHP context than was the processing of an HF target.

In *Experiment 2a*, VHP and VLP contexts containing high or low frequency target words yielded interactive effects of frequency and predictability on eye movement behaviour. Extraction of parafoveal information is influenced by the parafoveal word's frequency and predictability. As it such, it was argued that the interactive effects observed in Near launch distance conditions in *Experiment 1*, will be observed at both the Near and Middle launch distances when comparing VHP and VLP materials, due to the ability to extract information not just from proximity to the target word, but due to its linguistic characteristics. Conditionalised analyses of the VHP and VLP materials based on parafoveal preview as indexed by launch distance from the beginning of the target word did indeed exhibit interactive patterns of effects in both Near and Middle launch distance conditions.

In order to test our contention that HP target words in *Experiment 1* had in fact been MP, a further set of experimental passages were designed and tested in *Experiment 2b* These passages were termed MP, and had highly similar Cloze values to the HP contexts of *Experiment 1* (.54 vs. .57). Analyses comparing *Experiment 2b*'s MP items with VLP items revealed additive effects of word frequency and contextual predictability on eye movement behaviour, consistent with the results of *Experiment 1*. It was suggested that when presented with MP and VLP items, in order for frequency and predictability to yield interactive effects on processing, they must be supplemented by a high degree of parafoveal preview benefit. MP and VLP data from *Experiment 2b* were conditionalised by launch distance from the beginning of the target word. As in *Experiment 1* (which has been demonstrated to have utilised *MP* and LP items), an interactive pattern of word frequency and contextual predictability effects was observed, but only when parafoveal preview benefit was highest (Near launch site).

This implies that interactive effects of word frequency and predictability can be observed under two distinct sets of conditions: 1) when there is strong manipulation of target word frequency, moderate manipulation of contextual predictability, and participants are able to extract parafoveal information by fixating near the beginning of the target word on prior fixation (*Experiment 1*; *Experiment 2b* conditionalised preview analysis); and 2) when the manipulation of both frequency and predictability is sufficiently strong (*Experiment 2*a main and conditionalised analyses). In either manner, the ability of word frequency and contextual predictability to yield interactive effects on eye movement behaviour appears to be dependent upon extraction of information from the parafovea. When contextual support is moderate, interactive effects are solely dependent upon preview, as provided by participants fixating close to the beginning of the parafoveal word. However, when contextual support is maximal, the effects of word frequency and predictability appear to be interactive in global analyses, not purely dependent on distance from the target word. However, this interactive pattern is still driven by the extraction of parafoveal preview – in this case it is the ability of the linguistic features of the passage allowing for extraction of supportive parafoveal information at further launch distances which is driving the global pattern of interactive effects.

Due to the limitations of visual acuity, and the constraints of the word identification span, it is unlikely that interactive patterns of word frequency and contextual predictability will be detected at 8 or more characters from the beginning of a target word. It is argued that interactive patterns of effects are more likely to be observed when using extremely strong manipulations of frequency and predictability in order for readers to extract maximal information from the parafovea, but even as such, these interactive effects were confined to cases where participants had fixated between 1 and 6 characters from the beginning of target words.

Chapter 4

Fixation durations prior to word skipping in normal reading

Introduction

Readers do not always move their eyes from fixated word *n* to word *n*+1; instead readers often *skip* word *n* and progress to word *n*+1 (or very occasionally, to a further word *n*+*x*). As mentioned previously, short function words (e.g., "*if*", "*of*", "*the*") are skipped approximately 65% of the time, whereas content words (e.g., nouns) are skipped approximately 15% of the time (Carpenter & Just, 1983; Rayner & Duffy, 1988).

Word frequency has a substantial effect on fixation durations during reading. The effect of word frequency on word skipping, however, is not altogether clear. This is due in part to the strong correlation between word length and word frequency: shorter words occur much more frequently than longer ones. Evidence to suggest an effect of word frequency on skipping after controlling for word length has been reported by Rayner et al. (1996), who found that HF target words were skipped more often than LF target words. However, this effect was limited to trials where the fixation prior to the target word was 3-4 characters away from the beginning of the target word. Typically, word skipping behaviour is confined to such instances, regardless of the frequency of the target word (Rayner et al., 1996; Rayner et al., 2001). Contextual predictability is also known to influence fixation durations during reading. The effect of contextual predictability on word skipping is much clearer – HP words are skipped more often than LP words (Balota et al., 1985; Ehrlich & Rayner, 1981; Rayner et al., 2004; Rayner & Well, 1996).

Drieghe, Rayner, and Pollatsek (2005) provided a compelling demonstration of how visual and linguistic factors influence word skipping. It was shown in their first experiment that highly predictable words were more likely to be skipped than contextually neutral words, or words which were visually identical to the predictable target, save for one letter being replaced by an orthographically similar letter to create a pronounceable nonword. Drieghe et al. (2005) reported no difference between the skipping rates of contextually neutral words and visually similar nonwords, therefore the effect of predictability on skipping rates only emerged if the word perfectly matched the predictable word. Drieghe et al.'s (2005) second experiment revealed were skipped on a substantial amount of trials – too often to be attributed to factors such as saccadic targeting error. If it were the case that skipping a word was entirely dependent on successfully identifying words parafoveally, nonwords should only very rarely be "skipped". Drieghe et al. (2005) argue that it must be the case that factors at a lower level than lexical processing must play an important role in the decision to skip a word.

Research into eye movements during reading has allowed computational models of eye movement control during reading to be established. These models can be separated into three broad categories (Engbert et al., 2002): *sequential attention shift* (SAS) models, *guidance by attentional gradient* (GAG) models, and *primary oculomotor control* (POC) models (see Reichle et al., 2003 for a comparison of these models). As mentioned previously, research into eye movements during reading has revealed the importance of low-level word length information and higher-level frequency and predictability information, and the predictions of these models in this respect are well established (see Brysbaert & Vitu, 1998, for a meta-analysis). Although all three types of model (SAS, GAG, and POC) predict that short, HF, and HP words will be more likely to be skipped than longer, LF and LP words, one fundamental difference between these types of models is their predictions with regard to fixation durations before the skipping of a word.

Principally, two different processes predict increased fixation durations before skipped words: saccade cancellation and parafoveal pre-processing (Kliegl & Engbert, 2005). SAS models, such as *E-Z Reader* model of eye movement control in reading (Reichle et al., 2003), include word *n*+1 as the default target of a saccade from word *n*. Thus, word skipping typically requires the cancellation of a saccade, and the initiation of a new saccade program to word *n*+2 (see Engbert & Kliegl 2001; Reichle et al., 2003). Models such as E-Z Reader predict that word skipping incurs a cost in terms of fixation duration on word *n*, and such values have been obtained in simulations (Reichle et al., 2003). Furthermore, the parameters of the E-Z Reader model predict that the costs associated with the cancellation of a saccade should diminish as the frequency of word *n*+1 (the to-be-skipped word) increases, as cancellation (i.e., skipping) usually occurs for higher-frequency words. Thus, SAS models such as E-Z Reader stipulate that longer fixations prior to skipping are the result of saccadic reprogramming, and that the costs of this reprogramming should be inversely related to the frequency of the skipped word (Kliegl & Engbert, 2005).

One of the key tenets of SAS models is that words are processed in a strictly serial manner –semantic activations occur in a one-by-one, sequential manner. Contrastingly, GAG models allow for parallel processing of words. GAG models such as the *Saccade-generation With Inhibition by Foveal Targets* model (SWIFT; Engbert et al., 2005), suggest that longer fixation durations prior to skips imply a longer accumulation of information from the parafoveal word *n*+1. Such models argue that parafoveal pre-processing increases the probability of complete lexical access, and, thus, the skipping of word *n*+1 (Engbert et al., 2002; Reilly & Radach, 2003). As such, an alternative reason for skipping may be longer parafoveal processing during the previous fixation – in this manner, GAG models view longer fixations as a *cause* of skipping, rather than a *consequence*.

POC models typically assume that saccade generation is derived from a distribution of saccade amplitudes, adjusted in order to account for the difficulty of the text or section of text being processed (McConkie, Kerr, & Dyre, 1994). Such theories are primarily concerned with the effects of skipping on saccade amplitudes and do not predict a strong modulation of fixation durations before skipping. Such models generally assume that that the target of the next saccade is determined very in early during the reader's current fixation (Radach & Heller, 2000).

Experimental studies into the relationship between fixation durations and word skipping has yielded inconsistent results, with results ranging from word *n* fixations prior to skipping word *n*+1 being 84 ms longer to 26 ms shorter than fixations prior to fixating word *n*+1 (Kliegl & Engbert, 2005). Obtaining a conclusive answer to the question of the effects of words skipping on fixation durations during reading has important consequences for models of eye movement control during reading and for theories of language processing.

The ability to extract information from parafoveal word *n*+1 while fixating foveal word *n* has been shown to be influenced by both the frequency and predictability of word *n*+1. Relative parafoveal preview benefit is greater for HF words than LF words, and the extraction of parafoveal information is more efficient when aided by sentential context (Balota et al., 1985; Inhoff & Rayner, 1986). Hence, it is possible that the effects of skipping word *n*+1 on word *n* fixation duration may differ depending on the frequency and predictability of word *n*+1. Indeed, Rayner et al. (2004) examined fixation durations prior to skips in an experiment which orthogonally manipulated word frequency and contextual predictability. This particular study is not discussed in detail, as their results only reported a 2 (skip vs. no skip) × 2 (before target word vs. after target word) ANOVA, and did not report any potential effects of frequency or predictability on fixations prior to skips, nor any interactions between these factors.

Experiment 3 examines fixation durations on word *n* to determine whether there is inflation of fixation durations prior to skipping word *n*+1 relative to fixating word *n*+1. Any observed effects of eye movement behaviour (i.e., skip vs. fixation of word *n*+1) on the fixation duration of word *n* will be examined as a function of the word frequency and contextual predictability of word *n*+1.

Method

Experiment 3 is an additional analysis of data collected during *Experiment 1*. The same number of participants, materials and design were employed. The same apparatus and laboratory conditions were involved. For specific details, please see **Chapter 2 – Method**.

Results

The target region comprised the space before the target word and the target itself. Lower and upper cut-off values for individual fixations were 100 and 750 ms, respectively. Overall, 2.4% of the data were excluded for these reasons. A standard suite of analysis software was used to interpret the eye movement data. Experimental items were deleted when there was a track loss on either word *n* or word *n*+1, when participants blinked on either the word *n* or *n*+1 fixation, or when either the word *n* or *n*+1 fixation was the initial fixation on the line of text. Deletions accounted for 3.7% of the total experimental trials. Skipping was defined as trials where *n*+1 was skipped and only forward-going saccades were made after initial fixation of word *n*+*x*. Only trials where an SFD was made on word *n* were retained. As defined, there were 667 instances of skipping – 12% of the maximal amount of skipping data (100% = SFD on *n*, *n*+1 skipped on every trial, no regressive saccades made after fixation on word *n*+*x*). A 2 (frequency; HF,LF) × 2 (predictability; HP, LP) ANOVA was carried out by both participants (F_1) and items (F_2) on the probability of fixating (PrF) word *n*+1. Word *n* fixation durations were analysed by a 2 (skipping outcome: skip, fixation) × 2 (*n*+1 frequency: HF, LF) × 2 (*n*+1 predictability: HP, LP) ANOVA by F_1 and F_2. Mean *n*+1 PrF and word *n* fixation durations by condition are presented in Table 4.1. PrF was calculated on the basis of the whether word *n*+1 received a fixation, given that that trial was included in the analysis.

Table 4.1. Probability of fixating word *n*+1 and mean fixation durations on word *n* by *n*+1 condition

	PrF	Skip	Fixation	Sig.
HF-HP	0.83	272	252	$p<.001$
HF-LP	0.88	255	260	$F<1$
LF-HP	0.89	259	258	$F<1$
LF-LP	0.91	252	262	$p=.06$

Note. Mean values are shown in milliseconds. HF = high frequency, LF = low frequency, HP = high predictable, and LP = low predictable. sig. = significance of the effect of word skipping on fixation duration.

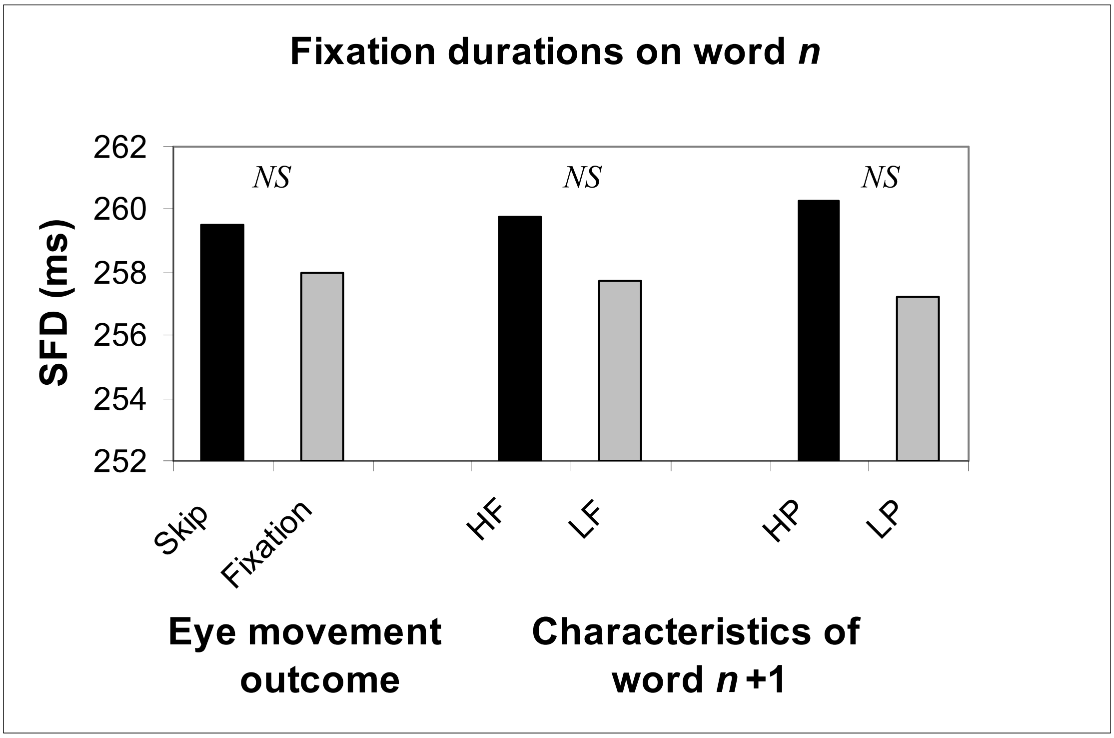
PrF.

The main effect of n+1 frequency was significant [$F_1(1,63)=29.51$, $MSE=.291$, $p<.001$; $F_2(1,43)=27.11$, $MSE=.312$, $p<.001$]. The probability of fixating HF word n+1 (.86) was less than that for LF word n+1 (.90). The main effect of n+1 predictability was also significant [$F_1(1,63)=21.83$, $MSE=.219$, $p<.001$; $F_2(1,43)=11.06$, $MSE=.432$, $p<.01$]. The n+1 frequency × predictability interaction was significant, although only by participants [$F_1(1,63)=4.13$, $MSE=.246$, $p<.05$; $F_2(1,43)=1.61$, $MSE=.644$, $p>.20$]. Follow-up contrasts for HF word n+1 showed that HF-HP word n+1 was less likely to be fixated than HF-LP word n+1 [$p_1<.001$; $p_2<.001$]. For LF word n+1, the equivalent comparison (LF-HP vs. LF-LP) was also significant, but only by participants [$p_1<.05$; $p_2>.25$]. Follow-up contrasts for HP word n+1 showed that HF-HP word n+1 was less likely to be fixated than LF-HP word n+1s[$p_1<.001$; $p_2<.001$]. For LP word n+1, however, the equivalent comparison (HF-LP vs. LF-LP word n+1) was significant by participants, but only marginally significant by items [$p_1<.01$; $p_2=.051$]. Overall, an HF-HP word n+1 was less likely to be fixated than word n+1 in other conditions.

Effects of word *n*+1 skipping, frequency and predictability on word *n* fixation duration

A non-significant effect of skipping was found on word *n* fixation durations. Analysis revealed that when word n+1 was skipped, word *n* fixation durations were 1.5ms longer compared to when word n+1 was fixated [both Fs<1; see Figure 4.1]. The frequency of word n+1 also had a non-significant effect on word *n* fixation durations. Fixation durations preceding HF words were 2.1 ms longer than fixation durations preceding LF words [$F_1<1$; $F_2(1,43)=1.196$, $MSE=572$, $p>0.25$; see Figure 4.1]. The effect of word n+1 predictability on word *n* fixation duration was also non-significant. Fixation durations preceding HP words were 2.65ms longer than fixation durations before LP words [both Fs<1; See Figure 4.1].

Figure 4.1. Word *n*+1 skipping, frequency and predictability effect on word *n* fixation duration

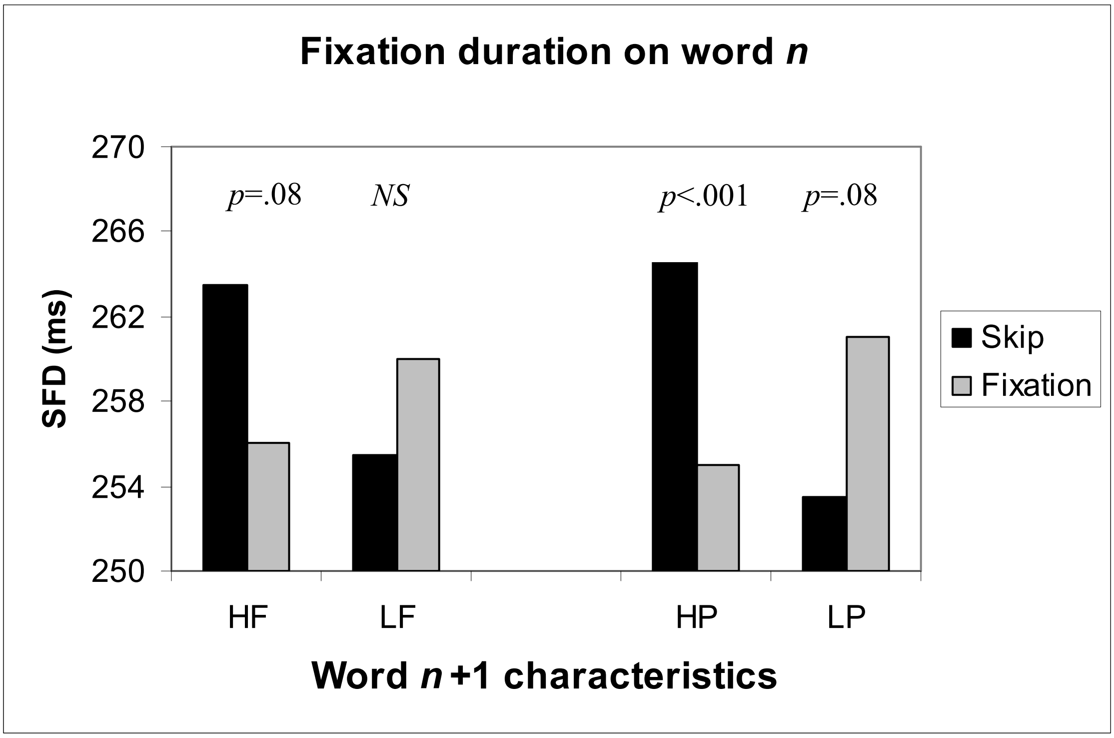


Note. HF / LF = high / low frequency; HP / LP = high / low predictable; SFD = single fixation duration. Fixation durations in milliseconds (ms). *NS* = non-significant difference (Fs<1.2, ps>.25)

Skipping outcome × word frequency

A significant interaction between skipping outcome and word *n*+1 frequency on word *n* fixation duration was observed, however, statistical support for this interaction was stronger in items analyses than by participants [$F_1(1,63)=3.39$, $MSE=1386$ $p=0.07$; $F_2(1,43)=4.22$, MSE=1411 $p<0.05$]. Follow-up comparisons revealed a significant inflation of word *n* fixation duration prior to skipping when word *n*+1 was HF but not LF, but as with the interaction between word frequency and skipping outcome, statistical support for this interaction was stronger in items analyses than by participants. When word *n*+1 was HF, word *n* fixations were 7.6ms longer when word *n*+1 was skipped compared to when word *n*+1 was fixated [$F_1(1,63)=2.99$, $p=0.08$; $F_2(1,43)=6.68$, $p<0.05$; see Figure 4.2]. There was no significant effect for fixation durations prior to LF word *n*+1s [both Fs<1; see Figure 4.2].

Figure 4.2. Fixation durations on word *n* by eye movement outcome and characteristics of word *n*+1



Note. HF / LF = high / low frequency; HP / LP = high / low predictable; SFD = single fixation duration. Fixation durations in milliseconds (ms). *NS* = non-significant difference (Fs<1, ps>.25)

<u>Skipping outcome × contextual predictability</u>

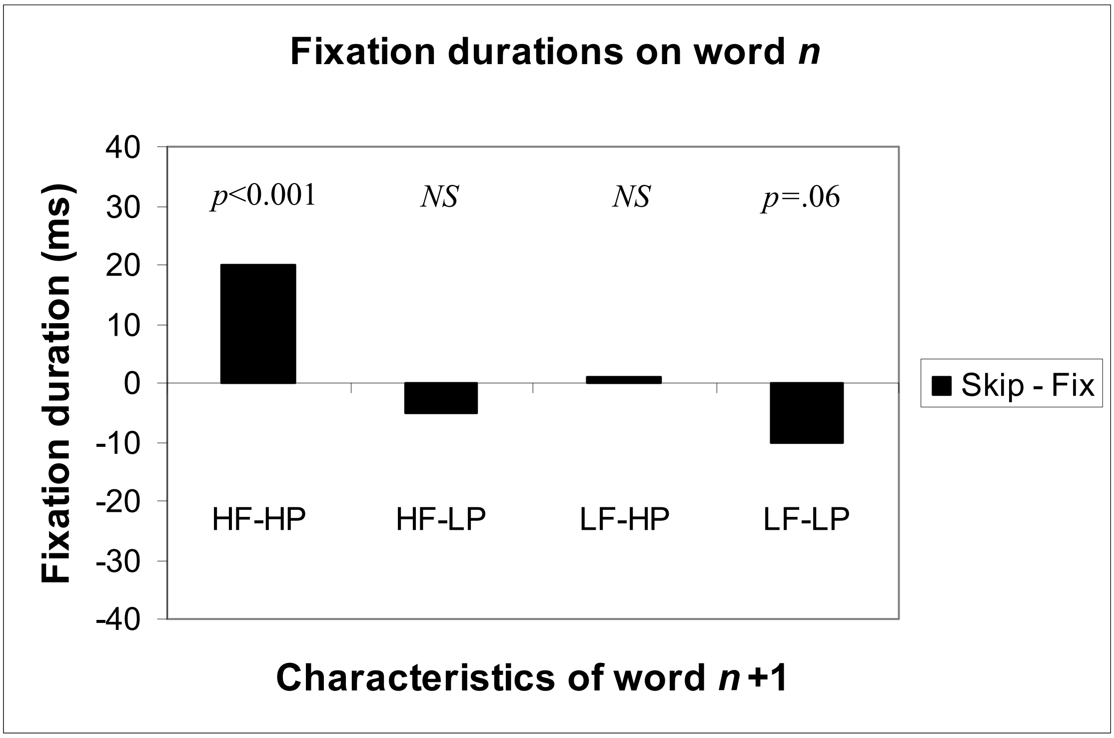
A significant interaction on word *n* fixation duration was also observed between skipping outcome and the contextual predictability of the word *n*+1 [$F_1(1,63)=8.44$, $p<0.01$; $F_2(1,43)=9.47$, $p<0.01$]. Planned follow-up comparisons revealed that there was a significant inflation of word *n* fixation durations when *n*+1 was skipped relative to fixated when *n*+1 was HP but LP. Fixations prior to HP words were 11 ms longer when the *n*+1 was skipped [$F_1(1,63)=21.9$, $p<0.001$; $F_2(1,43)=8.03$, $p<0.01$; see Figure 4.2]. Fixations prior to skipping LP words were actually found to be 8.1 ms shorter compared to when the *n*+1 were fixated, however, this difference was only shown to be marginally significant by participants, and non-significant by items [$F_1(1,63)=2.99$, $p=0.08$; $F_2(1,43)=1.85$, $p>0.15$; See Figure 4.2].

Skipping outcome × word frequency × contextual predictability

A non-significant 3-way interaction between the effects of skipping, word frequency and contextual predictability was reported both by participant and item analyses [$F_1<1$; $F_2(1,43)=1.29$, $p>0.25$]. It is interesting to examine the differences between fixation durations on word *n* prior to skipping *n*+1 versus prior to fixating it across the four conditions of word *n*+1 (see Figure 4.3); however, it must be qualified that these investigations are purely exploratory – they are included for illustrative purposes. The largest inflations of fixation durations prior to skipping occur when *n*+1 is HF-HP. When *n*+1 was HF-HP, word *n* fixation durations were 20 ms longer prior to skips as opposed to fixations [both ps<.001; see Figure 4.3]. When *n*+1 was HF-LP, word *n* fixation durations were actually 5 ms shorter prior to *n*+1 skips than those prior to fixations, but this difference was non-significant [both ps>.35; see Figure 4.3]. When *n*+1 was LF-HP, word *n* fixation durations were 1 ms longer prior to *n*+1 skips than those prior to fixations, but again this difference was not significant [both ps>.35; see Figure 4.3]. Finally, when *n*+1 was LF-LP, word *n* fixation durations were 10 ms shorter prior to *n*+1 skips than those prior to fixations [both ps=.06; see Figure 4.3].

Thus, it would appear that fixation durations are increased prior to skipping a word, but only when that word is both HF and HP. This suggests that it is the ability of the participant to extract information parafoveally which is resulting in inflated fixation durations, as HF and HP parafoveal words allow for greater extraction of parafoveal information (Balota et al., 1985; Inhoff & Rayner, 1986).

Figure 4.3. Inflated word *n* fixation durations before skipping word *n*+1 across word *n*+1 characteristics



Note. Positive values represent inflated fixation durations prior to skipping. HF / LF = high / low frequency; HP / LP = high / low predictable; SFD = single fixation duration. *NS* = non-significant difference (Fs<1)

Discussion

Experiment 3 was conducted in order to examine whether fixation durations on word *n* are significantly inflated prior to skipping word *n*+1 compared to when *n*+1 is fixated. The word frequency and contextual predictability of the *n*+1 was orthogonally manipulated in order to examine any possible differences between fixations prior to skips dependent on the lexical features of *n*+1. Word frequency and contextual predictability have been show to affect the amount of information that a reader can extract from parafoveal word *n*+1 while fixating foveal word *n* (Balota et al., 1985; Inhoff & Rayner, 1986). It was hypothesised that manipulating these features may differentially influence fixation durations prior to skips and fixations.

The results appeared to show non-significant main effects of skipping *n*+1 (skip vs. fixation), frequency of *n*+1 (HF vs. LF), and predictability of *n*+1 (HP vs. LP) on word *n* fixation durations. This would appear to suggest that there is no difference between fixation durations prior to skips and fixations, regardless of the characteristics of parafoveal word *n*+1. However, upon examining the interactions between the skipping outcome and word *n*+1 variables, evidence of inflated fixation durations prior to skips was observed. The inflated fixation duration effect was limited to cases when parafoveal word *n*+1 was HF, and cases where *n*+1 was HP. The biggest inflation of fixation durations prior to skipping occurred when word *n*+1 was *both* HF and HP (see Figure 4.3).

The probability of fixating word *n*+1 in *Experiment 3* was influenced by its frequency and contextual predictability. Word *n*+1 was significantly more likely to be skipped when it was both HF and HP, as compared to the other conditions which did not differ from one another (See Figure 4.3). The 667 cases of skipping included in the initial analyses were not evenly distributed across the four *n*+1 conditions (see Table 4.2). It may be the case that the differential amount of observations between conditions may be influencing the results of the skipping outcome by frequency and predictability analyses. In order to address this concern, 121 data points were selected randomly from each of the HP-HF, HF-LP, and LF-HP conditions. Data points in each condition were sorted by item, and then subject identifiers and numbered accordingly. Random number sequences for each of the HP-HF, HF-LP, and LF-HP conditions were generated (http://www.random.org). Each sequence began at 1 and terminated at the total number of observations in that condition (e.g., the sequence generated for HF-HP words ranged from 1 to 235). The first 121 integers from the random number lists were used to select the appropriate data points from the original analyses. This provided the highest possible equivalent numbers of skipping incidences in each of the four word $n+1$ conditions. 72.6% of the data from the original analyses remained after the random selection process. As before, word n fixation durations were analysed in a 2 (Skipping Outcome; skip, fixation) × 2 (frequency; HF, LF) × 2 (predictability; HP, LP) ANOVA both by participants (F_1) and items (F_2) sources of variance. Mean word n fixation durations by condition are presented in Table 4.3, and the significances of the main effects, interactions, and follow-up contrasts are provided in Table 4.4.

Table 4.2. Number of data points in original and equated analyses by condition

	Original	Equated
HF-HP	235	121
HF-LP	164	121
LF-HP	147	121
LF-LP	121	121
N	667	484

Note. HF = high frequency, LF = low frequency, HP = high predictable, and LP = low predictable.

Table 4.3. Mean fixation durations on word n by word $n+1$ characteristics – Randomly selected data points

	Skip	Fixation
HF-HP	288	252
HF-LP	254	260
LF-HP	242	258
LF-LP	258	262

Note. Mean values are shown in milliseconds. HF = high frequency, LF = low frequency, HP = high predictable, and LP = low predictable.

Table 4.4. Main effects, interactions and follow-up contrasts – Randomly selected data points

		F_1	*MSE*	*p*	F_2	*MSE*	*p*
Skipping	3 ms	<1			<1		
Frequency	8 ms	4.09	8923	.05	<1		
Predictability	1 ms	<1			2.87	1096	.10
Skip × Freq		7.13	2713	.01	3.37	1734	.07
Skip-HF vs. Fix-HF	15 ms			.05			.08
Skip-LF vs. Fix-LF	-10 ms			.08			*NS*
Skip × Pred		5.47	1428	.05	16.30	951	.001
Skip-HP vs. Fix-HP	10 ms			.10			.05
Skip-LP vs. Fix-LP	-5 ms			*NS*			.08
Freq × Pred		8.20	2130	.01	3.27	1988	.08
HF-HP vs. HF-LP	-13 ms			.05			.01
LF-HP vs. LF-LP	10 ms			.05			*NS*
Skip × Freq × Pred		9.98	2327	.01	5.53	1970	.05
Skip							
HF-HP vs. HF-LP	-34 ms			.01			.001
LF-HP vs. LF-LP	16 ms			.08			*NS*
Fix							
HF-HP vs. HF-LP	9 ms			.05			.01
LF-HP vs. LF-LP	4 ms			.13			*NS*

Note. HF = high frequency, LF = low frequency, HP = high predictable, and LP = low predictable. Skipping = main effect of skipping – positive integers reflect longer fixations prior to skips; Frequency = main effect of frequency – positive integers reflect longer fixations prior to LF words than HF; Predictability = main effect of predictability – positive integers reflect longer fixations prior to LP words than HP words; Skip × Freq / Pred = skipping outcome by frequency / predictability interaction – positive integers reflect longer fixation durations prior to skips; Freq × Pred = frequency by predictability interaction – positive integers reflect longer fixations prior to LP words; Skip × Freq × Pred = skipping outcome by frequency by predictability interaction – positive integers reflect longer fixations prior to LP words. Fixation durations in milliseconds (ms). *NS* = $p>.35$

The pattern of effects observed in the random-point analysis is highly similar to that observed in the main analyses. The main effects of skipping outcome, word *n*+1 frequency and word *n*+1 predictability showed no consistent significance across participants and items analyses (See Table 4.4). The main effect of frequency showed that fixation durations prior to HF words were 8 ms longer than those prior to LF words, but this difference was significant only by participants analysis (See Table 4.4). Consistent with the main analyses, a significant interaction between skipping outcome and word *n*+1 frequency was observed in the conditionalised analyses (See Table 4.4). Follow-up comparisons revealed that when word *n*+1 was HF, fixation durations were 15 ms longer prior to a skip than fixation durations prior to fixating word *n*+1.Fixation durations prior to LF word *n*+1 were 10 ms shorter prior to a skip than a fixation, but this difference was not consistently significant. As was demonstrated in the main analyses, a significant interaction between the effects of skipping outcome and word *n*+1 predictability was also observed in the random-point analysis (See Table 4.4). Follow-up comparisons revealed that when word *n*+1 was HP, fixation durations prior to skips were 10 ms longer than those preceding fixations of word *n* +1. Fixation durations prior to LP words were found to be shorter when *n*+1 was skipped compared to when it was fixated, but this difference was not significant.

Unlike the main analyses of *Experiment 3*, the conditionalised analyses revealed that the three-way interaction between skipping outcome, word *n*+1 frequency, and word *n*+1 predictability was found to be significant (See Table 4.4). However, it must be noted that the qualitative pattern of effects observed in the random-point analysis is highly similar to that observed in the main analyses. Fixation durations prior to skips showed the greatest amount of inflation compared to fixation durations prior to fixations when to-be-skipped word *n*+1 was both HF and HP (both ps<.001). Fixation durations in the three other word *n*+1 conditions (HF-LP, LF-HP, and LF-LP) showed no consistent significant differences between fixation durations prior to skips and fixations (-6, -16, and -4 ms respectively; both ps>.65, p_1=.09, p_2>.45, and both ps>.80 respectively).

The process of randomly selecting 121 data points to equate that number of observations across word *n*+1 conditions was repeated four more times, using newly-generated random number sequences. Each time the analyses were performed, highly similar (if not statistically identical) results were obtained. The results of these data point-equated analyses reveal that after controlling for the amount of fixation duration data in each condition, the results of the conditionalised analyses largely support those in the global analyses. The overall non-significant effect of skipping outcome on prior fixation duration appears to be somewhat misleading – the decision to skip *n*+1 results in a modulation of word *n* fixation duration, but this modulation is dependent on the characteristics of word *n*+1. The results of both the main analysis and random-point analysis reveal that fixation durations prior to skips are inflated respective to fixation durations prior to fixations, but only when to be-skipped word *n*+1 is HF and / or HP.

Drieghe (2008) conducted an eye movement reading experiment in order to investigate whether the relationship between the amount of parafoveal processing and the skipping rate of word *n*+1 is as tightly linked as is specified by the E-Z Reader model. If this coupling is tight, it should be that a condition which does not affect E-Z Reader's later stages of processing (e.g., a word displayed faintly in low contrast) should demonstrate skipping rates comparable to a normal condition. A condition which increases the duration of the later stage of processing within the E-Z Reader model (e.g., case alternation, "*house*" displayed as "*hOuSe*"), should decrease parafoveal processing, and consequently, reduce skipping rates of critical word *n*+1. The study conducted by Drieghe (2008) also examined the interaction between foveal load and preview. An interaction between these factors on word skipping rates is crucial in indicating the influence of the amount of parafoveal processing on word skipping. This interaction was not observed in a prior study by Drieghe, Rayner, and Pollatsek (2005), but has been observed on measures of fixation duration repeatedly (e.g., Henderson & Ferreira, 1990).

Using short, very frequent words (which are most likely to be skipped; see Brysbaert, Drieghe, & Vitu, 2005 for a review), Drieghe (2008) investigated fixation durations and skipping rates of word *n*+1 when word n was presented under normal conditions, in a faint, reduced contrast form, or in a case-alternated form. It was found that participants were significantly less likely to skip parafoveal word *n*+1 when they had previously fixated faint word *n*+1 than the case alternated and normal conditions (which did not differ from one another). The manipulations of prior word n had marginal influences on fixation durations on word *n*+1, however, Drieghe (2008) indicates that due to limited data and the design of the experiment (which was principally focused on the typographical manipulations of word n and the subsequent effects on word *n*+1 skipping rates), strong conclusions cannot be drawn from the analyses of word *n*+1 fixation durations.

Drieghe (2008) argues that if one assumed that fixation times and skipping rates are reflections of the same phenomenon (i.e., level of parafoveal processing), comparable effect patterns should be observed in both measurements. However, this was not the case in Drieghe's (2008) results. Skipping was not influenced exclusively by the amount of parafoveal processing, but also by the ease of foveal processing. Difficult foveal words causes the processor to adopt a more cautious strategy when deciding whether to skip parafoveal word *n*+1.

Models such as E-Z Reader posit that the processor's decision to skip a word can only be made when the to-be-skipped word has been completely identified on prior fixation, or when full recognition is imminent. Alternative models suggest that the decision to skip is based on coarser-grained information, and the decision to skip involves a certain element of educated guessing, accounting for factors such as word length, and partial word identification. Brysbaert and Vitu's (1998) EOVP model argues that the main determinants of the skipping decision are word length and the experience that the system has established of how often a word of a specific length at a certain eccentricity can be skipped without impeding upon the reader's comprehension of the material.

Models such as SWIFT or Glenmore exist somewhat between the two models outlined above in terms of the role placed on how much parafoveal processing occurs prior to skipping a word. SWIFT assumes that a word's lexical processing gradually increases until a maximal level is established, before this activity then declines. Words with higher levels of activation will attract saccadic movements, therefore, words that have received more parafoveal processing will already have achieved and surpassed their peak level of activation, and saccades will be more likely to be attracted to the comparatively highly activated word n+2. It is by this mechanism that the SWIFT model allows a word to be skipped, even though the word may not have reached the level of activation required by the E-Z Reader model. However, for a word to be skipped, the SWIFT model requires much more processing of a word than the EOVP model.

A comprehensive understanding of word skipping must incorporate visual, as well as linguistic elements. E-Z Reader incorporates the effect of word length on skipping by assuming an inverse relationship between visual eccentricity and the ability to extract letter information. The further a reader's eyes are from a word, the longer the processor will need to complete the initial stage of lexical access. Since skipping is dependent on word recognition, the increase in time taken to complete this process will result in an decreased likelihood of skipping that word. A very similar process is in operation within the SWIFT model: words at larger eccentricities have reduced efficiency of information extraction, therefore it is less likely that these words will have passed their maximum level of activation. The EOVP model does allow for some limited saccade target adaptation by upcoming linguistic information, however, this is after the initial decision to skip or fixate the word has been made.

Brysbaert, Drieghe, and Vitu (2005) conducted a meta-analysis of skipping studies which manipulated processing difficulty of words and also reported word lengths of critical words. The first group of studies examined by Brysbaert et al. (2005) featured those which manipulated the processing difficulty of critical words in terms of critical word characteristics (e.g., word frequency). The second group of studies examined manipulated processing difficulty in terms of the critical word's contextual predictability. Brysbaert et al. (2005) found a 5% difference in skipping rates between linguistically easier and more difficult words in the first group of studies. This effect was dwarfed by the effect of word length on skipping in these studies – a non-significant 2% skipping rate was found for nine-letter words, whereas an enormous 50% effects was found for two-letter words. The second group of studies examined by Brysbaert et al. (2005) demonstrated an average predictability effect on skipping of 8%; the length effect was highly comparable to the first group of studies. From the relative magnitudes of the linguistic and visual effects on skipping, Brysbaert et al. (2005) concluded that in order to predict the likelihood of skipping a word, it is more informative to know the length of the word, rather than how difficult it is to access or integrate.

Current theoretical accounts of word skipping behaviour differ considerably in the extent to which parafoveal preprocessing to determine intra-word saccadic target is allowed. E-Z Reader argues that in order for skipping to occur, parafoveal word *n*+1 must be fully recognised or that recognition must be imminent for it to be skipped. Other models, such as Brysbaert & Vitu's (1998) EOVP model argue that skipping behaviour is based on coarser information, such as the to-be-skipped word's length and its distance from current fixation. It is only after this decision has been made that linguistic features of the parafoveal word can have an influence, by either cancelling a skipping saccade, or cancelling a saccade programmed to fixate the upcoming word. All current instantiations of models of eye movement control which make explicit claims involve visual and linguistic elements. The issue remains as to which of these factors is the major determinant of word skipping behaviour.

The finding of inflated fixation durations is consistent with both SAS and GAG models of eye movement control during reading (Engbert et al., 2005; Reichle et al., 1998). However, the observed pattern of effects is most consistent with a GAG model of eye movement control. SAS models such as E-Z Reader stipulate that longer fixations prior to skipping are the result of saccadic reprogramming, and that the costs of this reprogramming should be inversely related to the frequency of the skipped word. However, the opposite pattern of effects was observed in the present study. When HF words were skipped in the present study, prior fixation durations were significantly inflated compared to when these words were fixated – no difference was observed between fixation durations prior to skips and fixations when parafoveal words were LF. GAG models such as SWIFT argue that parafoveal pre-processing increases the probability of complete lexical access, and, thus, the skipping of word *n* + 1 (Engbert et al., 2002; Reilly & Radach, 2003), thus longer fixations are a consequence of greater accumulation of information from the parafovea. In the present study, inflated fixation durations prior to skips were only observed in conditions where the parafoveal word was either HF or HP. Prior research has demonstrated that readers are able to acquire more information from parafoveal word *n*+1 when that word is HF or HP (Balota et al., 1985; Inhoff & Rayner, 1986). It is argued that the inflated fixation durations prior to skipping in the present study represent greater accumulation of information from the parafoveal word, rather than a process of saccadic cancellation and re-programming.

Chapter 5

Word-initial letter constraint influences lexical processing: Evidence from lexical decision and eye movement research

Introduction

Over three decades of eye movement reading research has demonstrated that the information available on a single fixation is not limited to the currently fixated (foveal) word. Readers are able to acquire information from the upcoming parafoveal word before its subsequent fixation. The importance of parafoveal vision in reading was substantiated in classic eye movement reading studies using the "moving window" (McConkie & Rayner, 1975; Rayner, 1975b) and "boundary" (Rayner, 1975a) paradigms. In these paradigms, changes are made in the text contingent on the reader's eye position.

In "moving window" studies, text *outside* a window defined around the fixated letter is altered in some way (e.g., valid text is replaced by strings of *x*s; see **Chapter 1**, Figure 1.4). Under such conditions, when parafoveal preview is invalid, reading time is slowed, demonstrating the use of both foveal and parafoveal information during normal reading. The *perceptual span* – the region of text from which useful information can be extracted – has been functionally approximated from "moving window" studies. For English, it is estimated to extend from 3 characters to the left of fixation (approx. the beginning of the fixated word) to around 14 characters to the right of fixation (McConkie & Rayner, 1975; Miellet et al., 2009). Although the span encompasses a significant number of letters to the right of fixation, the level of analysis drops off substantially from the fovea – from recognising words to identifying letters to merely determining the length of the upcoming parafoveal word(s). The *word identification span* – the area from which readers can identify words during a particular fixation – is smaller than the perceptual span, typically extending only to around 7 characters to the right of fixation (McConkie & Zola, 1987; Rayner et al., 1982; see **Chapter 1**, Figure 1.5).

In “boundary” studies, only a single word of the text changes. While reading, participants parafoveally view either a valid or invalid preview in the target location, which then changes to the target when the reader saccades across a pre-specified (invisible) boundary located just before the target word (See **Chapter 1**, Figure 1.3). “Boundary” experiments have varied the visual, phonological, and semantic similarity between the foveated target and its initial parafoveal preview and have generally shown that orthographic and phonological, but not semantic, information is extracted parafoveally (e.g., Balota et al., 1985; McConkie & Zola, 1979; Pollatsek et al, 1992; Rayner et al, 1980). The fixation time advantage on a target word (fixation *n*) when parafoveal information associated with that target (obtained from fixation *n-1*) is valid versus invalid is termed *parafoveal preview benefit*.

Lima and Inhoff (1985) conducted an eye movement study which focused on a hypothesis of lexical access based on word-initial letter information – the *constraint hypothesis*. This hypothesis postulates that lexical access is facilitated when the number of potential candidates is limited by the word-initial letter information. Words can be described as either high-constraint (i.e., a word with very few alternatives which share the same word-initial letter information, such as *dwarf*) or low-constraint (i.e., a word with many alternatives which share the same word-initial letter information, such as *clown*). Lima and Inhoff (1985) hypothesised that if word-initial letter information is crucial to lexical access, and the word identification span confines much of the information available parafoveally to the word-initial letter information of the word, then it may be that much of the information necessary to identify a high-constraint word is obtained parafoveally. If the parafoveal information can limit the candidate size in the lexicon, then facilitation due to parafoveal preview should reflect the amount of constraint imposed by the word-initial letter information. The second prediction of Lima and Inhoff (1985) was that parafoveal preview benefit would be greater for high-constraint words than low-constraint as determined by a greater reduction of fixation time on the target words that had previously been viewed parafoveally.

Using gaze-contingent display change paradigms, Lima and Inhoff (1985) demonstrated results that were inconsistent with the constraint hypothesis. It was observed that high-constraint words, such as *dwarf*, were actually fixated for *longer* than words such as *clown*, a low-constraint word. Lima and Inhoff (1985) also found that the size in reduction of foveal fixation time due to the availability of parafoveal preview was roughly equivalent for both high- and low-constraint words. Lima and Inhoff (1985) claimed that their results invalidated the constraint hypothesis as an explanation of lexical access, and suggested instead that word-initial letter information was not used to constrain the candidate set of possible words needing to be considered for access and integration into the developing discourse structure.

White and Liversedge (2004) conducted an eye movement study designed to investigate what types of nonfoveal processing influence initial fixation locations within words, focusing on the roles of sublexical and lexical processing of nonfixated text on initial fixation locations within words. The study by White and Liversedge (2004) follows on from work by Hyönä (1995) who presented words in Finnish which were contained either orthographically familiar or unfamiliar initial letter combinations. Hyönä found that readers' fixations landed closer to the beginning of orthographically unfamiliar words, particularly on the space before these words. It has been suggested that salient features of words (such as irregular orthography) "pop out" of nonfoveated text (Hyönä, 1993) and pull the eye towards them. Findlay and Walker (1999) have suggested that medium- and longer-term learning adapts the intrinsic salience of visual stimuli such as orthographic letter sequences. It has also been suggested that the processing difficulty associated with orthographically unfamiliar letter strings reduces the perceptual span and thus the extent of preprocessing, which subsequently shortens saccades (Hyönä & Pollatsek, 1998, 2000).

White and Liversedge (2004) conducted two experiments. The first was designed to investigate whether orthographic familiarity influences initial fixation positions within words. The second experiment investigated whether processing word initial letters to generate a set of alternative candidates influences initial fixation position within a word. Orthographic familiarity was measured using token frequency – the sum of word frequencies of words which include a particular letter sequence (White & Liversedge, 2004). Words were designated as "informative" if they contained an initial letter sequence which is shared by few other words, or "uninformative" if they contained an initial letter sequence which is shared by many other words. Informativeness was measured using type frequency – the number of words including a particular letter sequence (White & Liversedge, 2004). An additional manipulation was that the initial letters of critical words could be manipulated, such that the critical word was misspelled.

White and Liversedge (2004) found that words with more irregular misspelling (misspelled versions of words with informative beginnings) were harder to recognise than regular misspelled words, as indexed by measures of fixation duration. Examination of landing positions within words demonstrated that readers saccade further into correctly spelled words. However, the results of White & Liversedge's second experiment showed that when processing correctly spelled words, readers' initial landing positions within words occur closer to the beginning of orthographically unfamiliar words, compared to orthographically familiar words.

Williams, Perea, Pollatsek, and Rayner (2006) investigated the role of orthographic neighbours as parafoveal previews in reading. Orthographic neighbours are words of the same length that can be created by changing only one letter of a target word. For example, the neighbourhood of *sleet* is *fleet*, *sheet*, *skeet*, *sweet*, *slept*, *sleek*, and *sleep* (Coltheart, Davelaar, Jonansonn, & Besner, 1977). Orthographic neighbourhoods have been claimed to be a factor that can influence word recognition. In two experiments, Williams et al. (2006) compared fixation time on targets when parafoveal preview was either identical to the target, an orthographic neighbour of the target, or a non-word. Target words and orthographic neighbours were manipulated in terms of frequency: in the first experiment, LF words were targets, and HF words were parafoveal previews; in the second experiment, the roles were reversed (Williams et al., 2006). The results of Williams et al. (2006) demonstrated that the frequency of a preview influences the extraction of word-initial letter information. In their first experiment, neighbours provided as much facilitation as identical words, and were much better than non-words, whereas in their second experiment, neighbours provided no better preview than non-words (Williams et al., 2006). The results of Williams et al. (2006), in contrast to those of Lima and Inhoff (1985), are consistent with a model of word recognition, in which the initial stages are dependent largely on word-initial letter information.

White (2008) conducted an eye movement reading study examining the effects of orthographic familiarity and word frequency. This study attempted to examine word frequency effects while controlling for the effects of orthographic familiarity – frequent words are argued to be necessarily familiar, however, less frequent words may be orthographically unfamiliar. White (2008) makes the important distinction between type frequency and token frequency as a measure of orthographic familiarity. Type frequency – typically used in previous studies of orthographic familiarity (Bertram & Hyönä, 2003; Rayner & Duffy, 1986) – is the count of the number of words containing a particular bigram or trigram. This measure can be seen as a measure of lexical informativeness – the trigram "*pne*", when positioned at the beginning of a word has a very low type frequency and is highly informative to the reader. However, White (2008) argues that type frequency does not reflect letter sequence familiarity, as a number of words share the initial trigram "*irr*". However, very few of these words are high frequency words, thus, although "*irr*" has a high type frequency, it has a low orthographic familiarity. White argues that an improved measure of orthographic familiarity is token frequency – the sum of the frequencies of words containing a particular letter sequence.

Other studies have manipulated word frequency and the type and token frequency of word-initial trigrams on identifying words in isolation (Kennedy, 1998, 2000; Kennedy, Pynte & Ducrot, 2002). The results of these studies typically show that words which contain LC initial trigrams are processed with less difficulty than words which contain HC initial trigrams. Further studies have also examined word frequency and type and token frequency of word-initial letters in sentence reading tasks (Kennedy & Pynte, 2005; Pynte & Kennedy, 2006). These studies typically reported longer foveal inspection times on words which contained HC initial trigrams as opposed to words containing LC initial trigrams.

It may be that orthographic familiarity impacts upon visual, sublexical or lexical levels of processing (White, 2008). At a visual level, processing of a text may modulate the familiarity of the information, such that frequent letter strings develop higher visual familiarity compared to less frequent letter combinations (Findlay & Walker, 1999). Effects of orthographic familiarity could be interpreted as reflecting processing at least at the visual level. However, differences in orthographic familiarity could also be associated with differences in the informativeness of the text string; consequently, effects of orthographic familiarity may be driven by sublexical, or indeed, lexical processes.

White (2008) conducted a comprehensive examination of the separate effects of word frequency and orthographic familiarity on eye movement behaviour during reading. The principle purpose of this study was to investigate whether lexical processes influence saccadic programming such that both fixation durations and skipping are influenced by lexical aspects of words. White (2008) examined the frequency effect by comparing frequent and infrequent words which were matched for whole word orthographic familiarity. Orthographic familiarity effects were investigated by comparing orthographically familiar and unfamiliar words which were equally infrequent.

White (2008) observed shorter fixation durations on orthographically familiar words compared to unfamiliar words across standard measures of fixation duration. White (2008) showed clear effects of word frequency, independent of the effects of orthographic familiarity. These results demonstrated that the lexical processing of words influences saccadic programming, as indexed by fixation durations on target words. It is argued thus, that models of eye movement control during reading should include a Saccade programming mechanism which is sensitive to the lexical processing of word frequency.

In the E-Z Reader model (Reichle et al., 1998), completing the initial stage of word processing is the trigger for saccadic programming. Therefore, for a word to be skipped, both the currently fixated word and the parafoveal to-be-skipped word would have to be processed up to this point before the skipping programme could be finalised. In the SWIFT model, saccadic programming is generated by a random, stochastic process, and it is this process which is delayed or cancelled by linguistic processing by the mechanism termed foveal inhibition (Engbert et al., 2002, 2005). For such models to explain the results of White (2008), the lexical variable word frequency must an influence during a fixation – before saccadic programming commences. With this contention, lexical processing must be extremely rapid, or alternatively, a significant amount of processing must occur prior to fixating a word.

Alternatively, linguistic factors may influence saccadic programming at a later stage, but before the nonlabile stage of the saccade programme. The SWIFT model, for example, postulates that determining a saccadic target occurs towards the end of the labile stage of saccadic programming. If it were possible for linguistic processing to influence saccadic programming during the labile stage, more time would be allowed during the fixation for lexical processing to occur, so as to allow it to influence where the eyes move.

White's (2008) results also raise the question of how the effects of orthographic familiarity influence fixation durations on words. Models such as E-Z Reader argue that it could be that orthographic familiarity may influence the initial stage of processing a word, but not the later stage, therefore influencing current fixation duration, but not subsequent fixation durations. Indeed, the orthographic effects of White (2008) had a relatively brief influence on target word reading times.

The results of White (2008) show that lexical factors influence both the "where" and "when" decisions of eye movements during reading, but research has indicated that these processed may be controlled in qualitatively different ways. Fixation durations (the "when" decision) are influenced by both foveal and parafoveal linguistic information, but word skipping (a "where" decision) may be influenced by linguistic information only in the parafovea (Drieghe, Rayner, & Pollatsek, 2005; White, 2007).

The purpose of the *Experiments 4a* and *4b* was to further investigate the effect of WILC in written language processing. Like Lima and Inhoff (1985), processing time on HC (e.g., *dwarf*) and LC (e.g., *clown*) words will be compared. Unlike Lima and Inhoff, however, two key variables known to affect word recognition are additionally manipulated, namely, word frequency (*Experiments 4a* and *4b*) and contextual predictability (*Experiment 4b*).

If variables such as word length are controlled, HF words are processed faster than LF words. *Experiment 4a* employs a visual lexical decision experiment, using a 2 (Constraint: HC, LC) × 2 (Frequency: HF, LF) design, in order to investigate the main effects of WILC and word frequency on participants' reaction times to words presented in isolation. It was hypothesised that participants' reaction times to HC words would reflect increased processing difficulty associated with such words when compared to LC words, as seen in previous studies (Kennedy, 1998, 2000; Kennedy, Pynte & Ducrot, 2002). It may be that WILC impacts upon visual, sublexical or lexical levels of processing (White, 2008). At a visual level, processing of a text may modulate the familiarity of the information, such that frequent letter strings develop higher visual familiarity compared to less frequent letter combinations (Findlay & Walker, 1999).

Experiment 4a

Method

Participants

Forty members of the University of Glasgow community (20 females; mean age 23 years old) were paid £1 or given course credit for their participation. All participants were right-handed and were native English speakers with normal or corrected-to-normal vision and had not been diagnosed with any reading disorder.

Apparatus

Stimuli presented on a 19" flat screen monitor, using a 16-point non-proportional font (black characters on a white background), resolution 1280 × 1024 pixels, refresh rate 75 Hz. Stimulus presentation was controlled using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Participants responded using a standard PC keyboard.

Design and Materials

A 2 (Constraint: HC, LC) × 2 (Frequency: HF, LF) design was used. All target words were 5 letters long. With a total of 160 experimental items, there were 40 items in each of the 4 conditions. All experimental items are listed in **Appendix V**. An example set of materials and target word specifications for each condition is presented in Table 5.1

Table 5.1. Stimulus Specifications across Experimental Conditions – *Experiment 4a*

	LF		HF	
	LC	HC	LC	HC
Example	*clown*	*dwarf*	*train*	*girls*
Measure				
N	40	40	40	40
Length	5	5	5	5
Frequency	9	9	79	87
Number of Neighbours				
5-letter	18	1	17	3
x-letter	174	19	204	41
% of Trigram Neighbourhood				
5-letter	6%	95%	16%	96%
x-letter	2%	35%	6%	36%

Note. LF=Low Frequency, HF=High Frequency, LC=Low Constraint, HC=High Constraint, N=number of items, Length=average word length (number of letters), Frequency=average frequency of occurrence (per million), Number of Neighbours=average number of trigram neighbours for 5-letter or *x*-letter (any length) words, % of Trigram Neighbourhood=average word frequency percentage that each target represents of its 5-letter or *x*-letter trigram neighbourhood.

Constraint. Half of the target words had HC and half had LC initial trigrams. Constraint was determined by the following measures. First, for each (5-letter) target, the number of other 5-letter words as well as the number of words of any length (*x*-letter words) which shared the same initial trigram was computed. Second, the percentage that each target represented of its trigram neighbourhood, both for 5-letter words and for *x*-letter words was calculated. This involved dividing each target word's frequency of occurrence by the summed frequency of all 5- or *x*-letter words (including the target) that shared a given trigram. To determine the neighbourhood profiles for *x*-letter words, the Brigham Young University BNC on-line resource was used (http://corpus.byu.edu/bnc; Davies, 2004). Average values for each of these measures across conditions are presented in Table 5.1, values for individual target words are available in **Appendix V**. Overall, HC words had far fewer 5- and *x*-letter trigram neighbours and they accounted for a far greater percentage (in terms of word frequency) of their 5- and *x*-letter trigram neighbourhoods compared to LC words.

Frequency. In addition, half of the targets were HF and half were LF words. Word frequencies were obtained using the 90-million written word British National Corpus (BNC; http://www.natcorp.ox.ac.uk). Mean frequencies were 83 occurrences per million for HF targets (range 26-362 occurrences per million; see Table 5.1) and 9 occurrences per million for LF targets (range 0-23 occurrences per million; see Table 5.1). Word frequencies for individual target words are presented in **Appendix V**.

Procedure

On arriving for the experimental session, participants were given written and verbal instructions as to their task. After giving their informed written consent, participants were seated at a comfortable distance from the display monitor in a well-lit booth within the Psychology Department at the University of Glasgow. Participants were reminded to respond as quickly and as accurately as to whether or not the letter string presented in the centre of the screen was a legitimate English word or not. Participants were told to respond by pressing the “L” key if the string was a valid word, and to press the “A” key if the string did not form a valid word. Before beginning the main experimental session, participants completed a 10 trial practice block in order to familiarise themselves with the set-up and procedure. Participants had very little difficulty in performing the lexical decision task – all participants performed with greater than 95% accuracy.

Results

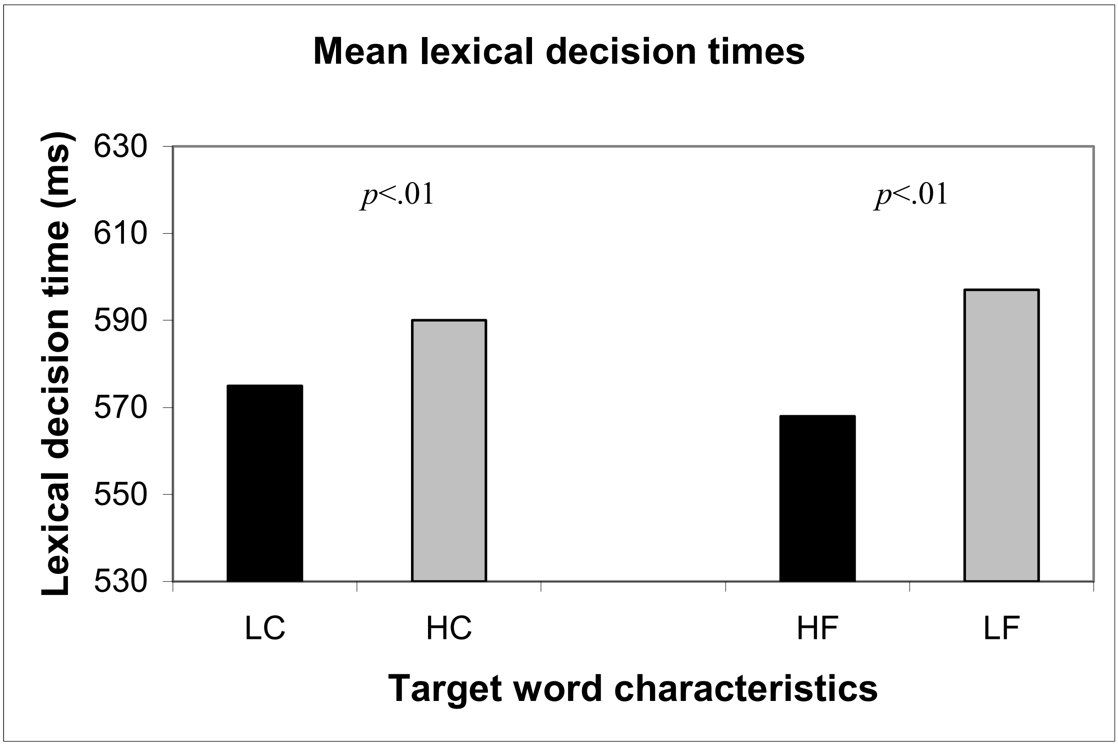
Prior to analysis, individual data points were excluded on the following grounds: 1) if participants made an incorrect response on the lexical decision task; 2) Any reaction times <250 ms or >1500 ms; and 3) if a participants reaction time was outwith ± 2 standard deviations of that participant's mean reaction time in that particular experimental condition. A total of 13.2% of the data was excluded under this criteria – 4.1% due to incorrect responses, and 9.1% due to exceedingly fast / slow responses. Mean lexical decision times across conditions are presented in Table 5.2. In order to ascertain the effects of WILC and frequency, a 2 (Constraint: HC, LC) x 2 (Frequency: HF, LF) ANOVA was conducted both by F_1 and F_2.

Table 5.2. Mean lexical decision times across conditions

	LF		HF	
	LC	HC	LC	HC
Example	*clown*	*dwarf*	*train*	*girls*
	583	611	566	569

Note. Lexical decision times in milliseconds. LF=Low Frequency, HF=High Frequency, LC=Low Constraint, HC=High Constraint.

Figure 5.1. Mean lexical decision times across conditions



Note. Lexical decision times in milliseconds. LF=Low Frequency, HF=High Frequency, LC=Low Constraint, HC=High Constraint.

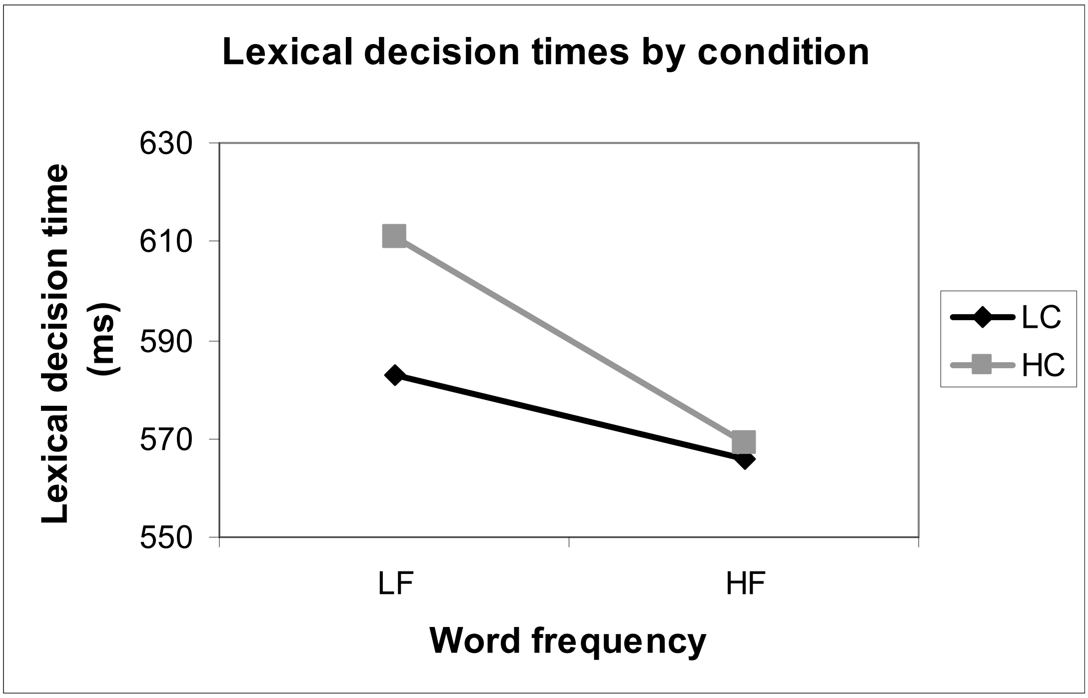
Main effects of Constraint and Frequency

It was hypothesised that LC words would elicit faster responses than HC words, on the basis that an LC trigram facilitates a "word" more than an HC trigram, as, by definition, an abundance of words share an LC trigram. Response times to LC words were indeed faster than those to HC words (575 ms vs. 590 ms; $F_1(1, 39)=7.44$, $MSE=1232$, $p<.01$, $F_2(1, 39)= 2.46$, $MSE = 2558$, $p=.13$; see Figure 5.1). HF words were identified much faster than LF words (568 ms vs. 597 ms; F_1 $(1,39)=18.93$, $MSE=1788$, $p<.001$, F_2 $(1, 39)=9.49$, $MSE=2620$, $p<.01$; see Figure 5.1).

Constraint × frequency

Although numerically and qualitatively suggestive of an interaction (see Figure 5.2), no statistical support for non-additivity of these factors on lexical decision times was observed [$F_1(1,39)=2.70$, $MSE=2349$, $p=.11$, $F_2(1, 39)=1.60$, $MSE=1879$, $p>.20$].

Figure 5.2. Mean lexical decision times by target word condition



Note. Lexical decision times in milliseconds. LF=Low Frequency, HF=High Frequency, LC=Low Constraint, HC=High Constraint.

Discussion

The WILC and frequency of target words was manipulated in a visual lexical decision experiment. Main effects of constraint and frequency were observed. Participants' reaction times were shorter in response to LC words compared to HC words. This may be due to the initial trigram of an LC word being shared with a large number of other words. When presented with an LC word, the initial trigram may activate a large set of candidate words, therefore facilitating the "word" response. Participants' response times were faster in response to HF words than LF words. No statistically significant interaction was observed between the two (despite qualitative suggestions otherwise).

It may be the case that there is an interactive relationship between WILC and frequency, but this effect does not manifest itself in visual lexical decision times. Displaying words in isolation in a visual lexical decision experiment removes two important factors in written language processing – parafoveal preview and contextual predictability information. Words preceded by a biasing context are processed faster than those in a neutral context. In Lima and Inhoff's (1985) study, target words were mainly LF words embedded in neutral contexts. Prior research, however, has demonstrated increased parafoveal preview benefit to HF versus LF words (Inhoff & Rayner, 1986) as well as to contextually predictable versus less predictable words (Balota et al., 1985). *Experiment 4b* implemented a 2 (WILC: HC, LC) × 2 (Frequency: HF, LF) × 2 (Context: Biasing, Neutral) design in order to determine the simultaneous effects of these factors on eye movements during normal reading. As parafoveal preview is modulated by frequency and contextual predictability, it is possible that HC words will, in fact, show a processing advantage over LC words when favourable parafoveal preview conditions are present. Accordingly, an interaction between Constraint and Frequency and/or Constraint and Context was expected to be found. In line with Lima and Inhoff's (1985) findings, *longer* fixations on HC vs. LC words for LF targets in Neutral contexts were anticipated. However, *shorter* fixations were predicted on HC vs. LC words for HF targets, for targets in Biasing contexts, or, minimally, for HF targets in Biasing contexts.

Experiment 4b

Method

Participants

Forty-eight members of the University of Glasgow community (30 females; mean age 23) were paid £6 or given course credit for their participation. All were native English speakers with normal or corrected-to-normal vision and had not been diagnosed with any reading disorder.

Apparatus

Eye movements were monitored via an SR Research Desktop-Mount EyeLink 2K eyetracker, with a chin/forehead rest. The eyetracker has a spatial resolution of 0.01^{o} and eye position was sampled at 1000 Hz using corneal reflection and pupil tracking. Text (black letters on a white background, using 14-point Bitstream Vera Sans Mono, a non-proportional font) was presented on a Dell P1130 19" flat screen CRT (1024 × 768 resolution; 100 Hz). At a viewing distance of 72 cm, approximately 4 characters of text subtended 1^{o} of visual angle. Viewing was binocular with eye movements recorded from the right eye.

Design and Materials

A 2 (Constraint: HC, LC) × 2 (Frequency: HF, LF) × 2 (Context: Biasing, Neutral) design was used. All target words were 5 letters long. With a total of 88 experimental items, there were 11 items in each of the 8 conditions. All experimental passages are listed in **Appendix VI**. An example set of materials, showing all 8 target conditions, is presented in Table 5.3. Target words were always positioned near the middle of a line of text. Because each participant only read a given target word in one of its Context conditions (Neutral or Biasing), two participant groups were used. One group read half of the materials in Neutral and the other half in Biasing contexts; the second group read the materials in their opposing context conditions. In addition, experimental items were blocked by Context condition, with all Neutral materials presented first followed by all Biasing materials. Within each block, experimental items were presented in a different random order to each participant. Stimulus specifications across conditions are presented in Table 5.4.

Table 5.3. Example Materials – *Experiment 4b*

Condition		Example
Neutral context		
LF	LC	He had enjoyed being a clown but it was time to retire.
	HC	In gym class, he felt like a dwarf next to his classmates.
HF	LC	He bought tickets for the train to Waterloo on the internet.
	HC	She wanted to talk to the girls about the incident.
Biasing context		
LF	LC	Pierre had entertained kids at the circus for fifty years. He had enjoyed being a clown but it was time to retire.
	HC	Jamie loved basketball but he was very short for his age. In gym class, he felt like a dwarf next to his classmates.
HF	LC	Stuart did not want to travel to London by bus or plane. He bought tickets for the train to Waterloo on the internet.
	HC	At school, Miss Jones told only the boys to leave early. She wanted to talk to the girls about the incident.

Note: LF=Low Frequency, HF=High Frequency, LC=Low Constraint, and HC=High Constraint.

Table 5.4. Stimulus Specifications across Experimental Conditions – *Experiment 4b*

	LF		HF	
Measure	LC	HC	LC	HC
N	22	22	22	22
Length	5	5	5	5
Frequency	8	10	86	90
Number of Neighbours				
5-letter	19	1	18	4
x-letter	187	15	238	44
% of Trigram Neighbourhood				
5-letter	5%	95%	15%	96%
x-letter	1%	39%	5%	33%
Cloze				
Neutral	0.03	0.04	0.04	0.03
Biasing	0.64	0.61 .	0.64	0.60
Predictability rating				
Neutral	3.70.	3.43	4.21	3.98
Biasing	5.87	5.76	6.01	5.92

Note. LF=Low Frequency, HF=High Frequency, LC=Low Constraint, HC=High Constraint, N=number of items, Length=average word length (number of letters), Frequency=average frequency of occurrence (per million), Number of Neighbours=average number of trigram neighbours for 5-letter or *x*-letter (any length) words, % of Trigram Neighbourhood=average word frequency percentage that each target represents of its 5-letter or *x*-letter trigram neighbourhood, Cloze=average Cloze value of target, on a scale of 0 (target word not guessed) to 1 (target word correctly guessed), Predictability Rating=average predictability rating of target in text, on a scale of 1 (highly unpredictable) to 7 (highly predictable), Neutral=neutral context condition (target sentence only), and Biasing=biasing context condition (context plus target sentence).

Constraint. Half of the target words had HC and half had LC initial trigrams. Constraint was determined by the following measures. First, for each (5-letter) target, we computed the number of other 5-letter words as well as the number of words of any length (*x*-letter words) which shared the same initial trigram. Second, we calculated the percentage that each target represented of its trigram neighbourhood, both for 5-letter words and for *x*-letter words. This involved dividing each target word's frequency of occurrence by the summed frequency of all 5- or *x*-letter words (including the target) that shared a given trigram. To determine the neighbourhood profiles for *x*-letter words, we used the Brigham Young University BNC on-line resource (http://corpus.byu.edu/bnc; Davies, 2004). Average values for each of these measures across conditions are presented in Table 5.4, individual values for each target word are presented in **Appendix VII**. Overall, HC words had far fewer 5- and *x*-letter trigram neighbours and they accounted for a far greater percentage (in terms of word frequency) of their 5- and *x*-letter trigram neighbourhoods compared to LC words.

Frequency. In addition, half of the targets were HF and half were LF words. Word frequencies were obtained using the 90-million written word British National Corpus (BNC; http://www.natcorp.ox.ac.uk). Mean frequencies were 88 occurrences per million for HF targets and 9 occurrences per million for LF targets (see Table 5.4). Individual target word frequencies are presented in **Appendix VII**.

Predictability. Finally, half of the targets were presented in a Neutral context and half in a Biasing context. As illustrated in Table 5.3, Neutral conditions comprised one single-line sentence. Biasing conditions, however, comprised two single-line sentences: for a given target, the first sentence contained contextually biasing information for that word; the second sentence was the Neutral sentence in which the target was embedded. In this way, biasing information was established in and confined to the first of two sentences. In addition, the identical sentence containing the target could be used across the Neutral and Biasing context conditions (between participant groups).

The level of contextual predictability was determined by two norming tasks – a Cloze probability task and a predictability rating task. In the Cloze task, 26 participants (none of whom participated in the main experiment or the predictability rating task) were given each experimental item up to but not including the target word. Their task was to generate the next word in the sentence. Items were scored as "1" for correct responses and "0" for all other guesses. A 2 (Constraint: HC, LC) × 2 (Frequency: HF, LF) × 2 (Context: Biasing, Neutral) ANOVA on Cloze probabilities by items (F_2) revealed, as expected, a main effect of Context, with more targets generated in Biasing (.62) than in Neutral (.04) contexts (see Table 5.4) [$F_2(1,21)=991.25$, $MSE=.02$, $p<.001$]. No other main effects or interactions were significant [all F_2s<1]. Cloze values for each target passage in each of its forms are available in **Appendix VII**.

In the predictability rating task, the materials were divided into two sets and were presented to two participant groups to avoid repetition of the target sentence in Neutral vs. Biasing conditions. Two groups of 13 participants (again, none of whom participated in the main experiment or Cloze task) were presented with each item in its entirety with the target word underlined. Ten percent of the materials were non-experimental filler items (one- and two-line texts) that were clearly anomalous. The participants' task was to indicate how predictable they considered the target word to be on a scale of 1 (highly unpredictable) to 7 (highly predictable). A 2 (Constraint: HC, LC) × 2 (Frequency: HF, LF) × 2 (Context: Biasing, Neutral) ANOVA on predictability ratings by items (F_2) revealed, as expected, a main effect of Context, with targets rated more predictable in Biasing (5.89) than in Neutral (3.83) contexts (see Table 5.4) [$F_2(1,21)=590.73$, $MSE=.32$, $p<.001$]. The relatively high ratings of targets in Neutral contexts reflected the fact that they were designed to be *less* predictable (and not implausible or anomalous) compared to targets in Biasing contexts. The main effect of Frequency, although numerically small, was also significant, with higher ratings for HF (5.03) than for LF (4.69) targets [$F_2(1,21)=4.64$, $MSE=1.08$, $p<.001$]. Most likely, this reflects the underlying fact that HF words are, by definition, more likely to occur than LF words within any context. The main effect of Constraint was not significant [$F_2(1,21)=2.45$, $MSE=.55$, $p=.132$], nor were any of the interactions [Frequency × Predictability: $F_2(1,21)=1.51$, $MSE=1.04$, $p>.20$; Constraint × Frequency, Constraint × Predictability, and Constraint x Frequency x Predictability: all F_2s<1]. Predictability ratings of each experimental passage are presented in **Appendix VII**.

Procedure

Participants were given written and verbal instructions about the eyetracking task. They were told to read for comprehension, as they would normally, and that questions would appear after half of the trials to ensure they were paying attention. The experiment involved the initial calibration of the eyetracking system, reading 5 practice 1-line (Neutral) sentences, recalibration, reading the 44 Neutral experimental sentences, recalibration, reading 5 practice 2-line (Biasing) passages, recalibration, and reading the 44 Biasing experimental passages. The 9-point calibration display comprised a series of calibration points extending over the maximal horizontal and vertical range of the display. After participants fixated each point in a random order, the accuracy of the calibration was checked (validation). The experiment proceeded only when the calibration was highly accurate (average error $<.30^{o}$; maximal error on any one point $<.50^{o}$). If necessary, participants could be recalibrated at any time during the experiment.

Each trial began with a black square which corresponded to the position of the first letter of the experimental item. An accurately calibrated fixation at this location triggered the presentation of the item. After reading each item, participants moved their eyes to the lower, right corner of the screen and pressed a button to clear the screen. On half of the trials, a Yes-No comprehension question followed. Participants had no difficulty in answering these questions correctly (average over 92% correct). Prior to each new trial, participants were required to fixate a central point allowing the experimenter to implement a drift-correction routine.

Results

The target region comprised the space before the target word and the target itself. Lower and upper cut-off values for individual fixations were 100 and 750 ms, respectively. Data were additionally eliminated if there was a blink or track loss on the target, or if the fixation on the target was either the first or last fixation on a line. Overall, 2% of the data were excluded for these reasons. In reading, most content words are generally fixated once – sometimes words are immediately refixated, sometimes they are skipped altogether. In the present study, the percentages of data for single fixation, immediate refixation, and skipping of the target were 67, 7, and 24%, respectively.

The resulting data were analyzed over a number of standard fixation time measures on the target word: (a) FFD; (b) SFD; (c) GD; and (d) TT. Several other commonly used measures were examined: (e) the duration of the next forward-going fixation from the target (T+1) as a measure of processing spillover; (f) the duration of the pre-target fixation (T–1; the last fixation before the target) as a measure of parafoveal pre-processing of the target; (g) the probability of making a first-pass fixation on the target (PrF); and (h) the landing position (LandPos) or location of the first fixation on the target. The average values across all measures are presented in Table 5.5. FFD, SFD, as well as PrF represent first-pass, more immediate measures of processing, whereas TT and T+1 represent relatively delayed, later stages of target word processing since these measures include fixations that occur after the initial fixation on the target. With respect to LandPos, although it represents fixation location on the target, itself, the saccade target is determined from the pre-target fixation (e.g., McConkie, Kerr, Reddix, & Zola, 1988; Rayner et al., 1996). As the majority of target word fixations were single fixations, SFD condition means, including standard error bars, are displayed in Figure 5.3. For all measures, 2 (Constraint: HC, LC) × 2 (Frequency: HF, LF) × 2 (Context: Biasing, Neutral) ANOVAs were conducted both by F_1 and F_2. A summary of all main effects is presented in Table 5.6 and the interactions across all measures is presented in Table 5.7.

Table 5.5 Means (Standard Deviations) of Fixation Time Measures, Fixation Probability, and Landing Position across Conditions

		LF		HF	
Measure	Context	LC	HC	LC	HC
FFD	Neutral	204 (32)	194 (32)	195 (26)	187 (23)
	Biasing	189 (29)	189 (29)	182 (29)	180 (25)
SFD	Neutral	207 (38)	196 (41)	197 (28)	189 (24)
	Biasing	190 (31)	189 (29)	183 (29)	179 (25)
GD	Neutral	223 (47)	208 (46)	206 (30)	201 (35)
	Biasing	201 (36)	196 (32)	188 (29)	184 (26)
TT	Neutral	261 (64)	234 (75)	233 (43)	223 (47)
	Biasing	212 (42)	204 (31)	207 (35)	196 (32)
T+1	Neutral	216 (33)	201 (34)	207 (35)	202 (32)
	Biasing	199 (27)	198 (28)	199 (30)	191 (27)
T–1	Neutral	202 (31)	191 (31)	193 (28)	191 (25)
	Biasing	191 (27)	190 (27)	188 (24)	181 (20)
PrF	Neutral	.82 (.14)	.79 (.16)	.86 (.14)	.80 (.15)
	Biasing	.71 (.19)	.69 (.19)	.66 (.21)	.67 (.20)
LandPos	Neutral	2.81 (.62)	2.64 (.54)	2.78 (.59)	2.63 (.57)
	Biasing	2.82 (.68)	2.88 (.63)	2.86 (.58)	3.02 (.56)

Note. FFD=first fixation duration, SFD=single fixation duration, GD=gaze duration, TT=total fixation time, T+1=next forward-going fixation from target, T–1=pre-target fixation duration, PrF=probability of target fixation, LandPos=landing position on target, LF=low frequency, HF=high frequency, LC=low constraint, and HC=high constraint.

Figure 5.3. Single fixation duration (ms) on target words as a function of Constraint (LC, HC), Frequency (LF, HF), and Context (Neutral, Biasing).

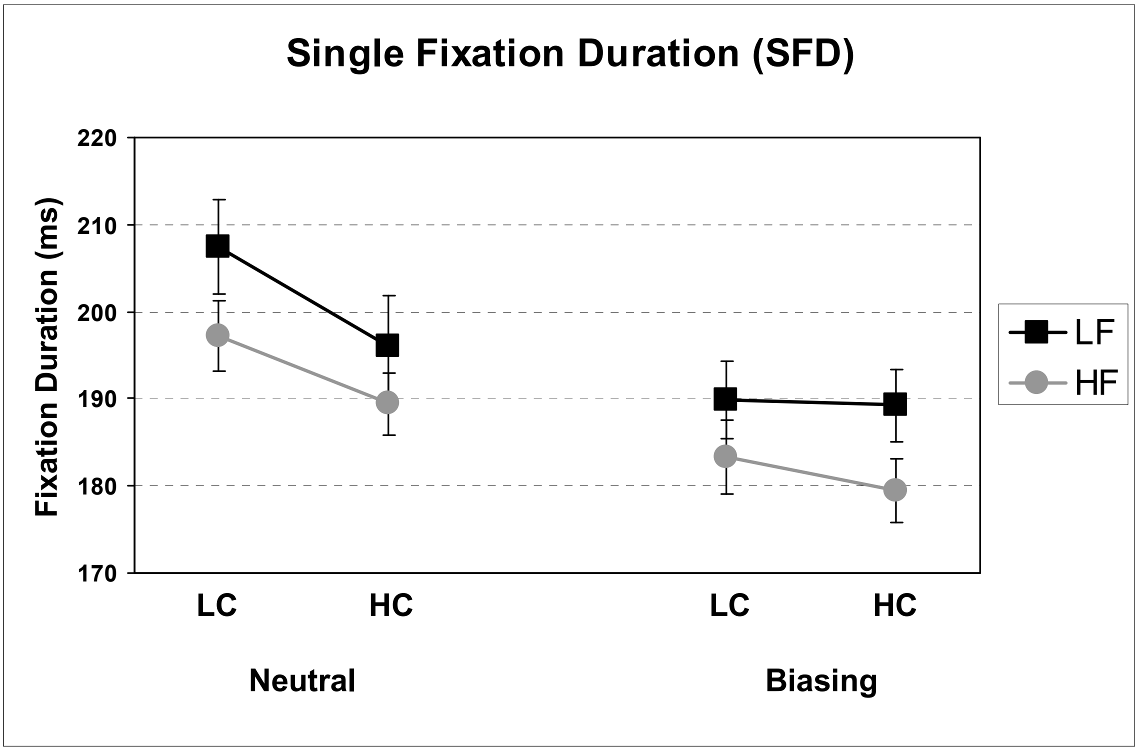


Table 5.6 Main Effects by Participants (F_1) and by Items (F_2) on All Measures

<u>Constraint</u>	<u>F_1</u>	<u>*MSE*</u>	<u>*p*</u>	<u>F_2</u>	<u>*MSE*</u>	<u>*p*</u>
FFD	7.56	357	<.01	5.31	242	<.05
SFD	7.38	453	<.01	4.46	321	<.05
GD	12.87	411	<.001	5.25	500	<.05
TT	15.51	1267	<.001	15.74	675	<.001
T+1	20.73	248	<.001	11.37	211	<.01
T–1	12.46	240	<.001	7.86	173	<.05
PrF	3.98	.02	=.052	1.94	.02	>.15
LandPos	<1			<1		
<u>Frequency</u>	<u>F_1</u>	<u>*MSE*</u>	<u>*p*</u>	<u>F_2</u>	<u>*MSE*</u>	<u>*p*</u>
FFD	12.75	451	<.001	11.49	276	<.01
SFD	12.57	532	<.001	9.13	304	<.01
GD	21.25	682	<.001	13.34	537	<.01
TT	11.15	1454	<.01	12.82	608	<.01
T+1	3.97	331	=.052	3.48	191	=.076
T–1	8.12	291	<.01	6.46	180	<.05
PrF	<1			<1		
LandPos	<1			1.03	.18	>.30

Context	F_1	*MSE*	*p*	F_2	*MSE*	*p*
FFD	16.89	610	<.001	30.53	139	<.001
SFD	20.42	688	<.001	32.48	132	<.001
GD	24.30	1191	<.001	38.65	304	<.001
TT	41.51	2531	<.001	77.98	612	<.001
T+1	16.74	527	<.001	19.71	216	<.001
T–1	9.30	480	<.01	12.72	157	<.01
PrF	96.04	.02	<.001	65.15	.01	<.001
LandPos	10.18	.30	<.01	11.62	.12	<.01

Note. FFD=first fixation duration, SFD=single fixation duration, GD=gaze duration, TT=total fixation time, T+1=next forward-going fixation from target, PrF=probability of target fixation, and LandPos=landing position on target. Degrees of freedom are $F_1(1,47)$ and $F_2(1,21)$.

Table 5.7 Interactions by Participants (F_1) and by Items (F_2) on All Measures

Constraint × Frequency	F_1	*MSE*	*p*	F_2	*MSE*	*p*
FFD	<1			<1		
SFD	<1			<1		
GD	1.40	465	>.20	1.00	570	>.30
TT	1.19	1170	>.25	<1		
T+1	<1			<1		
T–1	<1			<1		
PrF	<1			<1		
LandPos	<1			<1		
Constraint × Context	F_1	*MSE*	*p*	F_2	*MSE*	*p*
FFD	4.63	321	<.05	4.56	154	<.05
SFD	3.35	391	=.074	4.74	174	<.05
GD	1.69	557	>.15	<1		
TT	1.65	1062	>.20	1.20	730	>.25
T+1	1.66	456	>.20	1.87	198	>.15
T–1	<1			<1		
PrF	2.04	.02	>.15	1.02	.01	>.30
LandPos	4.96	.35	<.05	2.77	.18	=.11
Frequency × Context	F_1	*MSE*	*p*	F_2	*MSE*	*p*
FFD	<1			<1		
SFD	<1			<1		
GD	<1			<1		
TT	4.98	820	<.05	1.65	1177	>.20
T+1	<1			<1		
T–1	<1			<1		
PrF	4.87	.02	<.05	4.75	.01	<.05
LandPos	<1			2.05	.12	>.15

Constraint × Frequency × Context	F_1	*MSE*	*p*	F_2	*MSE*	*p*
FFD	<1			<1		
SFD	<1			<1		
GD	<1			<1		
TT	1.99	1387	>.15	<1		
T+1	5.21	374	<.05	4.19	228	=.053
T–1	4.31	316	<.05	3.19	204	=.089
PrF	1.19	.02	>.25	1.25	.01	>.25
LandPos	<1			<1		

Note. FFD=first fixation duration, SFD=single fixation duration, GD=gaze duration, TT=total fixation time, T+1=next forward-going fixation from target, PrF=probability of target fixation, and LandPos=landing position on target. Degrees of freedom are $F_1(1,47)$ and $F_2(1,21)$.

Main effects

Constraint. In each of the fixation time measures (FFD, SFD, GD, TT, T+1, and T–1), there was a significant main effect of Constraint (see Table 5.6). In contrast to Lima and Inhoff's (1985) earlier findings, HC words were fixated for *less* time than LC words (HC vs. LC: 187 vs. 193 ms for FFD, 189 vs. 194 ms for SFD, 197 vs. 205 ms for GD, 214 vs. 228 ms for TT, 198 vs. 205 ms for T+1; and 188 vs. 194 ms for T–1). For PrF, although the effect was not significant (marginal by participants, non-significant by items; See Table 5.6), the direction of the numerical effect was consistent with the fixation time results, with HC words (.74) less likely to be fixated than LC words (.76). Finally, the main effect of Constraint for LandPos was not significant.

Frequency. The main effect of Frequency (see Table 5.6) was significant across all target fixation time measures (FFD, SFD, GD, TT) and the pre-target T–1 measure, but only marginally significant (both by participants and items) in the post-target T+1 measure. In line with numerous eye movement studies on word frequency, HF words were associated with shorter fixations than LF words (HF vs. LF: 186 vs. 194 ms for FFD, 187 vs. 196 ms for SFD, 195 vs. 207 ms for GD, 215 vs. 228 ms for TT, 200 vs. 204 ms for T+1, and 188 vs. 193 ms for T–1). There was no reliable effect in the PrF and LandPos measures.

Context. The main effect of Context (see Table 5.6) was significant across all measures, including fixation probability and landing position (FFD, SFD, GD, TT, T+1, T–1, PrF, and LandPos). Again, similar to several eye movement studies investigating predictability, targets in Biasing contexts were fixated for less time than those in Neutral contexts (Biasing vs. Neutral: 185 vs. 195 ms for FFD, 185 vs. 198 ms for SFD, 192 vs. 210 ms for GD, and 205 vs. 238 ms for TT,), were less likely to be fixated (Biasing vs. Neutral: .68 vs. .82 for PrF), and were associated with shorter pre- and post-target fixations (197 vs. 207 ms for T+1, and 188 vs. 194 ms for T–1). For LandPos, readers fixated further into targets when they were more predictable (Biasing vs. Neutral: 2.89 vs. 2.72 characters).

Interactions

Although the interactions, in general, tended to be non-significant, there were a few exceptions (see Table 5.7).

Constraint × Frequency. The Constraint × Frequency interaction was not significant across any measure.

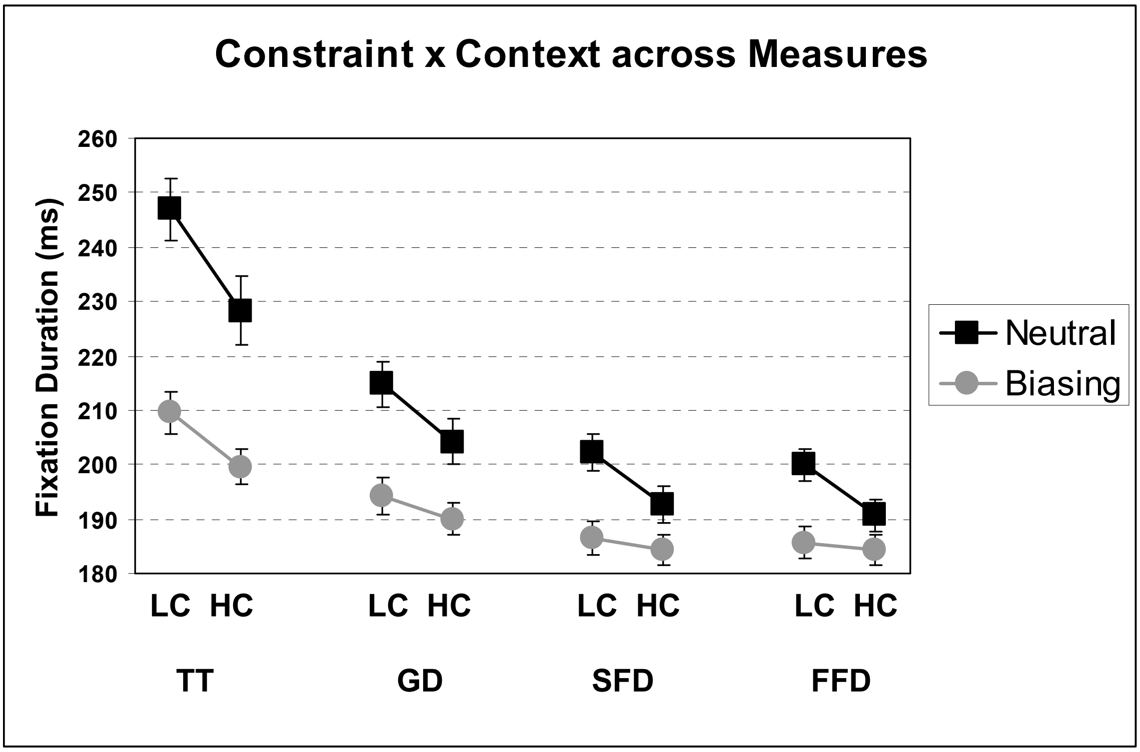
Constraint × Context. Constraint × Context, however, did reach significance in the more immediate fixation time measures of FFD and SFD (although this effect was marginal by participants in SFD; See Table 5.7) and, for LandPos, was significant by participants but only a statistical trend by items. In all other measures (GD, TT, T+1, T–1, and PrF), Constraint × Context failed to reach significance. For LandPos, although the numerical means suggested an opposing pattern of results, with landing positions for HC words nearer word beginnings in Neutral contexts (HC=2.64 and LC=2.80

characters), but nearer word endings in Biasing contexts (HC=2.95 and LC=2.84 characters), this pattern was not maintained statistically.

Rather, the follow-up contrasts in general were more supportive of an interpretation in which the landing position for HC-Neutral targets (2.64 characters) was nearer the beginning of the word compared to the other three conditions (2.80, 2.95, and 2.84 characters for LC-Neutral, HC-Biasing, and LC-Biasing, respectively) [HC-Neutral vs. LC-Neutral: F_1=3.55, p=.066, F_2=2.14, p=.158; HC-Neutral vs. HC-Biasing: F_1=13.42, p<.001, F_2=9.68, p<.01; HC-Biasing vs. LC-Biasing: F_1=1.60, p>.20, F_2<1; LC-Neutral vs. LC-Biasing: all Fs<1].

For FFD and SFD, follow-up contrasts revealed significant differences between LC-Neutral and LC-Biasing conditions [FFD: F_1=6.19, p<.05, F_2=4.84, p<.05; SFD: F_1=8.68, p<.01, F_2=3.88, p=.062], HC-Neutral and HC-Biasing conditions [FFD: F_1=30.59, p<.001, F_2=27.25, p<.001; SFD: F_1=30.62, p<.001, F_2=25.48, p<.001], LC-Neutral and HC-Neutral conditions [FFD: F_1=12.76, p<.001, F_2=12.62, p<.01; SFD: F_1=11.29, p<.01, F_2=12.73, p<.01], but not between LC-Biasing and HC-Biasing conditions [all Fs<1]. In sum, while the effect of Context was maintained for both LC and HC words, the effect of Constraint was only upheld in Neutral contexts. In Figure 5.4, we plotted the Constraint × Context data (collapsed across Frequency) over the different fixation time measures, from the longest to the shortest duration (TT, GD, SFD, FFD). It seems that the interaction in the early SFD and FFD measures may actually arise from floor effects. That is, fixation times in HC-Biasing conditions just cannot get any faster (See **Chapter 2** – Discussion and **Chapter 6** for further discussion of floor and ceiling effects).

Figure 5.4. Interaction between Constraint (LC, HC) and Context (Neutral, Biasing) across fixation time measures, from longest to shortest: TT, GD, SFD, and FFD.



Frequency × Context. With respect to Frequency × Context, the results of *Experiment 4b* confirmed those of past eye movement studies which typically demonstrate a lack of interaction in fixation times but the presence of one in PrF (e.g., *Experiment 1*, main analyses; *Experiment 2*, VLP vs. MP global analyses; Rayner et al., 2004; but cf. *Experiment 1* – conditionalised analyses, *Experiment 2* – VHP vs. VLP main analyses, *Experiment 2* – VLP vs. MP conditionalised analyses, and *Experiment 2* – VHP vs. VLP conditionalised analyses). With the exception of TT, in which the interaction was only significant by participants, all other measures (FFD, SFD, GD, T+1, T–1, and LandPos) failed to show an interaction. For the reliable interaction in PrF, follow-up contrasts were significant for LF-Neutral versus LF-Biasing [F_1=32.67, p<.001, F_2=32.02, p<.001] and HF-Neutral versus HF-Biasing [F_1=78.07, p<.001, F_2=76.42, p<.001], were not significant for LF-Neutral versus HF-Neutral [F_1=1.67,

p>.20, F_2=1.59, p>.20], and were only marginally significant for LF-Biasing versus HF-Biasing [F_1=3.34, p=.074, F_2=3.32, p=.083]. Thus, Biasing contexts gave rise to a lower likelihood of fixating the target (or an increased probability of skipping it), and when the target was additionally HF, these effects were enhanced. This pattern of differences stands in partial contrast to prior research which has found fewer fixations (or increased skipping) only in the combined condition of high predictability and high frequency (*Experiment 1*, main analyses; Rayner et al., 2004; but cf. *Experiment 3*, median split analyses).

Constraint × Frequency × Context. Finally, the three-way interaction was significant (although marginal by items) in both pre-target measures, T–1 and T+1 (see Table 5.7). All other measures (FFD, SFD, GD, TT, PrF, and LandPos) failed to demonstrate an interaction. Follow-up contrasts for T–1 and T+1 revealed similar effects, with Neutral and Biasing contexts producing distinct patterns (for condition means, see Table 5.5). In general, in Neutral contexts, pre- and post-target fixations were longer with LF-LC words (e.g., *clown*) compared to any other condition; in Biasing contexts, pre-and post-target fixations were shorter with HF-HC words (e.g., *girls*) relative to the other conditions. For T–1 in Neutral contexts, the three contrasts involving the LF-LC condition were significant by participants and items [LF-LC vs. LF-HC / HF-LC / HF-HC: all Fs>4.50, ps<.05]. The remaining Neutral conditions did not differ from each other [LF-HC vs. HF-LC vs. HF-HC: all Fs<1]. For T–1 in Biasing contexts, the three contrasts involving the HF-HC condition were significant by participants but marginal in two of the items contrasts [HF-HC vs. LF-LC / LF-HC / HF-LC: all F_1s>4.45, p_1s<.05; all F_2s>3.00, p_2s<.10]. The remaining Biasing conditions did not differ from each other [LF-LC vs. LF-HC vs. HF-LC: all Fs<1]. An identical pattern of means was obtained in T+1, although the results tended to be less reliable.

For T+1 in Neutral contexts, the three contrasts involving the LF-LC condition were significant by participants and items [LF-LC vs. LF-HC / HF-LC / HF-HC: all *F*s>4.75, *p*s<.05]. The remaining Neutral conditions did not differ from each other [LF-HC vs. HF-LC vs. HF-HC: all *F*s<1.80, *p*s>.15, except LF-HC vs. HF-LC with F_1=2.58, *p*=.115]. For T+1 in Biasing contexts, the contrasts involving the HF-HC condition were largely significant by participants (significant in two, marginal in one), but marginal at best by items (marginal in two, trend in one) [HF-HC vs. LF-LC / LF-HC / HF-LC: all F_1s>3.35, p_1s<.08; all F_2s>2.47, p_2s<.13]. The remaining Biasing conditions did not differ from each other [LF-LC vs. LF-HC vs. HF-LC: all *F*s<1].

Summary The overall pattern of results across all measures (FFD, SFD, GD, TT, T+1, T–1, PrF, and LandPos), with a few notable exceptions detailed below, generally showed main effects of Constraint, Frequency, and Context with no interactions. For the main effects of Constraint and Frequency, with the exception of PrF and LandPos, all measures showed reliable facilitation for HC over LC and for HF over LF words, respectively. For the main effect of Context, all measures, including PrF and LandPos, showed significant facilitation in Biasing versus Neutral conditions. In terms of the interactions, Constraint × Frequency was statistically unreliable. Constraint × Context generally reached significance (exceptions noted) in only three measures – LandPos (trend by items), FFD, and SFD (marginal by participants). However, the interaction in the early FFD and SFD measures seemed to be the result of a floor effect impeding HC-Biasing conditions. The Frequency × Context interaction was only reliable in the PrF measure (TT was significant by participants but non-significant by items), replicating prior eye movement studies. Target words were more likely to be skipped when they were in Biasing contexts with an additional (marginal) advantage when the target was HF versus LF. Finally, the Constraint × Frequency × Context was significant (marginal by items) only in T–1 and T+1. Although some of the follow-up contrasts were marginal, in general, the longest pre- and post-target fixations occurred with LF-LC words in Neutral contexts and the shortest with HF-HC words in Biasing contexts, a pattern that substantiated the underlying main effects of Constraint, Frequency, and Context.

Discussion

Experiment 4b was carried out in order to investigate whether there was a difference in processing words beginning with LC initial trigrams (e.g., *clown*), having numerous trigram neighbours, versus those with HC initial trigrams (e.g., *dwarf*), having few trigram neighbours. Previous work by Lima and Inhoff (1985) had found, contrary to their own predictions, that LC words received shorter fixations than HC words, but only in the FFD measure. In their study, however, LC and HC words were LF words embedded in Neutral contexts. *Experiment 4b* additionally manipulated the word frequency (LF vs. HF) of LC and HC targets as well as their predictability (Neutral vs. Biasing preceding context). It was expected that Lima and Inhoff's findings would be replicated in the LF-Neutral condition, with LC words fixated for less time than HC words. However, in HF, Biasing, and/or HF-Biasing conditions, it was expected that HC words might demonstrate a processing advantage over LC words. If, as prior research has demonstrated, parafoveal processing is facilitated for words that are HF (Inhoff & Rayner, 1986) or predictable (Balota et al., 1985), then it seemed probable that HC words in these conditions would show a processing benefit relative to LC words. In general, the findings of *Experiment 4b* showed that, regardless of target frequency or predictability, HC words were reliably fixated for *less* time than LC words.

These findings are reviewed within the context of a time-course framework, delineating the effects in terms of pre-target (T–1, PrF, and LandPos), target (FFD, SFD, and GD) and post-target (T+1 and TT) measures. Further analyses are then provided in an attempt to address possible methodological concerns with *Experiment 4b*, before returning to Lima and Inhoff's (1985) study to discuss differences in methods that may have led to their different pattern of results. Finally, recent eye movement studies investigating issues related to word-initial letter constraint whose results are more consistent with our findings are examined.

Patterns of effects

Pre-target effects Pre-target fixation duration effects have been a focus of several recent eye movement studies, with both positive and null effects reported (e.g., **Chapter 2** – *Experiment 1*; Drieghe, Brysbaert, & Desmet, 2005; Drieghe et al., 2008; Inhoff, Eiter, & Radach, 2005; Kennedy, 2008; Kennedy & Pynte, 2005; Kliegl et al., 2006; Miellet et al., 2009; Rayner, Warren, Juhasz, & Liversedge, 2004). Such effects are termed "parafoveal-on-foveal" effects because characteristics of the (parafoveal) target can begin to emerge in fixation time on the pre-target (foveal) word, before the target is directly fixated. There is no question that information about the upcoming parafoveal word is obtained prior to its fixation. The issues of debate, however, concern (1) the level of parafoveal pre-processing (whether it is limited to lower-level, perceptual analysis or can extend to higher-level, semantic activation); and (2) the implications for models of eye movement control in reading (whether visual attention is allocated in a serial or parallel manner which, consequently, determines if parafoveal information can affect the duration of the current fixation). In *Experiment 4b*, pre-target fixations (T–1) demonstrated sensitivity to the target word's constraint, frequency, and predictability, with shorter durations when the parafoveal target was HC, HF, or in a

Biasing context. The three-way interaction (marginal by items) showed, in Neutral contexts, a relative disadvantage to LF-LC parafoveal targets and, in Biasing contexts, a relative advantage to HF-HC parafoveal targets. Although such effects apparently support the notion of parafoveal-on-foveal processing at a deep level, firm conclusions on this matter are eschewed. The aim of *Experiment 4b* was not to investigate parafoveal-on-foveal processing. As such, pre-target text across conditions was not carefully controlled (e.g., use the same sentence frame for multiple targets, or insure that targets were preceded by content words of average length). This issue will be revisited when launch site (i.e., the location of the pre-target fixation) is examined for its influence on target fixation duration.

For PrF, readers were more likely to skip targets that were HC (vs. LC) or were embedded in a Biasing (vs. Neutral) context. Although there was no main effect of Frequency, there was a Frequency × Context interaction. The pattern of effects, in general, replicated past studies (**Chapter 2** – *Experiment 1*; Rayner et al., 2004) in which HF-Biasing targets were skipped more often than targets in the other conditions.

For LandPos, readers' fixation location on the target (determined from the pre-target fixation) was further into the word in Biasing (vs. Neutral) contexts. Although some eye movement studies show similar findings (e.g., Kennedy, Murray, Boissiere, 2004; Lavigne, et al., 2000; McDonald & Shillcock, 2003a), others do not (e.g., Rayner et al., 2001; Vainio, Hyönä, & Pajunen, 2009). The only other effect was a Constraint × Context interaction (significant by participants, trend by items), which generally showed that landing position within HC-Neutral words were further to the left than those in the other conditions.

Target effects. The three target fixation time measures (FFD, SFD, and GD) all exhibited a significant effect of Constraint, with shorter fixation times associated with HC (vs. LC) targets. The other main effects of Frequency and Context were also significant, replicating past eye movement studies that demonstrate an advantage for HF versus LF words and for words in Biasing versus Neutral contexts, respectively. The lack of a Frequency × Context interaction also replicated past studies. The only significant interaction was Constraint × Context in the earlier FFD and SFD measures (although marginal by participants in SFD), showing a null effect of Constraint selectively in Biasing contexts. It is suggested, however, that the lack of any difference here was most likely due to a floor effect in which individual fixation times on words in the HC-Biasing condition had reached their lower limit.

Post-target effects. Refixations on the target made after first leaving the target only contributed to 6% of the total possible data. Thus, TT effects tended to be similar to those of GD, demonstrating main effects of Constraint, Frequency, and Context. The only difference was a Frequency × Context interaction that was significant by subjects but not by items, a result similar to that reported in *Experiment 1*.

T+1 also showed main effects of Constraint, Frequency (marginal by participants and items), and Context. As with T–1, there was a 3-way interaction (significant by participants, marginal by items). The pattern of results from the follow-up contrasts (several of which were statistically marginal) revealed increased processing spillover in the LC-LF-Neutral condition and decreased spillover in the HC-HF-Biasing condition, the "hardest" and "easiest" conditions, respectively, as defined by the direction of main effects.

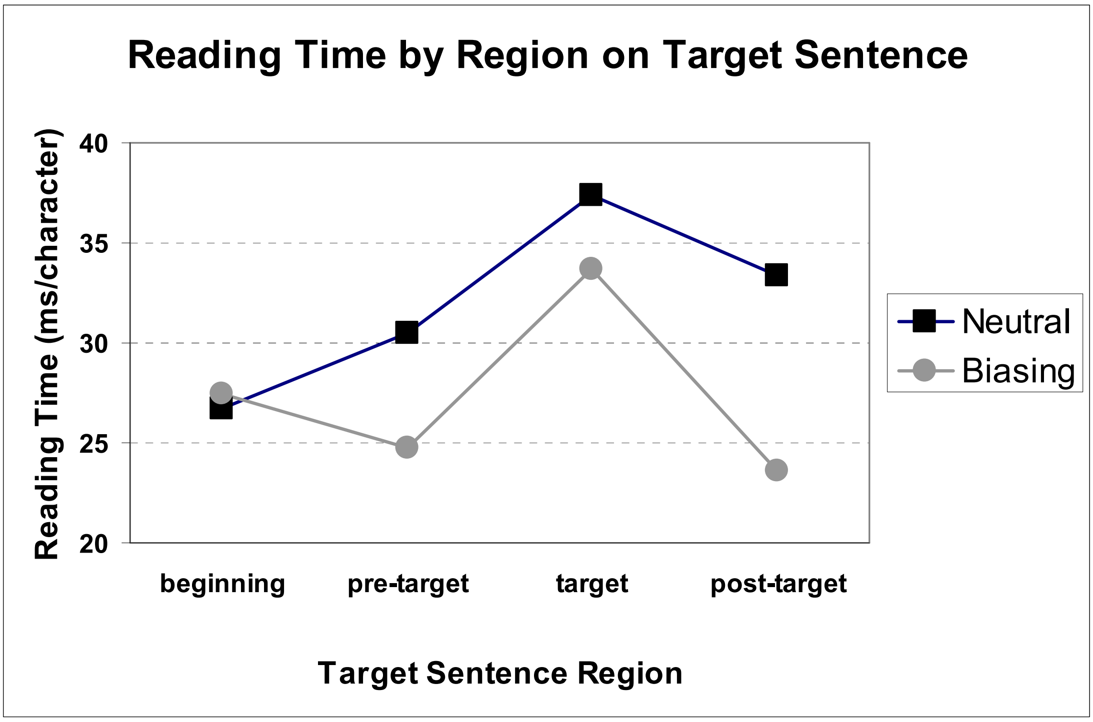
Further analyses

There are two issues with *Experiment 4b* that demand further attention. The first is related to the experimental method, the second to the interpretation. A potential confound of this study was that Neutral, single-line sentences were always presented as a first block, followed by a second block of Biasing, two-line materials. This approach was adopted for several reasons. It was thought that having the Neutral materials first would enable a more cautious comparison to Lima and Inhoff's (1985) original study which involved only single-line sentences. It was also thought that it would be less confusing to the participants if similar materials were presented together. Finally, it was considered that presenting the Biasing materials first may have induced participants to engage in different strategies when subsequently presented with Neutral materials. At the outset, construction of "empty" contexts to be presented as the first sentence for our Neutral materials was begun, and it had been intended to randomized all materials within a single block. However, the "empty" contexts generally served to introduce a certain degree of incoherence. Nevertheless, the issue remains that if participants tend to speed up over the course of the experiment, it is possible that our effect of Context may be due to practice effects and not our manipulation.

In general, it is not thought that the Context effect observed in *Experiment 4b* is an order effect – past eye movement studies that have manipulated the predictability of targets in fully randomized designs have found similar effects (e.g., **Chapter 2 –** *Experiment 1*; Rayner et al., 2004; see also, Rayner, 1998, 2009). Additionally, effects from fatigue could offset those of practice over the course of an experiment. To address this concern, however, separate Constraint × Frequency ANOVAs on FFD and SFD for Neutral and Biasing conditions were performed. FFD and SFD represent the earliest measures of processing. If participants sped up from Neutral to Biasing blocks, then it is possible that effects of Constraint or Frequency would likewise be attenuated. Recall, however, that Constraint interacted with Context for the early measures, with Biasing contexts functionally eliminating effects of Constraint. The separate ANOVAs confirmed this [Constraint: Neutral-FFD $F_1(1,47)=11.11$, $MSE=368$, $p<.01$, $F_2(1,21)=12.91$, $MSE=150$, $p<.01$; Neutral-SFD $F_1(1,47)=8.00$, $MSE=552$, $p<.01$, $F_2(1,21)=9.55$, $MSE=232$, $p<.01$; Biasing-FFD and Biasing-SFD all Fs<1]. These results cannot distinguish between an interaction (possibly due to floor effects) and a general acceleration of fixation times over the experiment. However, Frequency did not interact with Context and such effects were maintained in both halves of the experiment [Frequency: Neutral-FFD $F_1(1,47)=6.49$, $MSE=471$, $p<.05$, $F_2(1,21)=6.38$, $MSE=272$, $p<.05$; Neutral-SFD $F_1(1,47)=5.40$, $MSE=638$, $p<.05$, $F_2(1,21)=4.37$, $MSE=260$, $p<.05$; Biasing-FFD $F_1(1,47)=6.22$, $MSE=435$, $p<.05$, $F_2(1,21)=6.00$, $MSE=241$, $p<.05$; Biasing-SFD $F_1(1,47)=7.47$, $MSE=434$, $p<.01$, $F_2(1,21)=5.90$, $MSE=283$, $p<.05$].

Total reading time on each region of the target sentence (i.e., the only sentence in the Neutral condition; the second sentence in the Biasing condition) across Context conditions was also examined. Sentences were divided into four regions: the target, itself, including the space preceding it (always 6 characters); a pre-target region before the target (always 10 characters); a beginning region of text occurring before the pre-target region (13 characters on average); and a post-target region of all text occurring after the target (27 characters on average). For each region, the total reading time was divided by the number of characters in that region to yield a reading time per character measure. These averages for Neutral and Biasing conditions are presented in Figure 5.5. The fact that reading time per character is longer on the target than any other region is not surprising because the target region encompasses a single content word, whereas the other regions generally include multiple words, several of which are function words that are typically not fixated. In this way, reading time per character for larger regions tends to underestimate the time spent on content words within those regions. The differences (Neutral–Biasing) for the beginning, pre-target, target, and post-target regions were –1, 6, 4, and 10 ms/character, respectively. While most regions were read faster in the Biasing compared to the Neutral condition, there was no difference in the first region. The greatest numerical advantage for the Biasing condition arose from the final region, where discourse integration processes would be most facilitated. While the current data cannot unequivocally demonstrate that the present Context effect is *solely* due to the target's predictability (and not the by-product of an order effect), the overall weight of evidence seems to favour an interpretation in which reading behaviour across several measures is facilitated by more predictable contexts.

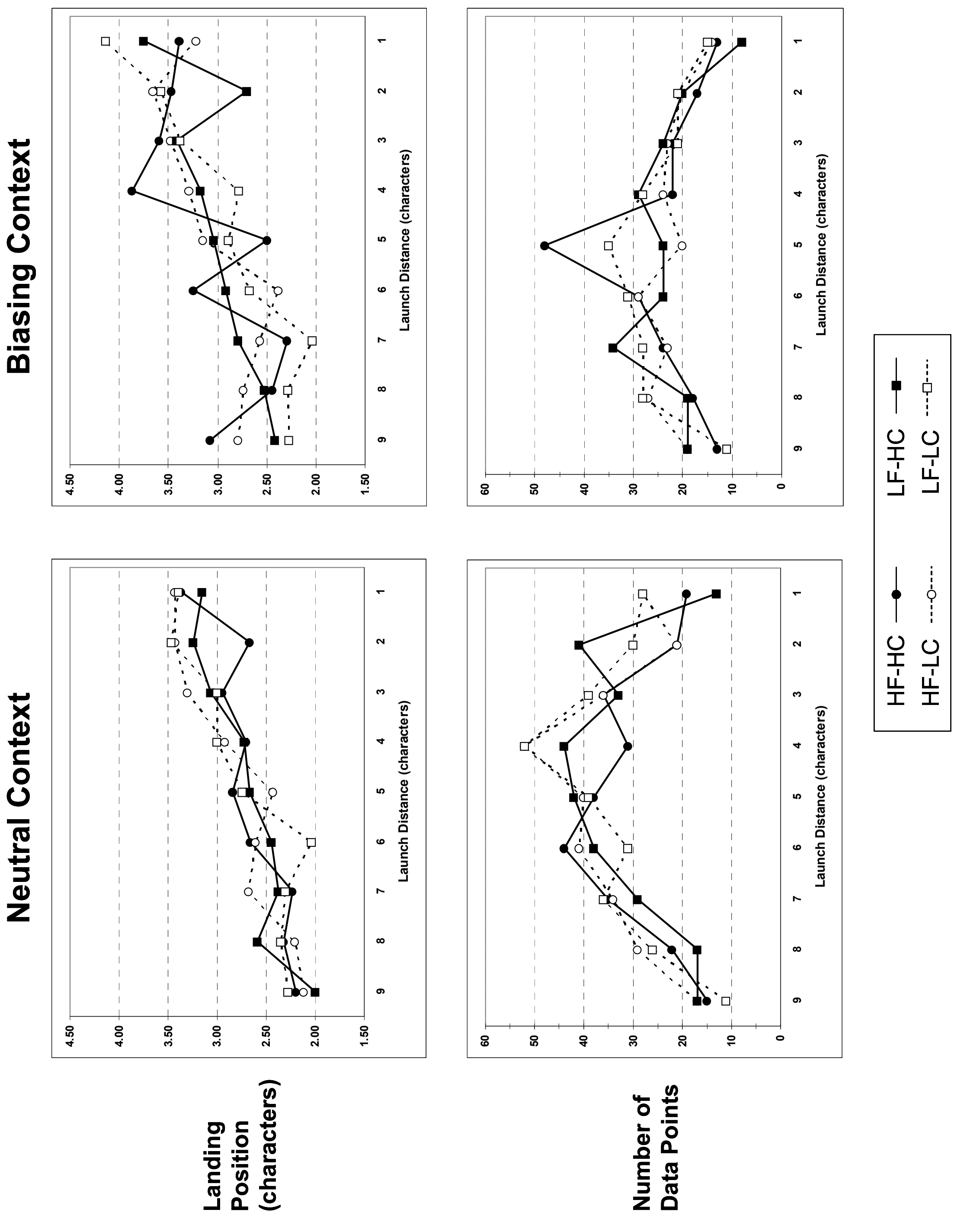
Figure 5.5. Comparison of sentence reading time by region and context condition



The second issue concerns how strong a conclusion can be made about parafoveal processing in the absence of employing a gaze-contingent display change paradigm. An invalid parafoveal preview (a letter string different from the target that changes to the target when eyes cross a pre-target boundary) can be used to insure foveal-only processing. By its nature, however, an invalid preview does not simply deny parafoveal processing; it permits parafoveal processing of an incorrect stimulus. Nevertheless, the complexity of *Experiment 4b*'s existing design (2×2×2) made an additional parafoveal preview manipulation impractical. However, some tentative conclusions about parafoveal processing can be made, based in part on the pre-target (T–1) findings of parafoveal-on-foveal effects as well as on further analyses of the data.

Launch distance (i.e., the number of characters from the pre-target fixation to the beginning of the target region) can be used as a proxy measure of the degree of parafoveal processing of the target (see, e.g., **Chapter 2** – *Experiment 1*). This argument assumes that nearer launch sites allow for better parafoveal pre-processing than further ones. Descriptive statistics were calculated for the launch site analysis. Figure 5.6 shows the landing position as well as the number of data points on target words as a function of launch distance across all conditions. The pattern of target landing position data shows that closer launch sites resulted in saccades further into the target. The pattern of data points shows that launch distance was relatively normally distributed. These patterns are confirmed by past eye movement research (e.g., McConkie et al., 1988; Rayner et al., 1996). There are more data points in Neutral context conditions as the target was more likely to be skipped in Biasing context conditions. While the data are somewhat noisy, there do not seem to be any systematic differences between the experimental conditions.

Figure 5.6. Target landing position (characters) and number of data points as a function of launch distance (characters) from the target for HF-HC, HF-LC, LF-HC, and LF-LC words in Neutral and Biasing contexts.



Note. Y-axis major units increase in increments of 50 from a minimum of 150 to a maximum of 450. X-axis major units decreases in increments of 1 character from a starting point of 9 to a finishing point of 1.

A 2 (Launch Distance: Near, Far) × 2 (Constraint) × 2 (Frequency) × 2 (Context) ANOVA on the FFD data by participants ($F_1(1,47)$) and by items ($F_2(1,21)$) was performed. For Launch Distance, Near was defined as saccades originating from 1-3 characters and Far as saccades originating from 7-9 characters. For missing data (less than 2% overall; 11 of 768 participant and 7 of 352 item cells), appropriate condition means adjusted by participant or item were substituted. As in the original analyses, the main effects of Constraint, Frequency, and Context were all significant [Constraint: F_1=8.89, p<.01, F_2=5.75, p<.05; Frequency: F_1=13.40, p<.001, F_2=13.49, p<.01; Context: F_1=15.24, p<.001, F_2=33.17, p<.001]. FFDs were shorter on HC versus LC targets (181 vs. 188 ms), on HF versus LF targets (180 ms vs. 188 ms), and on targets in Biasing versus Neutral contexts (178 vs. 191 ms). Launch Distance was also significant, with shorter FFDs associated with Near versus Far launch sites (175 vs. 193 ms) [F_1=33.61, p<.001, F_2=40.99, p<.001]. Two interactions were significant by participants but not by items [Launch Distance ×Constraint and Frequency × Context: F_1s>9.10, p_1s<.01, F_2s<1]. No other interactions approached significance. Thus, it seems that Launch Distance (within a range of 9 characters) did not modulate any of the reported main effects. However, these effects should be considered with caution as they only represent a relatively small sample of the data (see Figure 5.6).

Reconciling differences

Recall that Lima and Inhoff (1985) only found an advantage for LC words in the FFD measure. *Experiment 4b*'s finding of a processing advantage for HC words was demonstrated across several eye movement measures. The issue remains, however, as to how to best account for the pattern of these results, both in light of Lima and Inhoff's study as well as in the broader theoretical context of recent related research. It is possible that differences in results between *Experiment 4b* and Lima and Inhoff's were due to differences in aspects of materials and methods.

First, the specifications for the number of 5- and *x*-letter neighbours across conditions in their study was 9 and 80 for LC, and 1 and 5 for HC, respectively; in *Experiment 4b*, the corresponding values (for comparable LF targets) were 20 and 209 for LC, and 2 and 17 for HC, respectively. Thus, it seems that in *Experiment 4b*, LC words were more "unconstrained" than theirs, having denser neighbourhoods. In terms of the *lexical constraint hypothesis* – Lima and Inhoff's initial position, in which word-initial letter information acquired parafoveally is used to constrain the number of possible candidates – LC words having bigger trigram neighbourhoods should be additionally disadvantaged. The findings of *Experiment 4b* lend support to this account. According to Lima and Inhoff's revised view, however, larger trigram neighbourhoods should lead to even greater subsequent foveal processing efficiency. While both accounts seem plausible, it is believed that the weight of evidence, as discussed below, favours an interpretation in which a higher constraining parafoveal trigram, when clearly visible, acts to facilitate that word's recognition.

Second, in terms of methods, a combination of an expanded experimental design and a greater number of participants in *Experiment 4b* (N=48) compared to Lima and Inhoff's (N=18) resulted in over five times more data points available for analysis in *Experiment 4b* compared to theirs (4224 vs. 756 observations, respectively). Although the difference between studies in the number of data points per participant per condition was moderate (11 in ours vs. 7 in theirs), it does represent a 57% increase which, nonetheless, serves to enhance the reliability of the results of *Experiment 4b*.

Third, Lima and Inhoff (1985) always preceded their target word by a content word that had an average length of 7 characters. In *Experiment 4b*, the pre-target word tended to be a HF function word. The average length of these pre-target words was 4 letters. Although the analysis of launch distance and landing position (Figure 5.6) shows that fixations were made on the pre-target word (launch sites of 1-4 characters), the median launch site of *Experiment 4b*'s sample was 5 characters. It seems reasonable, then, to assume that pre-target words in *Experiment 4b* were skipped more often than those used in Lima and Inhoff's experiment. The consequences, however, are not straightforward. On the one hand, a single fixation on a longer, content, pre-target word would result in less parafoveal pre-processing of the subsequent target (e.g., Henderson & Ferreira, 1990). However, if a second fixation were made on that pre-target word (the probability of which increases with word length), then a greater degree of target pre-processing could occur (e.g., Sereno, 1992). On the other hand, a higher degree of skipping a shorter, function, pre-target word entails that, although launch distance to the target word is maintained, the parafoveal preview of the target would include an intervening word. Without knowing the frequencies of the different fixation scenarios or having adequate data to perform such post-hoc analyses, it is difficult to speculate further about how the variation in pre-target words between these experiments differentially affected target processing.

Fourth, Lima and Inhoff's materials were presented on a Hewlett-Parckard 1300A CRT with letters plotted in a dot-matrix font (cyan letters on a black background) in a darkened room. Under these conditions, the text can appear quite pixelated and is more difficult to read. The materials in *Experiment 4b* were presented in a situation more akin to natural reading – a high quality font (black letters on a white background) in a well-lit room. The difficulty reading a dot-matrix font is substantiated by the longer fixation times in Lima and Inhoff's study. The average FFD and GD in their full-line (i.e., normal reading) condition was 225 and 253 ms, whereas the average FFD and GD in *Experiment 4b's* LF-Neutral condition (i.e., the condition most comparable to their stimuli) was 199 and 216 ms, a reduction of 26 and 37 ms, respectively. Assuming that both experiments sampled typical university students with similar abilities in reading relatively simple short lines of text, it seems that the most plausible explanation for the slower reading times in the Lima and Inhoff study is related to the intelligibility of the font used.

In terms of the speed of identifying parafoveal letters in a dot-matrix font, it is possible that LC trigrams would show an advantage over HC trigrams for reasons related to differential lower-level visual processing. Recently, Kveraga, Boshyan, and Bar (2007) used low resolution (blurred) and high resolution (clear) stimuli to bias processing toward the magnocellular (M) and parvocellular (P) pathways, respectively. They found that M-stimuli were projected rapidly from early visual areas to the orbitofrontal cortex (OFC) which, in turn, sent rapid feedback in the form of predictions to inferotemporal (object identification) areas. P-stimuli, however, were only projected from occipital cortex to the fusiform gyrus, without the rapid mediation via the OFC. In the current context, a blurred (dot-matrix) parafoveal stimulus, in comparison to a clear one, paradoxically would lead to faster top-down processing. That is, top-down processing predicting a parafoveal word-initial trigram would be easier for common or prototypical (LC) trigrams than for rare (HC) ones.

Finally, a recent eye movement experiment by White (2008) examined the effects of word-initial orthographic familiarity, using HF-familiar, LF-familiar, and LF-unfamiliar words as targets in sentences. The comparison of interest for the current study is that between LF-familiar and LF-unfamiliar words. White (2008) measured orthographic familiarity in terms of *n*-gram token frequencies (i.e., the summed frequency of all words containing a particular letter sequence). White (2008) obtained trigram token values from CELEX (Baayen, Piepenbrock, & Gulikers, 1995). In particular, the token-initial trigram frequency was significantly larger for LF-familiar than LF-unfamiliar words. In this respect, these conditions are similar to the LF-LC and LF-HC conditions of *Experiment 4b*, respectively. White found that SFD was significantly longer for LF-unfamiliar words (FFD was significant by participants but trend by items; GD was significant by participants and marginal by items; TT was not significant). As with the Lima and Inhoff (1985) study, although the effect is less well expressed in fixation time measures in comparison to *Experiment 4b*, the direction of the effect is, nevertheless, inconsistent with the findings of *Experiment 4b*.

In order to appropriately evaluate White's words, the same measures used to characterise the trigram (*x*-letter) neighbourhoods in *Experiments 4a* and *b* were used on the materials used by White. Namely, the number of trigram neighbours (type frequency), the summed frequency of the trigram neighbourhood (token frequency, per million), the percentage of the trigram neighbourhood accounted for by the target based on its frequency, and the rank of the target within the trigram neighbourhood, again, based on its frequency (see Table 5.4). Specifically, *Experiment 4b*'s LF-LC words (versus White's LF-familiar words) had substantially more trigram neighbours (209 vs. 121) and a slightly higher trigram neighbourhood summed frequency (1615 vs. 1144 per million), while accounting for a similar percentage of the trigram neighbourhood (1 vs. 2%) and relative rank within the trigram neighbourhood (28 vs. 30). *Experiment 4b*'s LF-HC words (versus White's LF-unfamiliar words) had fewer trigram neighbours (17 vs. 31), had a lower summed frequency of trigram neighbours (31 vs. 192 per million), accounted for a greater percent of the trigram neighbourhood (38 vs. 22%), and were higher ranking within the trigram neighbourhood (1 vs. 9). In neighbourhood terms, in comparison to White's words, *Experiment 4b*'s LF-LC words were unknown members lost in larger crowds and *Experiment 4b*'s LF-HC words were unique members conspicuous within smaller gatherings. That is, *Experiment 4b*'s LF-LC words came from larger trigram neighbourhoods, while *Experiment 4b*'s LF-HC words came from smaller ones. In general, there was a greater difference between *Experiment 4b*'s LF-LC and LF-HC words than White's LF-familiar and LF-unfamiliar words which could have contributed to the different pattern of results.

Related findings

Within the eye movement reading literature, two recent studies have examined issues related to word-initial letter constraint. In the first, Williams, Perea, Pollatsek, and Rayner (2006) investigated the role of orthographic neighbours as parafoveal previews to targets in a reading study using the boundary paradigm. A word's orthographic neighbours are words of the same length that differ by only a single letter from that word (Coltheart, Davelaar, Jonansson, & Besner, 1977). For example, the neighbours of *sleet* are *fleet*, *sheet*, *sweet*, *slept*, *sleek*, and *sleep*. Williams et al. (2006) compared fixation time on targets when the parafoveal preview was identical to the target (e.g., *sleet*), an orthographic neighbour of the target (e.g., *sweet*), or an orthographically matched nonword (e.g., *speet*). In their first experiment, targets were LF and orthographic neighbour previews were HF words; in their second experiment, targets were HF and orthographic neighbour previews were LF words. They found that the amount of preview benefit depended on the frequency of the preview. When orthographic neighbour previews were HF, the preview benefit was equivalent to identical (LF) previews, with both conditions showing facilitation relative to the nonword preview condition. When orthographic neighbour previews were LF, only the identical (HF) preview condition was facilitated. These results, in partial contrast to those of Lima and Inhoff (1985), demonstrate that when parafoveal information is orthographically similar as well as lexical (word vs. nonword) and salient (HF vs. LF), lexical processing, as reflected in the subsequent fixation time on the parafoveal word, is facilitated.

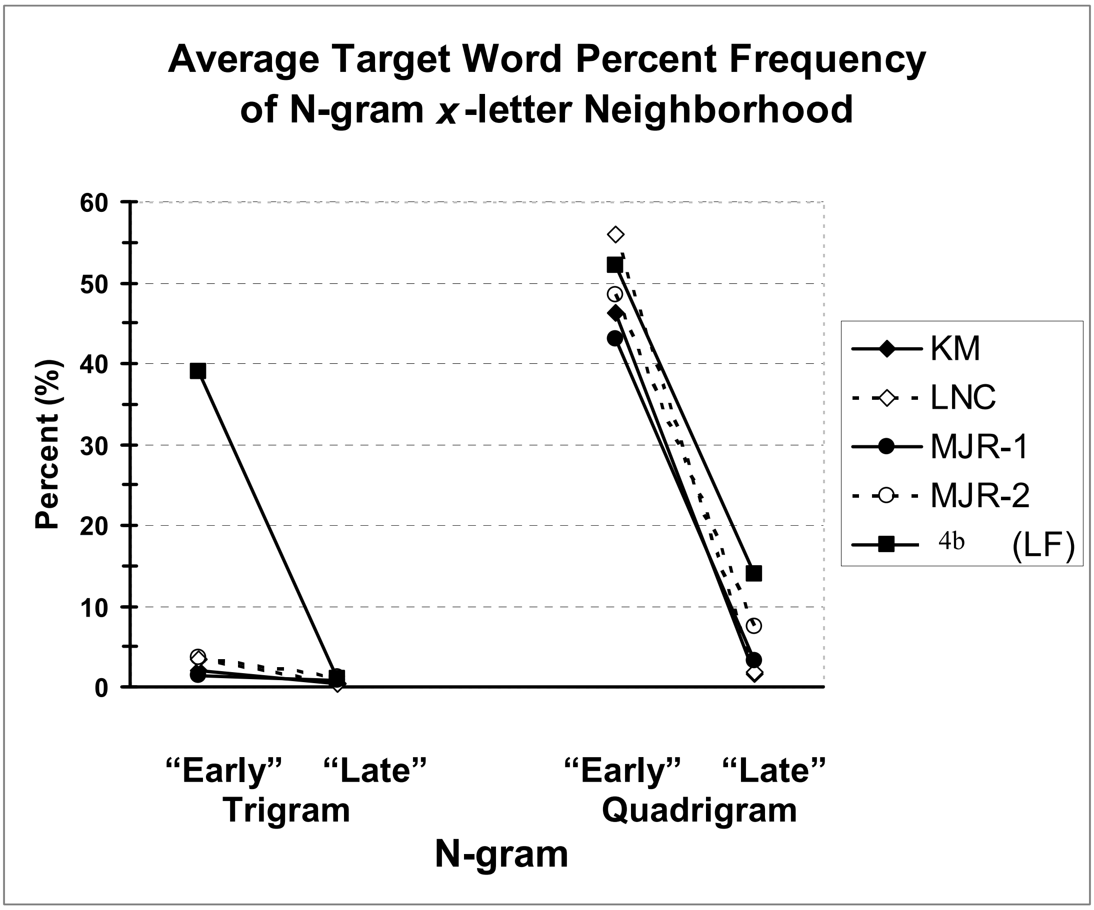
The second study examined the *orthographic uniqueness point* (OUP) in fluent reading (Miller, Juhasz, & Rayner, 2006). The OUP is the visual analogue of the spoken-word uniqueness point, that is, the letter position in a word that differentiates that word from other words based on orthography. For example, a typical early OUP word has its uniqueness point at letter position 4 (e.g., *actress*) whereas a late OUP word cannot be specified until letter 6 or 7 (e.g., *cartoon* or *curtail*). Prior research had used foveally presented words for naming (Kwantes & Mewhort, 1999) and lateralized presentation for a lexical decision task (Lindell, Nicholls, & Castles, 2003) to investigate the OUP. Both studies found an RT advantage for early compared to late OUP words, providing evidence that a word's letters are at some point processed serially, in a left-to-right manner (in English). Specifically, according to Kwantes and Mewhort (1999), the seriality in processing occurs when a reader begins searching for the word in memory, not at the earlier stage of letter identification. Miller et al. (2006), however, raised several methodological concerns with these studies which they addressed in two experiments. First, they used early and late OUP words in the context of a normal reading task while recording participants' eye movements. Second, they generally used different words than those that had been previously tested (Lindell et al.'s words were a subset of those used by Kwantes & Mewhort). In Experiment 1, Miller et al. expanded and altered the stimulus list from the earlier studies. In Experiment 2, Miller et al.

further refined their stimuli to address Lamberts' (2005) prior criticism that early OUP words tended to have fewer orthographic neighbours than late OUP words. Finally, using the boundary paradigm, Miller et al. manipulated the parafoveal preview of early and late OUP words across three conditions. The preview could be identical to the subsequent target, have the same first 4 letters as the target with the remaining letters visually different, or be entirely visually different from the target. Across both experiments, Miller et al. found no evidence to support the notion of serial processing. Late OUP words were read as fast as early OUP words, regardless of the amount of preview available. They attributed the lack of an OUP effect to differences in methodology and stimuli employed in the prior studies.

In the context of *Experiment 4b*'s findings, a positive OUP effect could be interpreted as a relative advantage for words beginning with HC four-letter (quadrigram) combinations (i.e., early OUP words, whose OUP is at letter position 4) versus words beginning with LC quadrigrams (i.e., late OUP words, whose OUP is at letter position 6 or 7). Because the eye movement experiments (Miller et al., 2006) which did not find an OUP effect used different stimuli than the naming (Kwantes & Mewhort, 1999) and lexical decision (Lindell et al., 2003) studies which did, the differing results may have arisen from the level of constraint conferred by the word-initial quadrigram. One of *Experiment 4b*'s measures of constraint was the percentage that each word represented of its entire (*x*-letter) trigram neighbourhood (see Table 5.4). For this measure, the frequency of each target word was divided by the summed frequency of all words (including the target) of any length that shared that word-initial trigram. Using this same procedure, the average percentage that a given target represented of its quadrigram neighbourhood in early and late OUP conditions was calculated (as per Davies, 2004). It was found that, across all three of the above studies, early OUP words represented a far greater proportion of their quadrigram neighbourhoods (average 48%, range 43-55%) than late OUP words (average 3%, range 2-7%). The percentages for each study are presented in Figure 5.7. While early OUP words, by definition, should comprise a larger percentage of their quadrigram neighbourhoods than late OUP words, there was no apparent difference in these means across the different studies.

The possibility remains, however, that the experiments reporting an advantage for early over late OUP words (Kwantes & Mewhort, 1999; Lindell et al., 2003) may have used early OUP words that had higher constraining *trigram* neighbourhoods than the experiments that found no such difference (Miller et al., 2006). For each study, the percentage that each early and late OUP word represented of its trigram neighbourhood was calculated (using Davies, 2004). These percentages are presented in Figure 5.7. In terms of trigrams, both early and late OUP words represented only a negligible percentage of their neighbourhoods, with a minimal difference between early OUP (average 2.6%, range 1.4-3.6%) and late OUP (average 0.7%, range 0.4-1.1%) words. As with the quadrigram neighbourhoods, these proportions did not differ between studies. Thus, although the results of RT and eye movement experiments were in conflict, the profiles of quadrigram and trigram neighbourhoods for early and late OUP words were similar.

Figure 5.7. KM=Kwantes and Mehwort (1999), LNC=Lindell, Nicholls, and Castles (2003), MJR-1=Experiment 1 of Miller, Juhasz, and Rayner (2006), MJR-2=Experiment 2 of Miller et al., 4b (LF)=Low Frequency condition of *Experiment 4b*, "Early" and "Late" refer to Early OUP and Late OUP conditions in KM, LNC, MJR-1, and MJR-2, but to HC and LC conditions, respectively, in *Experiment 4b*.



Assuming that the presence of an OUP effect in naming and lexical decision is due to task effects and that the lack of one in fluent reading more accurately reflects processes associated with recognizing words in text (for an extended discussion, see Miller et al., 2006), the question remains why *Experiment 4b* found a fixation time advantage for words with HC trigrams while Miller et al. found no such advantage for words with HC quadrigrams. As noted previously, the stimuli used in the prior OUP studies were generally LF words; thus, any comparisons to *Experiment 4b* will be limited to the LF-

HC and LF-LC conditions. With respect to trigrams, *Experiment 4b*'s (LF) HC words represented a much larger proportion of their neighbourhoods than did the LC words (see Table 5.4 and Figure 5.7). In contrast, Miller et al.'s early OUP words were equally as unrepresentative as their late OUP words in corresponding neighbourhoods. With respect to quadrigrams, the percentage that *Experiment 4b*'s HC and LC words represented of their quadrigram neighbourhoods was calculated (using Davies, 2004). Similar to Miller et al.'s early and late OUP stimuli, respectively, *Experiment 4b*'s HC words comprised a large proportion (52%) and *Experiment 4b*'s LC words a relatively small proportion (14%) of their quadrigram neighbourhoods (see Figure 5.7). In short, the stimulus conditions of *Experiment 4b* became differentiated one letter position prior to those used in Miller et al. These differences in *n*-gram profiles and in the empirical findings, taken together, would seem to suggest that word-initial letter constraint is only effective if it occurs within the first 3 (and not 4) letters of a word.

Although this is a rather bold claim, eye movement research on the use of parafoveal information does provide support for the attentional relevance of word beginnings (e.g., McConkie & Zola, 1987; Rayner et al., 1982). Nonetheless, the intention is not to imply that *no more than* the first 3 letters of a word are processed in a certain way. Rather, it is suggested that the rate of gain of parafoveal information levels out the further the distance (in letters) from the beginning of the parafoveal word. Other issues, however, would also come into play. First, fixations to a target can originate from closer or further launch distances which would affect the amount of parafoveal preview obtained (e.g., *Experiments 1* and *2*). Also, on any given fixation, more or less parafoveal preview can be acquired as a function of the difficulty of the currently fixated, foveal word (e.g., Henderson & Ferreira, 1990). One way to test the limits of parafoveal information capture of word-initial quadrigrams in early and late OUP words would be

– as suggested at the outset regarding Lima and Inhoff's (1985) findings – to additionally manipulate word frequency and contextual predictability. That is, an early OUP word may be facilitated if it were both an HF and highly predictable word. As mentioned previously, OUP stimuli tend to be LF words. In the Miller et al. (2006) study, OUP targets appeared in contextually neutral sentences (average Cloze values were less than 0.01). If high frequency and predictability of the parafoveal word increases the parafoveal preview benefit of that word, as prior research has demonstrated (e.g., Balota et al., 1985; Inhoff & Rayner, 1986), then it is possible that the highly constraining quadrigrams of such early OUP words would facilitate that word's recognition.

Theoretically, while the results of *Experiment 4b* have implications for a range of word recognition models, caution must be exercised in making generalisations beyond the specific reading task employed. Effects do not always generalise from lexical decision, or even self-paced reading, to fluent reading conditions. With respect to orthographic neighbourhood size (i.e., the number of words differing from the target by exactly one letter), Pollatsek, Perea, and Binder (1999) reported a pattern of results homologous to the findings of *Experiment 4b*. They showed that a large neighbourhood size facilitated lexical decision but had an inhibitory effect on reading, even when using the same experimental target words. Such differences in findings are sometimes explained by different mechanisms which are engaged by the different tasks. Norris (2006), on the other hand, adopts a more parsimonious approach in arguing that readers behave like optimal Bayesian decision-makers and exploit whatever statistical patterns that are available in order to deliver the most efficient result. In these terms, a word-initial HC trigram viewed parafoveally greatly raises the post-hoc probability of the occurrence of that target. Proponents of Bayesian reading models would therefore suggest that the choice of a reading mechanism should be secondary to assuming that readers will learn to recognize visual words in an optimal manner.

Conclusion

The word-initial letter constraint of target words was examined in an eye movement reading study that additionally manipulated the word frequency and contextual predictability of these targets. Several results replicated prior research – for example, demonstrating frequency and predictability effects in fixation times and an interaction of these effects in word skipping rates. In direct contrast to Lima and Inhoff (1985), however, an effect of trigram constraint in which HC words (e.g., *dwarf*) were consistently fixated for *less* time than LC words (e.g., *clown*) was found. Although Constraint interacted with Context, it did so only in early fixation time measures and was most likely the result of a floor effect. It is suggested that the differences in *Experiment 4b*'s findings in relation to those of Lima and Inhoff were due to differences in materials and methods. Finally, recent related eye movement research was evaluated in light of *Experiment 4b*'s findings. Although this research does not fully corroborate the results, neither does it refute the claims made. Additionally, the findings of *Experiment 4b* are consistent with a Bayesian account (Norris, 2006) in which readers respond to the statistical information available to perform in an optimal fashion. In sum, *Experiment 4b* reports evidence that supports the notion that the level of orthographic constraint conferred by the first few letters of an upcoming word is advantageously processed by the reader.

Chapter 6

Discussion

The present thesis was conducted in order to further examine the nature of the word frequency × predictability interaction in reading. Past eye movement experiments have generally found an additive pattern of effects (e.g., Rayner et al 2004). However, it is possible that these effects only emerge under certain conditions and/or certain measures of processing. For example, Rayner et al.'s additive fixation time pattern was accompanied by interactive PrF results. To this end, this thesis employed different ways of examining the frequency-predictability interaction: by examining the effects of parafovea preview as indexed by launch distance to the beginning of target words; by examining VHP vs. VLP words and MP vs. VLP words; by examining the combined effects of frequency and predictability on skipping behavior, particularly on fixation durations prior to word skipping; and examining the role of WILC.

The present thesis also examined launch distance as a measure of assessing the effects of parafoveal preview. Gaze-contingent visual display change paradigms, such as boundary techniques (see **Chapter 1**, Figure 1.3) and moving window techniques (see **Chapter 1**, Figure 1.4) have proved invaluable in determining the amount and types of information that can be acquired parafoveally. However, both these techniques involve presentation of non-normal textual displays. Using launch distance from the beginning of a parafoveal word allows for the presentation of normal passages of text, and preview is assessed on the basis that visual acuity decreases as foveal eccentricity of a stimulus increases, albeit in a necessarily post-hoc fashion. The present thesis examined the effects of parafoveal preview (as indexed by launch distance) on the individual and combined effects of the above factors.

<u>Summary of Experimental Results</u>

Standard effects of frequency and predictability were found across all studies. Lower-frequency words (LF) were processed with greater difficulty than higher-frequency words (HF); low-predictability words (LP) were processed with greater difficulty than (HP) words. Consistent with prior research (Rayner et al, 2004), *Experiment 1* found additive effects of frequency and predictability on eye movement behaviour. However, further investigation revealed that when preview was highest (i.e., Near launch distances), frequency and predictability exerted an interactive effect.

Experiments 2a and *2b* further investigated the simultaneous effects of frequency and predictability, addressing methodological concerns about *Experiment 1*. Principally, that HP contexts in *Experiment 1* were medium-predictability (MP), potentially obscuring any interaction as the acquisition of parafoveal information is influenced by the frequency and predictability of the parafoveal word. Comparing very low-predictability (VLP) items to very high-predictability (VHP) items, the interactive pattern of effects observed in the Near launch distance condition of *Experiment 1* was replicated in the global analyses of *Experiment 2a*. Conditionalised analyses of HF and LF words in VLP and VHP materials revealed an interactive pattern of frequency and predictability effects at both Near and Middle launch distances. *Experiment 2b* examined HF and LF words in VLP specifically-designed MP items and yielded an additive pattern of effects, consistent with *Experiment 1*. Furthermore, conditionalised analyses of these items by launch distance showed an interactive pattern of effects, but only at Near launch distances, again consistent with the results of *Experiment 1*. It is argued that frequency and predictability can interact under two distinct conditions, but both manners are dependent on preview. VHP contexts allow for sufficient extraction of parafoveal information at both Middle and Near launch distances, therefore an interactive pattern of frequency and predictability effects are observed when comparing VHP and VLP materials, such as in *Experiment 2a*. However, MP items do not allow for sufficient extraction of information at Middle launch distances. Therefore, if there is to be an interaction between the effects of frequency and predictability when comparing MP and VLP items, participants must obtain parafoveal information by fixating very close to the beginning of the target word on the fixation prior to eventual foveal processing of that target word.

Experiment 3 examined whether fixation durations are inflated prior to skipping a word in text. An overall non-significant effect of word skipping on prior fixation durations was observed. However, this result was somewhat misleading – inflated fixation durations prior to skipping were observed, but only when to-be-skipped words were either HF or HP; indeed, the largest mean inflation prior to skipping was observed when the to-be-skipped word was both HF and HP. These results suggest that when readers are able to extract most information about parafoveal words (e.g., when those words are HF or HP), fixation durations prior to skipping these words are inflated. It is tentatively suggested that these effects reflect a longer accumulation of information from parafoveal to-be-skipped word. These effects are consistent with models of eye movement control permitting parallel processing of written information, as opposed to a strictly serial approach.

Experiments 4a and *4b* tested the effects of WILC. *Experiment 4a* employed a lexical decision task, examining the separate and combined effects of WILC and frequency. LF words were responded to less quickly than HF words. LC words were processed more quickly than HC words. It is suggested that in a lexical decision task, LC words are responded to quickly as their initial trigram is shared by many viable words, facilitating a "word" response. The initial trigrams of HC words are shared by few other words, potentially hindering a "word" response. *Experiment 4b* re-tests the role of WILC on eye movement behaviour during reading, based on an earlier study by Lima and Inhoff (1986). Unlike Lima and Inhoff's study, the frequency and predictability (known to influence the extraction of parafoveal information) of LC and HC target words was also manipulated. In contrast to the findings of Lima and Inhoff (*but*, consistent with their original *prediction*), HC words were found to exhibit a processing advantage over LC words in measures of eye movement behaviour reflecting early, lexical processing. Further analyses based on launch distances from, and landing positions within target words suggested that the pattern of effects observed may be due to the accumulation of WILC information from the parafovea.

<u>The effect of word frequency on probability of fixation</u>

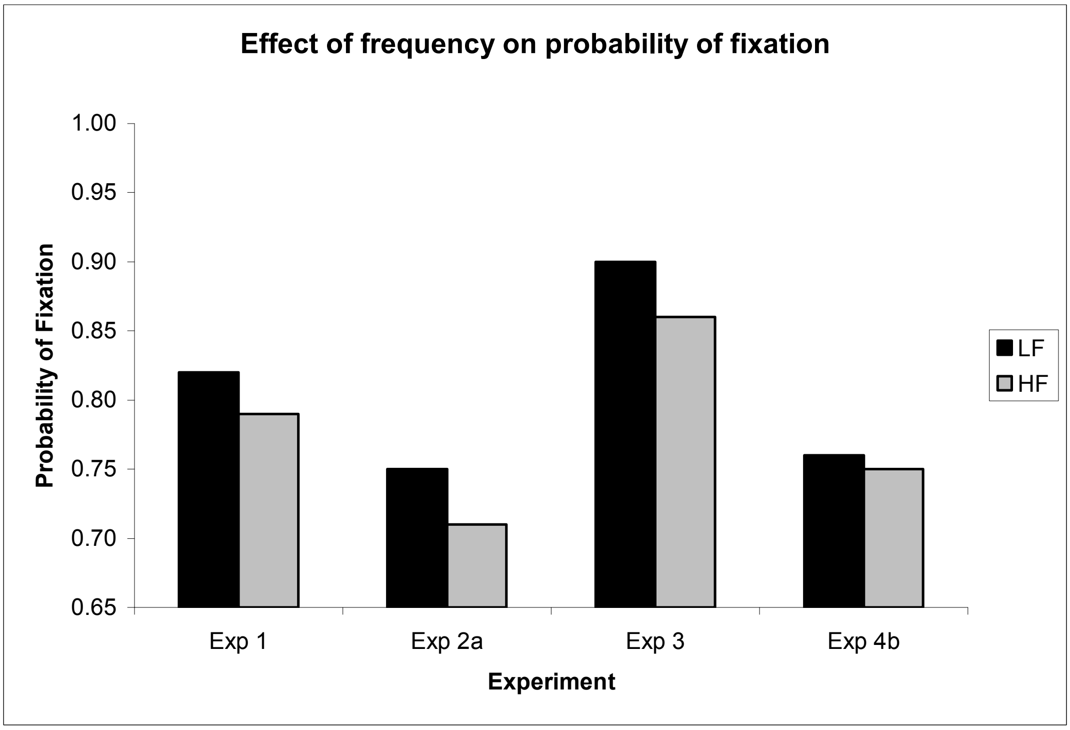
The effect of word frequency on fixation durations is well-documented (Inhoff & Rayner, 1986; Just & Carpenter, 1980; Kennison & Clifton, 1995; Kliegl et al., 2004, 2006; Rayner & Duffy, 1986; Rayner & Raney, 1996; Rayner et al., 1996; Rayner et al., 2004; Schilling et al., 1998; Sereno et al., 1992, 2006; Sereno & Rayner, 2000; Slattery et al., 2007). The results of the present thesis are consistent with this body of research. However, what is less clear is the effect of word frequency on the probability of fixating a target word (PrF). Previous research (Radach & Kempe, 1993; Rayner & Fischer, 1996; Rayner et al., 1996) has demonstrated an effect of word frequency on PrF, but only when participants had prior fixations located at Near launch distances to target words. The present thesis provided mixed evidence for the existence of word frequency effects on PrF. Table 6.1 demonstrates the mean frequencies of LF and HF target words in these studies, the PrF of LF and HF words in these studies, and whether the effect of frequency on PrF was significant. Figure 6.1 demonstrates mean PrF of LF and HF words across *Experiments 1*,*2*,*3* and *4b*[1].

Table 6.1 Effect of word frequency on probability of fixating (PrF) target words

	BNC Freq		**PrF**		
	LF	**HF**	**LF**	**HF**	**Sig.**
Exp 1	5 (3.16)	144 (104)	.82	.79	<.01
Exp 2a	7 (3.84)	172 (118)	.75	.71	<.01
Exp 3	5 (3.16)	144 (104)	.90	.86	<.001
Exp 4b	9 (5.56)	88 (76.3)	.76	.75	*F*<1

Note. SDs shown in parentheses. BNC Freq = BNC frequency per million occurrences; Sig. = significance level of difference between LF and HF PrF; Exp 1 = *Experiment 1* (PrF collapsed across predictability); Exp 2a = *Experiment 2* (PrF collapsed across predictability); Exp 3 = *Experiment 3* (PrF collapsed across predictability and skipping outcome); Exp 4b = *Experiment 4b* (PrF collapsed across predictability and WILC). Exp 1 conducted using dual-Purkinje eyetracker, Exps 2, 3 and 4b conducted using EyeLink 1000 system.

Figure 6.1 Effect of word frequency on probability of fixating (PrF) target words



Note. Exp 1 = *Experiment 1* (PrF collapsed across predictability); Exp 2a = *Experiment 2a* (PrF collapsed across predictability); Exp 3 = *Experiment 3* (PrF collapsed across predictability and skipping outcome); Exp 4b = *Experiment 4b* (PrF collapsed across predictability and WILC). Exp 1 conducted using dual-Purkinje eyetracker, Exps 2, 3 and 4b conducted using EyeLink 1000 system.

Footnote[1]. *Experiment 3* is not strictly a stand-alone experimental study, it is a re-evaluation of data collected for *Experiment 1*. The criteria for inclusion of "skip" trials is more stringent in *Experiment 3*, thus yielding differential PrFs than *Experiment 1*.

As can be seen in Table 6.1, the majority of experiments within the present thesis demonstrated a significant effect of word frequency on PrF, such that readers are more likely to fixate LF than HF words. However, in *Experiment 4b*, a non-significant effect of frequency on PrF was observed. It is argued that this is due to the mean frequencies of LF and HF words used in *Experiment 4b* being insufficiently well-manipulated to generate a significant difference between these groups in PrF. The mean frequency of LF words in *Experiments 1*,*2*, and *3* is 5.67 occurrences per million and the mean frequency of HF words in these studies is 153.33 occurrences per million. All of these experiments demonstrate significant frequency effects on PrF. However, the mean frequencies of LF and HF words in *Experiment 4b* are 9 and 88, respectively. The non-significant effect of frequency on PrF in *Experiment 4b* may be the result of the LF words selected having too high a mean frequency and / or the HF words selected having too low a mean frequency.

To test the contention that the HF and LF words in *Experiment 4b* were less HF and LF than the words used in *Experiments 1*, *2a*, and *3*, a selection of 44 words from each frequency band were selected from each study. *Experiment 3* frequencies were not included in the analyses as they were identical to those of *Experiment 1*. A median split of items was used to determine which items were selected – thus providing the maximum number of items for a comparison to be made. Separate One-Way ANOVAs were conducted on HF and LF item frequencies in order to examine whether frequencies were reliably different across studies, and if so, between which studies there were reliable differences. Comparisons of individual HF item frequencies revealed that there were significant differences between studies [$F_2(2,129)=6.64$, $MSE=7967$, $p<.001$]. Planned follow-up comparisons revealed that HF word frequencies in *Experiments 1* and *2a* did not differ from one another (see Table 6.1; $p_2>.95$); however, the HF word frequencies of *Experiment 4b* were reliably lower frequency than the HF words of both *Experiments 1* and *2a* (see Table 6.1; both p_2s<.05).

The results of the One-Way ANOVA on LF target frequencies revealed significant differences between studies [$F_2(2,129)=13.52$, $MSE=15.31$, $p<.001$]. Planned follow-up comparisons revealed that LF word frequencies in *Experiments 1* and *2a* did differ from one another. LF words in *Experiment 2a* were reliably higher frequency than those in *Experiment 1* (see Table 6.1; $p_2<.05$). The LF word frequencies of *Experiment 4b* were reliably higher than the LF word frequencies of both *Experiments 1* and *2a* (both p_2s<.05).

Overall, the results of the present thesis do suggest a reliable effect of word frequency on PrF, but it may be that this effect is only be observed when the LF and HF words examined fulfil certain frequency criteria. The results of the analyses on the target word frequencies across studies suggest that the HF words selected in *Experiment 4b* were not as HF as the words in the other studies (which yielded reliable effects of frequency on PrF). Analyses also suggested that the LF word selected in *Experiment 4b* were not LF enough compared to the other studies. Although the LF words in *Experiment 2a* were reliably higher-frequency than those used in *Experiment 1*, both these studies gave significant effects of frequency on PrF. Therefore, it may not be that the frequencies of HF and LF words themselves may be important, rather that the distance between the frequencies of HF and LF targets may be the key factor in whether a frequency effect is observed on PrF.

Parafoveal-on-foveal effects

A somewhat contentious topic in the field of eye movement research is whether the semantic features of parafoveal word *n*+1 influence fixation duration on word *n*. Studies have demonstrated mixed effects of parafoveal word *n*+1 on fixation time on foveal word *n* (e.g., Drieghe et al., 2007; Inhoff, Radach, Starr, & Greenberg, 2000; Kennedy, 1998, 2000; Kennedy & Pinte, 2005; Kennedy, Pynte, & Ducrot, 2002; Pynte, Kennedy, & Ducrot, 2004; Rayner & Juhasz, 2004; Schroyens, Vitu, Brysbaert, & d'Ydewalle, 1999; Starr & Inhoff, 2004; Underwood, Binns, & Walker, 2000; Vitu, Brysbaert, & Lancelin, 2004). The mechanisms underlying PoF effects are disputed (see Miellet et al., 2009), and any observed effects tend to be numerically very small, and difficult to demonstrate reliably (Kliegl, 2009).

The present thesis examined the effects of parafoveal target word *n*+1 on fixation durations on foveal word *n* in *Experiments 1*, *3* and *4b*. Mixed results were observed. In *Experiment 1*, a non-significant effect of word *n*+1 frequency was observed on word *n* fixation duration [$F_1(1,63)=1.74$, $MSE=1731$, $p>.15$; $F_2(1,43)=1.39$, $MSE=1340$, $p>.20$]. However, a significant effect of word *n*+1 predictability was found on word *n* fixation duration, such that fixation durations prior to HP words were reliably shorter than fixation durations prior to LP words [256 ms vs. 264 ms; $F_1(1,63)=9.73$, $MSE=1304$, $p<.01$; $F_2(1,43)=4.81$, $MSE=1271$, $p<.05$]. In *Experiment 3*, both the effects of parafoveal word *n*+1 frequency and predictability had non-significant effects on word *n* fixation durations [all *F*s<1]. In contrast to the mixed or null effects observed in these two studies, *Experiment 4b* reported consistently significant effects of parafoveal word *n*+1 frequency, predictability and WILC on word *n* fixation durations (see Table 6.2; Figure 6.2). Fixation durations prior to LF words were reliably longer that those preceding HF words [193 ms vs. 188 ms; $F_1(1,39)= 8.12$, $MSE = 291$, $p<.01$; $F_2(1,21)=$

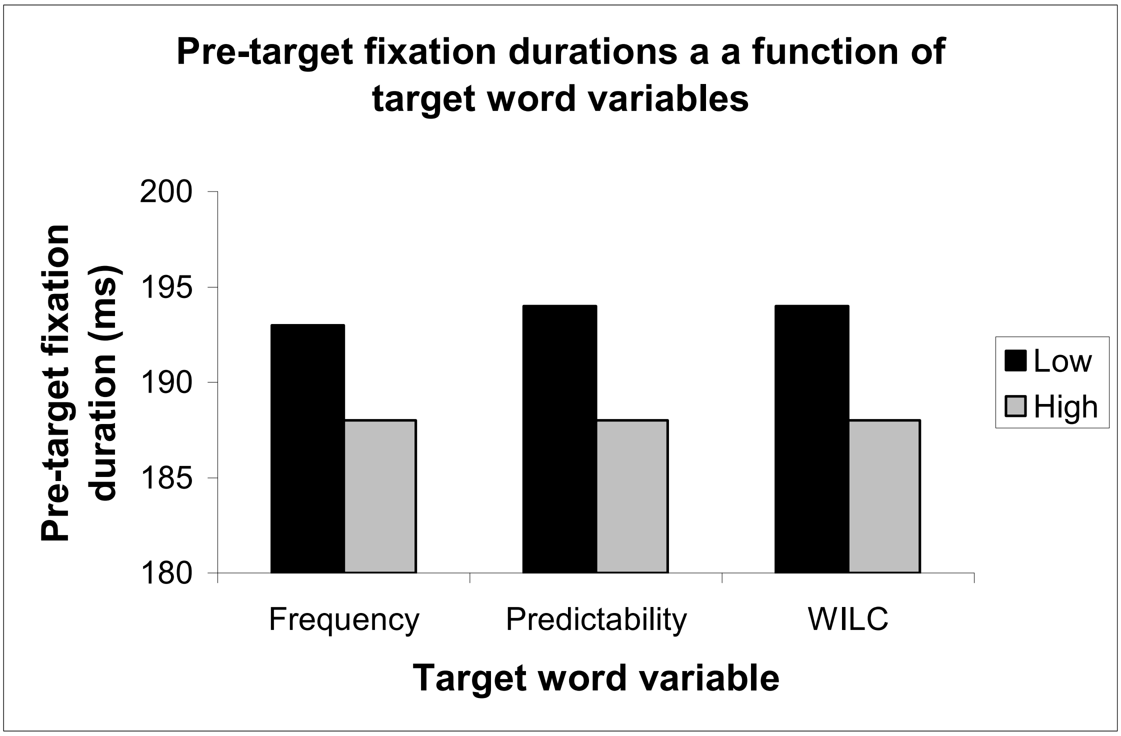
6.46; *MSE*= 180, p<.05]. Consistent with the results of *Experiment 1*, fixation durations prior to LP words were significantly longer than those prior to HP words [194 ms vs. 188 ms; $F_1(1,39)$= 9.30, *MSE* = 480, p<.01; $F_2(1,21)$= 12.72; *MSE*= 157, p<.01]. Finally, fixation durations prior to LC words were significantly longer than those prior to HC words [194 ms vs. 188 ms; $F_1(1,39)$= 12.46, *MSE* = 240, p<.001; $F_2(1,21)$= 7.86; *MSE*= 173, p<.05].

Table 6.2 *Experiment 4b*: Pre-target fixation durations as a function of target word frequency, predictability and WILC

	LF	**HF**	**F_1 sig.**	**F_2 sig.**
Frequency	193	188	<.01	<.05
	LP	**HP**		
Predictability	194	188	<.001	<.05
	LC	**HC**		
WILC	193	188	<.01	<.01

Note. Fixation durations in milliseconds. LF / HF = low / high frequency;; LP / HP = low / high predictability; WILC =word-initial letter constraint; LC / HC = low / high constraint; F_1 / F_2 sig. = significance of participants / items analysis of variance;

Figure 6.2 Pre-target fixation duration as a function of target word variables.



Note. Fixation durations in milliseconds. WILC = word-initial letter constraint.

The existence (or non-existence) of PoF effects can inform as to whether words are being processed in a parallel or serial fashion – reliable PoF effects lend support to an argument in favour of parallel processing, whereas a lack of these effects is consistent with a serial processing account. Prior research have led to conflicting serial (Drieghe et al., 2007) and parallel (Kennedy & Pynte, 2005) interpretations of how foveal and parafoveal information is processed. The existence (or non-existence) of PoF effects has implications for general models of eye movement control during reading. PoF effects are considered to be damaging to SAS models, e.g., E-Z Reader model (Reichle et al., 2003), wherein word recognition is assumed to be a serial process. However, GAG models e.g., SWIFT (Engbert et al., 2005) & Glenmore (Reilly & Radach, 2006) allow for the parallel processing of foveal and parafoveal words, and are therefore more accommodating to PoF effects.

Evidence indicates that eye movements are highly variable, and that often, saccades do not land on their intended target (Engbert, Nuthmann, & Kliegl, 2007; McConkie et al., 1988). Saccades may often fall short of their intended target location, therefore fixated word *n* is the unintentional landing place of a saccade intended for word *n*+1. Proponents of serial processing accounts often explain observed PoF effects in terms of a mislocated fixation account, and that any benefit due to the features of parafoveal word *n*+1 are not due to parallel processing *per se*, but due to parafoveal processing followed by an erroneous eye movement (Drieghe et al., 2008). If mislocated fixation locations explain the PoF effects observed in *Experiment 4b*, a “target word variable” × Launch Distance interaction should be observed, and effects of target word frequency, predictability and WILC should only be observed when fixations were located 3-1 characters from the beginning of the target word (i.e., an erroneous landing position from the prior saccade). If analyses by Launch Distance reveal that the initially observed PoF effects are still present at further launch distances, this would suggest that mislocated fixations do not explain the PoF effects initially observed.

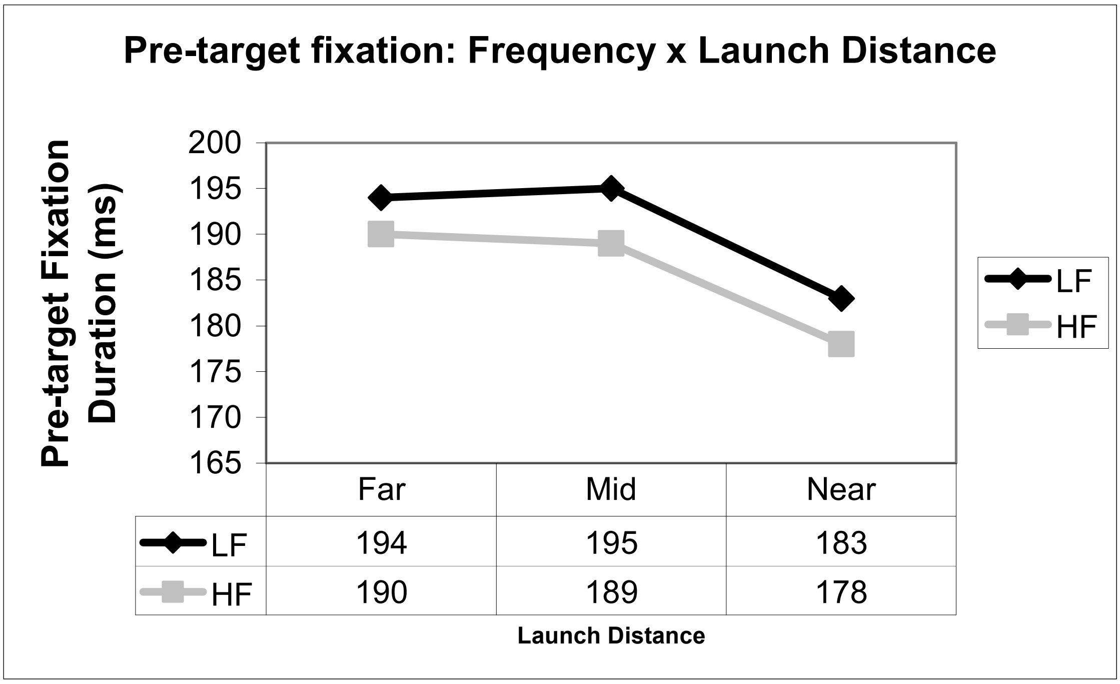
In order to examine whether mislocated fixations accounted for the pattern of PoF effects observed in *Experiment 4b*, pre-target fixation durations were conditionalised upon their distance from the beginning of the target word (launch distance). As in *Experiments 1* and *2*, *3* groups of launch distance were generated: Far (9-7 characters from beginning of the target word); Middle (6-4 characters from the beginning of the target word), and Near (3-1 characters from the beginning of the target word). After conditionalising pre-target fixations, over 76% of the original trials were available for analyses (3176 trials; Far = 880 trials; Middle = 1186 trials; Near = 1117 trials). Analyses revealed that with the smaller conditionalised data set, main effects of frequency, predictability, and WILC on pre-target fixation duration were still observed (all *p*s<.05). Condition means for the frequency × launch distance, predictability × launch distance, and WILC × launch distance interactions are presented in Table 6.3 and Figures 6.3, 6.4, and 6.5 respectively.

Table 6.3 Effects of frequency, predictability, WILC on pre-target fixation durations conditionalised by launch distance from target.

	Launch Distance			**Variable × Launch Distance**	
	Far	Mid	Near	F_1 Sig.	F_2 Sig.
LF	194	195	183	*F*<1	*F*<1
HF	190	189	178		
LP	195	191	182	>.35	>.20
HP	188	192	179		
LC	195	194	185	*F*<1	>.30
HC	189	190	176		

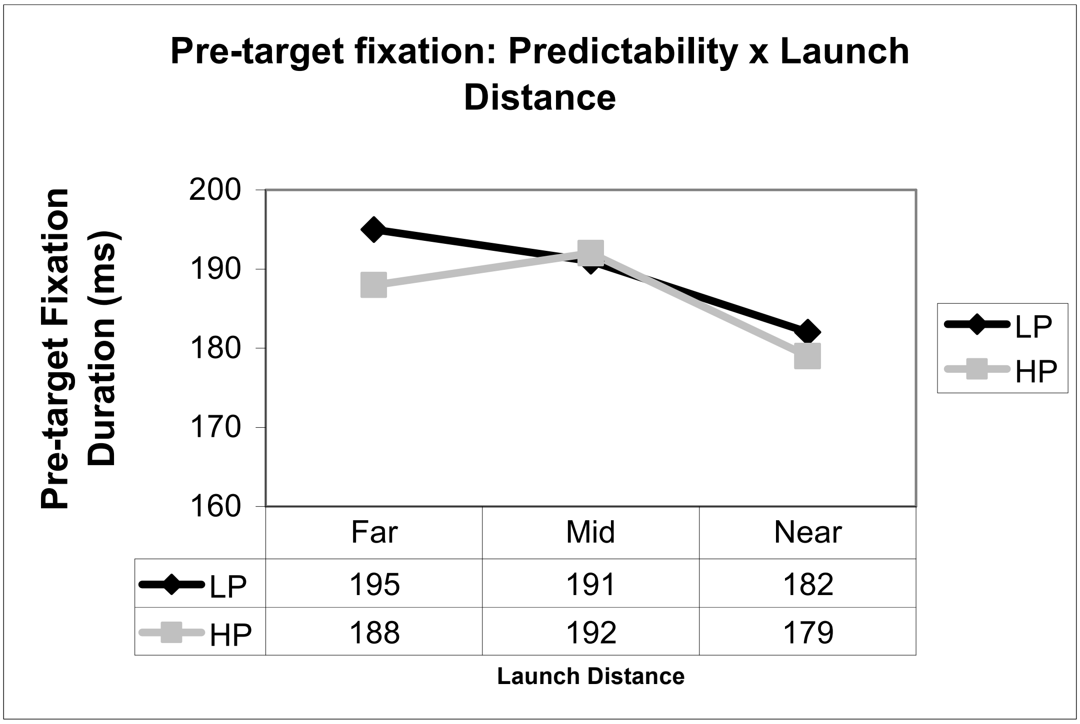
Note. Fixation durations in milliseconds. Far = 9-7 characters from beginning of target word; Mid = 6-4 characters from beginning of target word; Near = 3-1 characters from beginning of target word. LF = low-frequency; HF = high-frequency; LP = low-predictability; HP = high-predictability; LC = low-constraint; HC = high-constraint. F_1 sig. = significance of “variable” × launch distance analysis of variance by participants; F_2 sig. = significance of “variable” × launch distance analysis of variance by items.

Figure 6.3 Pre-target fixation duration: Word frequency × Launch Distance



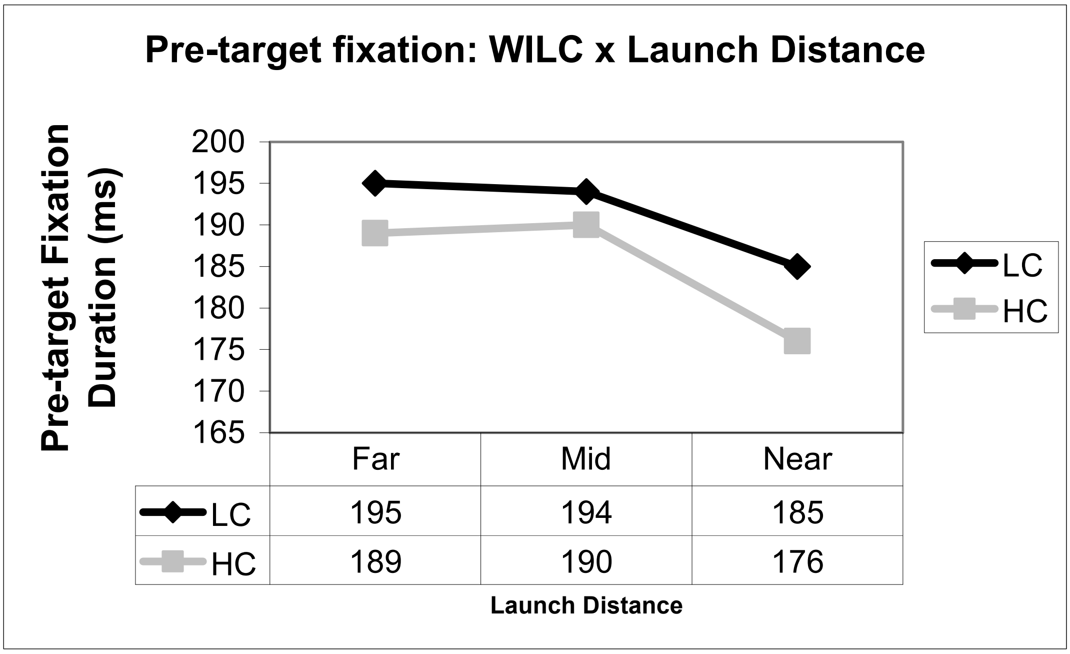
Note. Fixation durations in milliseconds. Far = 9-7 characters from beginning of target word; Mid = 6-4 characters from beginning of target word; Near = 3-1 characters from beginning of target word. LF = low-frequency; HF = high-frequency.

Figure 6.4 Pre-target fixation duration: Predictability × Launch Distance



Note. Fixation durations in milliseconds. Far = 9-7 characters from beginning of target word; Mid = 6-4 characters from beginning of target word; Near = 3-1 characters from beginning of target word. LP = low-predictability; HP = high-predictability.

Figure 6.5 Pre-target fixation duration: WILC × Launch Distance



Note. Fixation durations in milliseconds. Far = 9-7 characters from beginning of target word; Mid = 6-4 characters from beginning of target word; Near = 3-1 characters from beginning of target word. WILC = word-initial letter constraint; LC = low-constraint; HC = high-constraint.

As can be seen in Table 6.3, no interactions between target word variable and launch distance on pre-target fixation duration were significant. Although these interactions are non-significant, to examine whether mislocated fixations are driving PoF effects, the simple main effects of each word variable must be examined at each launch site. For a mislocated fixation account to explain the observed PoF effects, effects of factor should be confined to Near launch distances. However, if PoF of factors are observed at launch distances other than those Near the beginning of the target word, then a mislocated fixation account perhaps does not explain the observed PoF effects. The significance of simple main effects of each factor at each launch site are presented in Table 6.4 and Figures 6.3, 6.4, and 6.5. As can be seen from examining the simple main effects in Table 6.4, and in Figures 6.3, 6.4, and 6.5, the effects of target word variable on pre-target fixation duration are not confined to Near launch distances (where a mislocated fixation would be located). As such, it is argued that a mislocated fixation account of PoF effects does not explain the pattern of effects observed in *Experiment 4b*.

Table 6.4 Simple main effects of factors on pre-target fixation duration by launch distance.

	F_1 Sig. Launch Distance			F_2 Sig. Launch Distance		
	Far	Mid	Near	Far	Mid	Near
LF vs. HF	>.20	.06	.11	F<1	.10	.15
LP vs. HP	.08	F<1	.09	.08	F<1	.05
LC vs. HC	<.05	>.15	<.01	.05	F<1	<.05

Note. Fixation durations in milliseconds. Far = 9-7 characters from beginning of target word; Mid = 6-4 characters from beginning of target word; Near = 3-1 characters from beginning of target word. LF = low-frequency; HF = high-frequency; LP = low-predictability; HP = high-predictability; LC = low-constraint; HC = high-constraint. F_1 sig. = significance of “variable” × launch distance analysis of variance by participants; F_2 sig. = significance of “variable” × launch distance analysis of variance by items.

The present thesis found mixed evidence in support of PoF effect in reading. In *Experiment 4b*, a consistent pattern of PoF effects were observed. This experiment demonstrated reliable effects of target word frequency, predictability and WILC on pre-target fixation duration. Conditionalised analyses based on launch distance suggested that these effects were not due to readers’ mislocated fixations. However, the extent to which strong claims can be made about these results in terms of reflecting parallel processing of words in text is limited. *Experiment 4b* was not specifically designed to examine PoF effects, and as such, pre-target contexts were not as rigorously controlled as they would have been in a PoF effect-specific study. Furthermore, *Experiment 4b* does not employ a gaze-contingent display change paradigm, therefore, conclusions cannot be firmly drawn about what would happen if parafoveal text were replaced by visually-similar letters, or indeed, replaced by a string of *x*s. The PoF effects observed in *Experiment 4b* of the factors frequency, predictability and WILC merit further investigation, and that for the present set of results, with the present experimental set-up and data set, a mislocated fixation account of PoF effects does not appear to explain the observed effects.

White (2008) demonstrated an approximately 6 ms PoF effect of orthographic familiarity, and that these effects were also not confined to cases where participants had fixated 3 characters or fewer from the beginning of critical words. It may be that attention is allocated to multiple words in parallel, such that foveal word processing may occur simultaneously with the processing of the orthographic characteristics of the parafoveal word (Engebert et al., 2002, 2005; Kennedy, 2000; Kliegl & Engbert, 2003; Reilly & Radach, 2003, 2006). Alternatively, it is argued by White (2008) that attention may be allocated in a serial fashion, but that the orthographic characteristics of parafoveal words be be processed concurrently in a manner which does not require overt attention. This manner of early, preattentive visual processing of parafoveal words may affect processing of the foveal word, generating orthographic PoF effects (Reichle, Rayner, & Pollatsek, 2003; Reichle, Pollatsek, & Rayner, 2006). As with the results of White (2008), the observed orthographic PoF effect observed in *Experiment 4b* cannot distinguish between the parallel attention and visual preattentive accounts provided by, for example, SWIFT and E-Z Reader models, respectively.

<u>Launch distance as a metric of parafoveal preview benefit</u>

As stated previously, parafoveal preview is crucial for reading to proceed at a normal rate (Rayner, 1998, 2009). Typically, the amount and type of information that can be extracted parafoveally has been investigated using gaze-contingent visual display change paradigms, such as boundary techniques (see **Chapter 1**, Figure 1.3) and moving window techniques (see **Chapter 1**, Figure 1.4). The use of boundary change and moving window techniques have proved invaluable in determining the nature and amount of information that can be acquired parafoveally during reading. However, a possible limitation of these studies is that both involve non-natural presentation of text. The “boundary” paradigm manipulates parafoveal preview typically in a binary way (i.e., valid or invalid), although it must be noted that participants are very rarely aware of the display change (White, Rayner, & Liversedge, 2005). Non-foveal information is removed to varying degrees in a moving window experiment (N.B., the replacement of text outwith the boundary of the window is, in effect, a form of invalid preview).

The present thesis investigates an alternative approach to measuring parafoveal preview information to be considered, based on the established knowledge that visual acuity drops off as a function of retinal eccentricity (See **Chapter 1**, Figure 1.5.; see also Kennison & Clifton, 1995; Lavigne, Vitu, & d'Ydewalle, 2000; Rayner, 1975b; Rayner, Binder, Ashby, & Pollatsek, 2001; White & Liversedge, 2006, White, 2008). Assuming that the amount of parafoveal preview obtained is largely related to the pre-target launch distance – with greater distances giving rise to lesser previews – then target word processing as a function of launch distance should represent a more continuous, although necessarily *post-hoc*, assessment of parafoveal processing. It is proposed that the greatest strength in using launch distance as a metric of parafoveal preview is that all text – foveal and non-foveal – can be displayed without manipulation. There is evidence that the complexity of the pre-target word influences the amount of parafoveal processing on the subsequent target (e.g., Henderson & Ferreira, 1990), such effects should also be modulated by visual acuity as gauged by launch distance.

Launch distance was used as a metric of parafoveal preview benefit in *Experiments 1*, *2a*, *2b*, and *4b*. Mean SFDs on target words, conditionalised by launch distance from prior fixation are presented in Table 6.5 and Figure 6.6. Fixations prior to target words were conditionalised into Near (1-3 characters), Middle (4-6 characters), and Far (7-9 characters) launch distance groupings (N.B., in *Experiment 4b*, only Near and Far launch distances were examined due to a lack of data in the Middle launch distance group). The main effect of launch distance on target fixation duration was found to be significant in each analysis, with the diminished parafoveal preview at farther launch distances resulting in longer fixation durations on target words. The significance of comparisons of fixation times on target words from Far and Middle, Far and Near, and Middle and Near launch distances are presented in Table 6.5. As can be seen from this table, significant differences are observed between each launch distance group in each analysis.

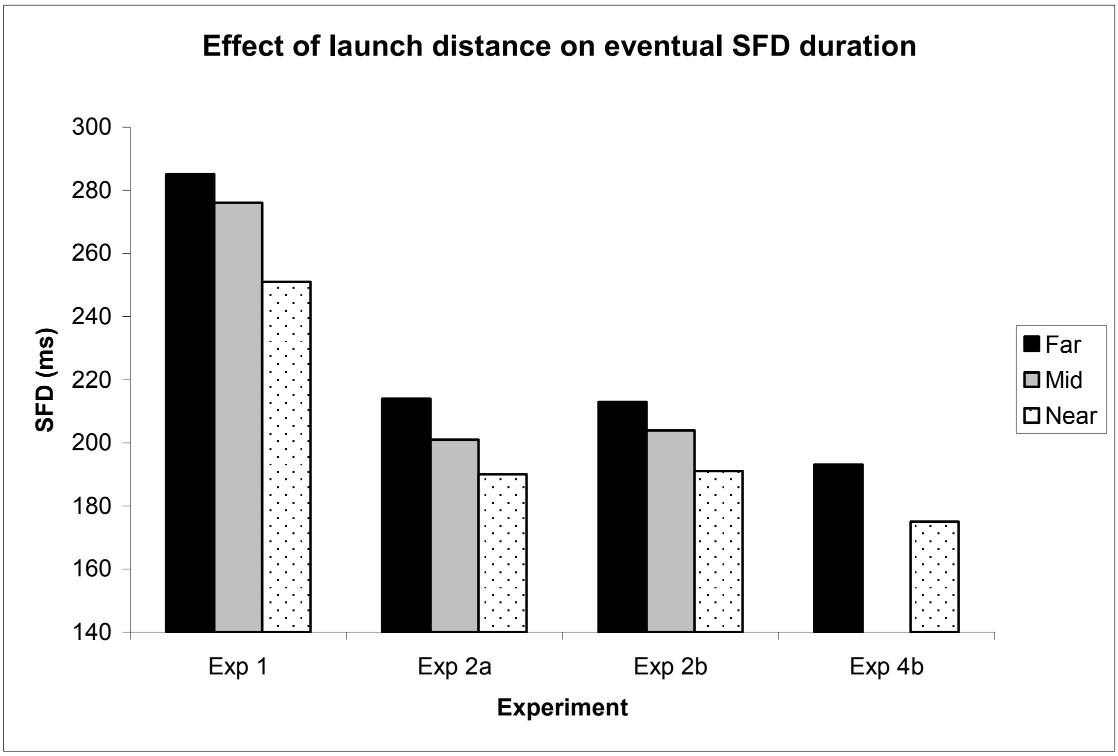
The results of these current experiments demonstrate that there are reliable effects of launch distance from target words and eventual fixation duration. Fixation duration increases as foveal eccentricity of target words increases. There are reliable differences between Far, Middle and Near launch distances, suggesting that launch distance effects are linear. Effects of launch distance must be considered when examining eye movement behaviour during reading in future, as launch distance itself influences eventual fixation duration on a word, but also influences the separate and combined effects of target word variables on target word processing.

Table 6.5 Single Fixation Durations (SFDs) on target words as a function of launch distance of prior fixation

	Launch Distance			**Comparison**		
	Far	Mid	Near	Far vs. Mid	Far vs. Near	Mid vs. Near
Experiment 1	285	276	251	<.05	<.001	<.001
Experiment 2a	214	201	190	<.01	<.001	<.05
Experiment 2b	213	204	191	<.05	<.001	<.001
Experiment 4b	193	N/A	175	N/A	<.001	N/A

Note. SFDs presented in milliseconds. Experiment 1 collapsed across frequency and predictability; *Experiment 2* collapsed across frequency and predictability; *Experiment 4b* collapsed across frequency, predictability and WILC. VLP = very low-predictability; MP = medium predictability; VHP = very high predictability. Far = 9-7 characters from beginning of target word on prior fixation; Mid = 6-4 characters from beginning of target word on prior fixation; Near = 3-1 characters from beginning of target word on prior fixation. Exp 1 conducted using dual-Purkinje eyetracker, Experiments 2 and 4b conducted using EyeLink 1000 system.

Figure 6.6 Comparison of Single Fixation Durations (SFDs) on target word as a function of launch distance of prior fixation



Note. SFDs presented in milliseconds. Exp 1 = Experiment 1 (collapsed across frequency and predictability); Exp 2a = Experiment 2a (collapsed across frequency and predictability); Exp 2b = Experiment 2ab (collapsed across frequency and predictability); Exp 4b = *Experiment 4b* (collapsed across frequency, predictability and WILC). Far = 9-7 characters from beginning of target word on prior fixation; Mid = 6-4 characters from beginning of target word on prior fixation; Near = 3-1 characters from beginning of target word on prior fixation. No Mid launch distance analyses were conducted in *Experiment 4b*. Exp 1 conducted using dual-Purkinje eyetracker, *Experiments 2* and *4b* conducted using EyeLink 1000 system.

Opportunities for further investigation

The present thesis focuses on the effects of word frequency, contextual predictability, WILC and parafoveal preview on the processing of written language. However, while the present thesis examines the individual and combined effects of these factors, there may be further factors which influence the individual and combined effects of these variables.

Transposed letter effects Fully understanding written word processing must involve a consideration of whether there is flexibility in letter encoding; particularly, whether a letter at a certain position in a word is encoded more easily than those in other positions. From an anecdotal perspective, "words" containing transposed letters (e.g., the word "*scholar*" typed / displayed as "*scohlar*") are often encountered during the course of the day – in carelessly typed e-mails, poorly proof-read articles in newspapers, and in text messages. How these transposed letter non-words are processed has been the focus of recent research. Researchers have systematically transposed letters at different positions in words to investigate the relative processing detriment caused by these transpositions (Grainger & Whitney, 2004; Rayner, White, Johnson, & Liversedge, 2006; White, Johnson, Liversedge, & Rayner, 2008).

Research using visual lexical decision tasks demonstrates that non-words composed of transposed viable words ("e.g., *jugde* from the word *judge*"; White et al., 2008, pg. 1261) are more similar to their viable form than non-words in which letters have been replaced by alternative letters ("e.g., *jupte*"; White et al. 2008, pg. 1261; Chambers, 1979; Forster, Davis, Schoknecht, & Carter, 1987; O'Connor & Forster, 1981; Perea & Lupker, 2003a, 2003b, 2004). The results of these studies suggest that transposed letter non-words may activate the lexical representations of their correct forms.

The above visual lexical decision studies investigate the lexical processing of isolated words. However, we do not normally process words as isolated tokens. Written words are more commonly processed as parts of a sentence, or indeed, as part of a paragraphs in a more global discourse context. Due to the sensitivity of written information processing to lexical variables, it is important to consider the use of eye movement methodology, not only to investigate normal aspects of lexical access, but also to investigate the processing of transposed letter non-words. Using eye movement recording techniques as opposed to isolated word techniques allows the reader to acquire information parafoveally, known to have an important role in written information processing. Furthermore, the effects of letter transposition may occur across a number of fixations and words in sentences – utilising eye movement techniques allows for the investigation of this possibility in a way not possible using isolated word techniques.

Examples of sentences containing transposed letter non-words are presented in Table 6.6. Johnson, Perea, and Rayner (2007) demonstrated that previewing a word with a transposed form of that word ("*jugde*" as a preview for "*judge*") conveys more benefit than a preview of the word with visually similar letters substituted into that word ("*jupte*"). Rayner et al. (2006) and White et al. (2008) conducted eye movement recording studies examining a series of reading time measures. The results of these studies indicated that sentences containing transposed letter non-words are read slower than normally presented sentences, but only by approximately 9% (White et al., 2008). One can subjectively experience this by reading the "Normal" example in Table 6.6., followed by the examples containing transposed letter non-words.

Table 6.6. Examples of sentences containing transposed letter non-words.

Normal	He often enjoyed a **cigar** in the evening after dinner.
IntBeg	He otfen ejnoyed a **cgiar** in the eevning atfer dniner.
IntEnd	He ofetn enjoeyd a **ciagr** in the evennig afetr dinenr.
ExtBeg	He foten nejoyed a **icgar** in the veening fater idnner.
ExtEnd	He oftne enjoyde a **cigra** in the evenign aftre dinnre.

Note. Target words presented in **bold**. Normal = no letter transpositions; IntBeg = Interior-Beginning transposition (letters 2 and 3 transposed); IntEnd = interior end transposition (penultimate and pre-penultimate letters transposed); ExtBeg = exterior beginning transposition (letters 1 and 2 transposed); ExtEnd = Exterior end transposition (penultimate and final letters transposed)

Rayner & Kaiser (1975) conducted eye movement reading studies in which letters in experimental materials were substituted for visually similar letters. In contrast to the studies of Rayner et al. (2006) and White et al. (2008), processing times for substituted letter non-words could be as much as four times longer than normal reading. Readers find it much easier to process letter transpositions when compared to letter substitutions, demonstrating that the specific letters which form a word are crucial to its identification (White et al., 2008). Readers are more capable at recovering word form when presented with transposed letter non-words as opposed to letter-substituted non-words.

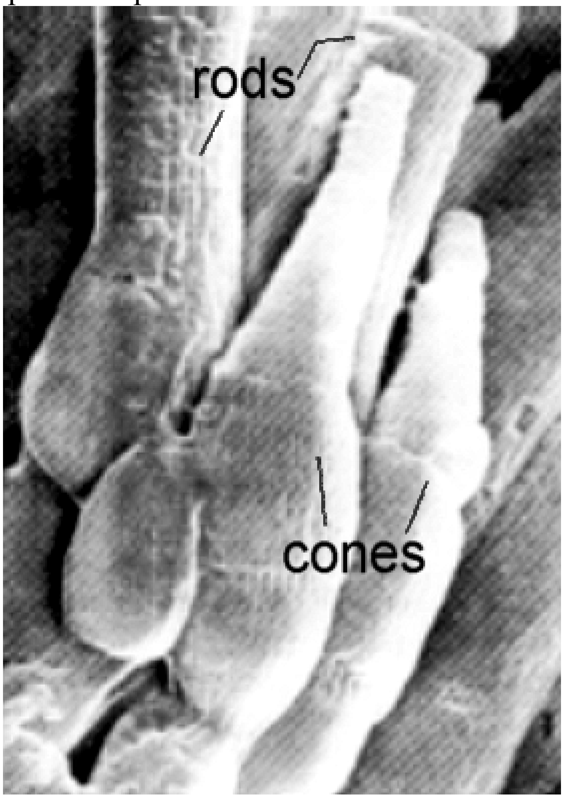
The studies by Rayner et al. (2006) and White et al. (2008) demonstrated that the difficulty in processing transposed letter non-words is dependent on how lexically difficult the word is in its correct form and which letters of the word are transposed. White et al. (2008) found that transposing letters in a lower-frequency word resulted in longer reading times than the same transpositions in a higher-frequency word. White et al. (2008) also demonstrated that certain letter positions within a word are more important than other positions – external letters are more important than internal letters (especially the word-initial letter) for successful word recognition, and that word-beginning letters are more important than word-ending letters.

It may be of interest to study the effects of letter transposition in an experimental study where the orthographic and semantic properties of target words are explicitly manipulated. For example, a visual lexical decision experiment which examines the effects of the position of a letter transposition on processing time. In addition to the effects of transposition position, the WILC and frequency of the intact word could be manipulated. This would allows the examination not only the effects of transposition, but also whether the lexical difficulty of processing the intact word influences the size of any effects of letter transposition. Alternatively, the effects of letter transpositions on eye movement behaviour during reading could be examined. Again, WILC and word frequency may be manipulated in order to see whether any observed effects of transposition were modulated by the WILC and / or frequency that target words.

Luminance contrast of parafoveal stimuli Written language is composed of visual stimuli. Photons from a visual stimulus are destined to reach the retina – the curved surface at the back of the eye. The surface human retina is covered with more than 100-million photoreceptors – cells which convert visible light into neural activity (Palmer, 1999). The amount of light which reaches the retina is governed by the pupil and the iris. Pupils constrict when presented with very well illuminated stimuli to prevent light reaching the retina; pupils dilate when responding to poorly illuminated stimuli in order to allow more light to reach the retina (Palmer, 1999). Pupil diameter is not only influenced by purely physical features of a stimulus, but also by its psychological properties. Stimuli which are emotionally positive result in pupil dilation (Hess & Polt, 1960), and stimuli which require a great deal of concentration and mental effort to process cause pupil constriction (Hess & Polt, 1964; Kahneman & Beatty, 1967).

The retina contains two different categories of photoreceptor cells – rods and cones. The names for these photoreceptors are derived from their physical shape. Rods are typically longer than cones and have untapered ends (Palmer, 1999); cones are shorter, thicker and are tapered at their ends (Palmer, 1999). Figure 6.7, taken from Lewis, Zeevi, & Werblin (1969) demonstrates the differences in physical structure of rods and cones on the surface of the retina.

Figure 6.7. Retinal photoreceptors



Note. Electron micrograph of rods and cones. Rods have a more cylindrical shape, with untapered ends; whereas cones have a more conical shape (Palmer, 1999; image taken from Lewis et al., 1969).

The retina contains approximately 120 million rods. Rods are highly sensitive to light, and are distributed throughout the retina except at the fovea (the very centre of the retina). Rods are used exclusively for vision at very low light levels. The retina contains far fewer cones than rods – there are approximately 8 million cones in contrast to 120 million rods. Cone distribution is heavily concentrated in the centre of the retina, and are responsible for vision under normal lighting conditions. The fovea, where visual acuity is highest, is populated entirely by cones.

From the study of the properties and distribution of rods and cones, it is apparent that sensitivity to *contrast* ("the relative luminance of two adjacent regions"; Palmer, 1999, pg.707) differs between foveal and parafoveal regions. The fovea is composed solely of cones, which are insensitive to contrast, whereas parafoveal regions are dominated by rods, which are highly sensitive to contrast, and function well under conditions of low illumination. It may be the case that the processing of a parafoveal stimulus may be influenced by the stimulus' contrast with its background.

The effect of luminance contrast on the processing of the parafoveal processing of written language could be investigated. Such an experiment could employ a version of a primed visual lexical decision study. Prior to being presented with target words, participants could view either a valid or invalid parafoveal prime – either the target word itself or a non-pronounceable string of letters displayed in the parafoveal region of vision for a variable amount of time prior to target word presentation. Valid primes confer a processing advantage to target words, as reflected in shorter response times to primed target words. The parafoveal prime could either be presented in high-contrast (e.g., "dwarf") or low-contrast (e.g., "dwarf"). The contrast of parafoveal primes would be manipulated in order to assess the role of rod photoreceptors in the extraction of parafoveal information. Contrast-sensitive rods are predominantly located in extrafoveal regions of the retina. As such, there may be a difference in the size of priming effects (indexed by response times to primed foveal target words) as a function of the contrast of the parafoveal prime.

Target words and associated primes could be manipulated across the dimensions of word frequency and WILC in order to examine the importance of these factors in extracting information from the parafoveal prime. Although participants' task in such an experiment is a visual lexical decision experiment, their eye movements could be monitored using an eye tracking system to ensure that fixation is maintained on a central fixation point. Eye movements toward parafoveal primes could result in trial cancellation, as any foveal processing of what is supposed to be parafoveally presented information would lead to greater amounts of information being extracted from the prime, and therefore an unfair advantage to processing of the eventual centrally presented target word.

Conclusion

The present study was conducted to examine the individual and combined effects of word frequency, contextual predictability, WILC and parafoveal preview benefit as indexed by launch distance from target words on prior fixation on a range of written language processing measures. Typical individual effects of word frequency and contextual predictability were observed. Word frequency was also found to influence the probability of fixating a target word, but only when those target words fulfilled certain frequency criteria. The effects of word frequency and contextual predictability were found to exert interactive effects on fixation durations, wherein the processing of an LF word was facilitated to a greater extent by a supportive context than was the processing of an HF word. However, this pattern only arose when contexts are VHP, or alternatively, when contexts were MP, and parafoveal preview is high (as provided by a Near launch distance). Effects of WILC were observed, but the nature of these effects were task-dependent. In a visual lexical decision task, LC words were processed faster than HC words. In reading, HC words were processed faster than LC words. It is argued that in visual lexical decision tasks, the common initial trigram of an LC word facilitates the “word” response, while the unusual initial trigram of the HC word impedes this response. During reading, information provided from both the parafovea and sentential context appears to provide a processing advantage for HC words. Fixation durations on target words increased as launch distance increased, and reliable differences between Far, Middle and Near groups of launch distance were observed. Thus, it is argued that launch distance provides a useful, but necessarily post-hoc, measure of parafoveal preview benefit.

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Appendix I

Experimental Materials – Chapters 2 and 4

Note. Target words are presented in **bold**. HF / LF = high / low frequency targets; HP / LP = high / low predictability targets. [lb] indicates where experimental items were split over two lines of on-screen display.

HF-P | LF-U	On holiday for a week, Jill and Harry decided to redecorate [lb] some rooms in their **house** | **motel** that they felt needed making over.
LF-P | HF-U	Exhausted from driving, and lost on the dusty highway, [lb] Tony decided to stop at the first **motel** | **house** to get directions.
HF-P | LF-U	The gifted students were selected to receive extra lessons [lb] at the local **school** | **circus** during weekends and holidays.
LF-P | HF-U	All the children were thoroughly amused by the clowns that [lb] came once a year to the **circus** | **school** in their village.
HF-P | LF-U	Denice was inconsolable after her friend's death. At the [lb] funeral, she wore a sombre **black** | **satin** dress and cried throughout.
LF-P | HF-U	In preparation for her luxury spa weekend trip, Lucy treated [lb] herself to some fancy, new **satin** | **black** pyjamas from the boutique.
HF-P | LF-U	Helena enjoyed literature and writing essays. She was going [lb] to university to study **English** | **Zoology** and hoped to teach one day.
LF-P | HF-U	Paul was sure he'd be made curator of exotic animals at the [lb] nature park. He had a degree in **Zoology** | **English** and vast experience.
HF-P | LF-U	Construction work was now complete, and everyone was excited [lb] about the opening of the new **building** | **monument** in the city centre.
LF-P | HF-U	Many locals had died in the battle. In their memory, the [lb] community erected a **monument** | **building** in the town square.
HF-P | LF-U	When Ann served against a superior tennis opponent, she [lb] always expected that the ball would **return** | **bounce** even faster.
LF-P | HF-U	Robbie enjoyed playing football. He spent hours kicking the [lb] ball against a wall and having it **bounce** | **return** back to him.
HF-P | LF-U	A problem with the cattle was that they would occasionally [lb] wander into the nearby **field** | **swamp** that belonged to Farmer Smith.
LF-P | HF-U	When crossing the marshlands, it was possible to become [lb] trapped in a muddy **swamp** | **field** if there had been heavy rainfall.
HF-P | LF-U	Rinsing hadn't stopped the bleach from burning his eyes. [lb] He needed emergency attention from the **hospital** | **optician** immediately.
LF-P | HF-U	As he had grown older, his eyesight had deteriorated. He [lb] thought he should visit the **optician** | **hospital** and get new glasses.

HF-P | LF-U   Guests were arriving and Jen's flat was a sty. She picked up [lb]
her clothes from the **floor | couch** and quickly cleaned the bathroom.

LF-P | HF-U   Clare had been on her feet all day. Armed with a pizza and [lb]
a video, she laid down on the **couch | floor** for a relaxing evening.

HF-P | LF-U   None of the baker's plans for the wedding cake had satisfied [lb]
the bride. He had completely run out of **ideas | yeast** and was irate.

LF-P | HF-U   Amy's bread dough for the dinner wouldn't rise and the shops [lb]
were now closed. She had run out of **yeast | ideas** and was panicking.

HF-P | LF-U   Before her big date tonight, Natalie brushed her teeth until [lb]
she was sure they were thoroughly **clean | shiny** before meeting Luke.

LF-P | HF-U   Wanting to make a good impression at the interview, Albert [lb]
polished his nicest shoes to make them as **shiny | clean** as possible.

HF-P | LF-U   They could have spent a week at the castle, but their train [lb]
was leaving. They rushed to the **station | dungeon** before time ran out.

LF-P | HF-U   Hearing about torture in the castle made Debbie squeamish. [lb]
She left the tour group in the **dungeon | station** and went for a smoke.

HF-P | LF-U   The dentist carelessly let the extracted tooth slip from his [lb]
tweezers into the patient's **mouth | beard** to their mutual surprise.

LF-P | HF-U   As the scruffy professor struggled for inspiration, he would [lb]
pace his office and stroke his **beard | mouth** hoping to find answers.

HF-P | LF-U   Frank was going to call the police. He was fed up with kids [lb]
throwing stones at his **windows | chimney** as damage could be done.

LF-P | HF-U   The real coal fire was wonderful, but every month we had to [lb]
have the sooty **chimney | windows** cleaned, to our great inconvenience.

HF-P | LF-U   Arriving late, Penelope thought the birthday cake would be [lb]
finished, but there was still a small **piece | crumb** left in the box.

LF-P | HF-U   Roger loved eating biscuits in bed. However, he was very [lb]
careful not to drop a single **crumb | piece** as his wife would be mad.

HF-P | LF-U   Because of heavy congestion on the roads, most of the [lb]
freight was transported by **train | barge** whenever possible.

LF-P | HF-U   The gypsies travelled along the canal by hiding in the [lb]
cargo of a slow moving **barge | train** in the middle of the night.

HF-P | LF-U   While Linda was away on holiday, she arranged for her friend [lb]
to come by and water all the **plants | tulips** in her window boxes.

LF-P | HF-U   Our photos from Holland were mostly of museums, windmills, [lb]
and well-kept parks full of **tulips | plants** of all different colours.

HF-P | LF-U	The Boy Scouts' weekend trip was a good way to teach them how to set up camp in the **forest** | **jungle** should they ever have to.
LF-P | HF-U	Their plane went down miles from any village. Injured and lost, they had to survive the **jungle** | **forest** to make it back alive.
HF-P | LF-U	At her favourite band's concert, Melissa pushed to the front [lb] and was so close that she could almost **touch** | **grope** the singer.
LF-P | HF-U	The boss would lose his job. His secretary had reported him [lb] after he had tried to **grope** | **touch** her in the stationary cupboard.
HF-P | LF-U	After dessert, they ordered some **coffee** | **brandy** and took it through [lb] to the bar so that Jean could have a cigarette.
LF-P | HF-U	Dinner in the Paris bistro was superb. They agreed to finish [lb] their meal with a luxury **brandy** | **coffee** as they were on holiday.
HF-P | LF-U	Kyle knew he would go to prison. He had been caught outside [lb] the club selling ecstasy-laced **drugs** | **mints** to undercover police.
LF-P | HF-U	The smell of garlic was on his breath. Before going out, he [lb] thought he should take some **mints** | **drugs** in case he met a girl.
HF-P | LF-U	John's bank manager would not give him the loan because [lb] he hadn't brought a valid **document** | **passport** for identification.
LF-P | HF-U	The immigrant was sure he would be deported. He had been [lb] caught with a fake **passport** | **document** by customs officers at the port.
HF-P | LF-U	Dave's birthday was usually an event to remember. This year [lb] he and his friends were having a huge **party** | **disco** to celebrate.
LF-P | HF-U	My parents met in the Seventies, when every Saturday night [lb] they would go into town to a **disco** | **party** and dance the night away.
HF-P | LF-U	Gillian was on the last mile of the women's marathon. She [lb] grabbed a bottle of **water** | **lager** from a spectator and drank it.
LF-P | HF-U	Although a rugby player, Clive struggled through the crowd [lb] at the bar carrying glasses of **lager** | **water** and bags of crisps.
HF-P | LF-U	George had been raised to be kind to everyone in his life [lb] and was undoubtedly the nicest **person** | **waiter** Angela had ever met.
LF-P | HF-U	The starters had not yet arrived. Annoyed, Peter decided to [lb] stop the next **waiter** | **person** he saw and complain about the service.
HF-P | LF-U	When Colin needed refuge from the pressures of everyday [lb] life, he would go to the **church** | **quarry** to sit alone and reflect.
LF-P | HF-U	The children were warned about throwing stones and playing [lb] in the abandoned **quarry** | **church** as they could get seriously injured.

HF-P | LF-U The boss and foreman argued. Feeling awkward, the workers [lb]
thought it was best to **leave | drill** and let them argue in private.

LF-P | HF-U They knew the other area had much more oil, but their bosses [lb]
wouldn't allow them to **drill | leave** until the current job was done.

HF-P | LF-U At school, Nigel enjoyed painting with wild brush strokes. [lb]
He covered every inch of his **paper** | **easel** with untidy smears.

LF-P | HF-U In art class, the first thing that Phillipa did was ensure [lb]
that she had correctly set up her **easel** | **paper** before painting.

HF-P | LF-U The noise from next door was outrageous. No one could get [lb]
any sleep because of the loud **music** | **siren** that went on all night.

LF-P | HF-U The civil defence drill had been a great success. Everyone [lb]
had been able to hear the **siren** | **music** that would signal an attack.

HF-P | LF-U Simon was stressed. His had to e-mail his coursework to his [lb]
tutor but his **computer** | **keyboard** had broken and he couldn't fix it.

LF-P | HF-U Rachael was finishing typing in the report when she spilled [lb]
her tea, getting her desk and **keyboard** | **computer** completely soaked.

HF-P | LF-U Sheila's son had been involved in a fight at school. Before [lb]
deciding what to do, she would talk to her **husband | nephews** tonight.

LF-P | HF-U Mary loved toyshops at Christmas. Although she did not have [lb]
children, she would buy gifts for her **nephews | husband** instead.

HF-P | LF-U The storm had come unexpectedly. The tarpaulin would have [lb]
to be stretched to provide a **cover** | **quilt** for everyone caught out.

LF-P | HF-U After purchasing a new mattress and pillows, it made sense [lb]
to buy a new **quilt** | **cover** and cotton sheets for their new bedroom.

HF-P | LF-U Mr. Bain had the flu. Being a busy man, he made an emergency [lb]
appointment with his **doctor** | **banker** before rushing to the office.

LF-P | HF-U Fiona was interested in finance. After obtaining a degree in [lb]
Accounting, she hoped to become a **banker | doctor** and live in London.

HF-P | LF-U Gardening is a very rewarding hobby. I enjoy being able [lb]
to feel the **earth** | **filth** between my fingers when planting bulbs.

LF-P | HF-U The youth hostel hadn't been cleaned in months. Maria had [lb]
never seen so much **filth** | **earth** on one floor in her whole life.

HF-P | LF-U Jamming all my laundry into the washer, I ignored the fact [lb]
that it could **break | erupt** because I had overloaded its capacity.

LF-P | HF-U The geologists hurried to get away from the volcano. Their [lb]
measurements suggested that it could **erupt** | **break** at any moment.

HF-P | LF-U	Their day at the zoo was certain to be good. The children [lb] looked forward to seeing the **animals** | **giraffe** and having a picnic.
LF-P | HF-U	On safari, we witnessed the upper leaves of the acacia tree [lb] being eaten by the hungry **giraffe** | **animals** and we took a picture.
HF-P | LF-U	Callum was having trouble with his homework. He asked his [lb] uncle who was a **teacher** | **plumber** to help him with the assignment.
LF-P | HF-U	Ingrid's boiler had suddenly broken down. Fortunately, her [lb] neighbour's father was a **plumber** | **teacher** and would be able to help.
HF-P | LF-U	Little Joey loved the story his father told about the cowboy [lb] and his faithful **horse** | **puppy** and the adventures they had together.
LF-P | HF-U	Emma prayed for a cute pet every Christmas. Her heart leapt [lb] when she saw a beautiful **puppy** | **horse** waiting outside in the pen.
HF-P | LF-U	Sitting outside at his barbecue, Brian got so drunk that he [lb] almost fell off his **chair** | **patio** and was very embarrassed indeed.
LF-P | HF-U	As a kid, when summer came, I spent my days playing in the [lb] park and my nights out on my Grandad's **patio** | **chair** reading comics.
HF-P | LF-U	Arranging tables in the cafe was difficult. Some were oblong [lb] and others were **square** | **chrome** and they differed in height as well.
LF-P | HF-U	The tenants liked the look of their new bathroom. All the [lb] fixtures were **chrome** | **square** and fit the modern design of the house.
HF-P | LF-U	Nowhere was safe for the prime suspect. A national manhunt [lb] was underway as the **murder** | **thefts** had caused public outcry.
LF-P | HF-U	Locals were advised to lock all doors and especially their [lb] windows. There had been reports of **thefts** | **murder** in the town.
HF-P | LF-U	Unusually, the children weren't home yet. Their parents [lb] hoped they would be home for **dinner** | **sunset** as they were worried.
LF-P | HF-U	Living on the coast meant that Jane and Dan could enjoy a [lb] beautiful **sunset** | **dinner** before going for a stroll along the beach.
HF-P | LF-U	The police had been on Wayne's tail for a long time. He was [lb] well known to be a **criminal** | **hooligan** but they had little evidence.
LF-P | HF-U	Sid was not allowed into Austria to watch his favourite [lb] football team. He was a known **hooligan** | **criminal** and troublemaker.
HF-P | LF-U	After the war, there was much rebuilding to do. To maintain [lb] order, British **troops** | **cadets** had visible presence as peacekeepers.
LF-P | HF-U	The young men all wanted to be in the army. Until they were [lb] old enough, they would serve as **cadets** | **troops** in local forces.

Appendix II

Target word characteristics – Chapters 2 and 4

Note. All figures shown to 2 decimal places. HF = high frequency; LF = low frequency; Freq per million = frequency of occurrence per million words; HP/LP= target in high predictability context / target in low predictability context; Rating = predictability rating (1=highly unpredictable, 7=highly predictable); Cloze = cloze predictability rating.

HF Target	length	Freq per million	Rating LP	Rating HP	Cloze LP	Cloze HP
house	5	512.32	4.40	6.63	0.00	0.80
school	6	367.33	5.00	5.29	0.00	0.75
black	5	257.91	3.47	6.93	0.00	0.05
English	7	246.64	2.21	6.67	0.00	0.95
building	8	195.26	3.20	5.93	0.00	0.05
return	6	180.37	4.53	6.50	0.10	0.15
field	5	162.91	5.67	6.80	0.05	0.40
hospital	8	156.67	2.27	6.67	0.00	0.40
floor	5	117.41	3.53	5.93	0.00	0.90
ideas	5	115.27	5.00	5.73	0.00	0.65
clean	5	111.43	5.64	6.20	0.10	0.95
station	7	102.82	2.33	6.47	0.00	0.80
mouth	5	98.52	2.87	6.29	0.00	0.65
windows	7	91.79	4.00	5.73	0.00	0.80
piece	5	89.99	4.13	6.13	0.00	0.45
train	5	81.71	4.33	5.80	0.00	0.40
plants	6	77.82	4.53	6.67	0.00	1.00
forest	6	76.88	4.33	5.80	0.00	0.70
touch	5	67.92	4.80	6.33	0.15	0.80
coffee	6	63.6	4.93	6.47	0.15	0.75
drugs	5	56.18	1.60	6.40	0.00	0.05
document	8	53.52	5.47	6.27	0.00	0.05
party	5	421.66	5.14	6.73	0.00	1.00
water	5	357.54	3.14	6.47	0.00	0.95
person	6	249.46	3.87	6.33	0.00	0.80
church	6	215.48	4.27	5.73	0.05	0.05
leave	5	195.08	5.40	6.13	0.00	0.50
paper	5	166.04	4.80	6.00	0.00	0.60
music	5	158.07	1.93	6.40	0.00	0.65
computer	8	144.04	5.40	6.80	0.10	0.80
husband	7	115.77	4.47	5.67	0.00	0.75
cover	5	112.28	5.87	5.20	0.00	0.35
doctor	6	104.34	3.93	6.33	0.00	1.00
earth	5	101.58	2.13	5.93	0.00	0.10
break	5	92.8	2.40	5.73	0.00	0.70
animals	7	90.6	5.00	7.00	0.00	0.30
teacher	7	89.47	2.00	6.73	0.00	0.75
horse	5	79.14	3.00	6.07	0.00	0.80
chair	5	77.47	4.60	6.60	0.00	0.80
square	6	71.27	4.13	5.36	0.00	0.85
murder	6	64.24	5.13	6.13	0.00	0.11
dinner	6	58.97	4.13	6.00	0.00	1.00
criminal	8	55.26	5.27	6.13	0.30	0.35
troops	6	52.41	5.00	5.40	0.00	0.55
Average	5.89	144.48	4.07	6.19	0.02	0.60

LF Target	length	Freq per million	Rating LP	Rating HP	Cloze LP	Cloze HP
motel	5	1.58	1.64	5.63	0.00	0.40
circus	6	7.54	2.00	5.67	0.00	0.35
satin	5	5.00	3.27	5.87	0.00	0.00
Zoology	7	1.26	1.79	6.40	0.00	0.90
monument	8	7.92	4.20	6.63	0.00	0.60
bounce	6	5.08	4.00	6.60	0.20	0.75
swamp	5	3.33	3.00	6.47	0.00	0.30
optician	8	0.86	4.07	6.60	0.05	0.95
couch	5	5.59	4.07	6.20	0.00	0.95
yeast	5	4.17	2.47	5.93	0.00	0.25
shiny	5	7.67	4.00	6.00	0.00	0.75
dungeon	7	1.41	5.00	6.07	0.00	0.30
beard	5	9.74	3.67	6.00	0.00	0.65
chimney	7	6.73	3.33	6.53	0.00	0.65
crumb	5	0.81	4.53	6.47	0.00	1.00
barge	5	3.50	4.86	5.67	0.00	0.85
tulips	6	1.16	4.36	6.36	0.00	0.50
jungle	6	10.41	4.53	5.00	0.00	0.05
grope	5	0.49	3.36	6.40	0.00	0.05
brandy	6	9.66	5.00	5.13	0.00	0.05
mints	5	1.03	4.27	6.40	0.00	0.85
passport	8	8.40	6.07	6.43	0.30	0.80
disco	5	7.49	5.53	6.47	0.00	0.90
lager	5	5.17	1.33	5.07	0.00	0.65
waiter	6	8.14	2.80	6.67	0.00	0.75
quarry	6	9.34	3.07	5.93	0.00	0.00
drill	5	10.10	3.40	5.86	0.00	0.40
easel	5	1.96	3.93	5.71	0.00	0.55
siren	5	2.68	3.43	5.93	0.00	0.30
keyboard	8	9.91	5.53	6.20	0.00	0.20
nephews	7	1.22	3.33	5.80	0.00	0.85
quilt	5	1.98	2.67	5.87	0.00	0.55
banker	6	6.07	3.53	6.67	0.00	0.20
filth	5	3.10	2.40	6.33	0.00	0.45
erupt	5	1.37	3.53	6.67	0.00	0.80
giraffe	7	0.74	5.47	6.60	0.20	0.80
plumber	7	1.99	2.57	6.54	0.00	0.80
puppy	5	4.79	2.47	6.27	0.00	0.85
patio	5	4.34	3.80	5.53	0.00	0.00
chrome	6	2.03	2.47	5.57	0.00	0.05
thefts	6	2.67	4.60	6.53	0.00	0.45
sunset	6	6.13	4.47	5.67	0.00	0.15
hooligan	8	2.21	4.47	6.36	0.00	0.70
cadets	6	2.21	4.07	6.20	0.00	0.60
Average	5.89	4.52	3.69	6.11	0.02	0.52

Appendix III

Experimental Materials – Chapter 3

Note. Target words presented in underlined font. HF = high-frequency targets; LF = low-frequency targets; VHP = high predictability targets; MP = medium predictability targets; VLP = low predictability targets.

LF-VLP

Henry loved going out for a pint of lager after finishing work.
Sometimes, he would have lime cordial added to give it a twist.

Patsy strongly believed that the UK judicial system needed reform.
It was clear that jail was not enough of a deterrent to criminals.

The careless trainee caused havoc on the petrol station forecourt.
He knocked over an entire drum of oil and it made a dreadful mess.

Anthony and Harriet were allowed to go out and play after school.
Their parents wanted them home before dusk because it was a weeknight.

Seeing a lot of hornets in Britain is somewhat unusual.
It is more common to see a hive of bees or a wasps' nest.

Overnight, vandals had ruined my prized cherry blossom tree.
They had ripped off the bark and scattered it across the lawn.

Arthur was at home, preparing vegetables to accompany his dinner.
He steamed some peas and spooned them onto the side of his plate.

The house hunters had a very good idea of what they were looking for.
They wanted a house with a large attic to convert into a home office.

Justin was an enthusiastic baker and was eager to try new things.
He was excited about trying his new recipe for icing at the weekend.

It was very difficult finding a new leather jacket that fitted.
I eventually found one at a stall at the local outdoor market.

Jessica was keen to try and improve her diet by eating more fruit.
She went to the shop to buy some melon chunks to eat at her desk.

City officials planned to improve levels of public welfare.
They were to upgrade the sewer system with improved filters.

Sara always remembers to collect her morning paper on the way to work.
She enjoys the puzzle pages and eagerly tries to finish the crossword.

Zak wasn't enjoying working as the mechanic in the farming village.
He hated it when the grease from the engines got onto his overalls.

Tracy got a glass and began making herself a Bloody Mary.
She added some pepper to give it a little bit of a kick.

The bird watchers were silent as they waited for the rare swallows.
They were startled when a rabbit suddenly dashed out from the bushes.

The old pirate sat in the ale house thinking back to his younger days.
He fondly remembered his parrot who had been a great companion at sea.

Mr. Anderson, the French teacher, had a slight wardrobe malfunction.
Embarrassingly, his <u>button</u> came off his trousers as he was teaching.

Heather had spent the last few nights tossing and turning in bed.
She thought she should change her <u>pillow</u> for a new feather one.

Paul had to go into town to pick up some groceries.
He got on the <u>scooter</u> and revved up the engine.

The distraught child was in floods of tears and inconsolable.
He'd lost his <u>balloon</u> and the man selling them had none left.

The local community centre was offering a variety of evening classes.
Denise enrolled in the <u>pottery</u> class since she wanted to make vases.

The evening news carried a special report about conflict in the Sudan.
The story was told by a <u>refugee</u> who had managed to escape the country.

The defendant stood up and the judge announced the guilty verdict.
There was a van waiting to take the <u>convict</u> to prison immediately.

The electrical goods shop was having a huge sale this weekend.
There was a good deal on a <u>blender</u> that had multiple settings.

The old friends were heading away for a golfing weekend in Portugal.
It would be nice to have a <u>reunion</u> every year but it was not possible.

My Mum has many delicate china trinkets arranged on her mantle piece.
She carefully dusts each <u>ornament</u> every week to keep them pristine.

Everyone was pleased when Jason arrived at the pub unexpectedly.
He had just popped in to say <u>farewell</u> before he went on holiday.

German U-boats patrolling the Atlantic fired torpedoes at the convoy.
One of them struck a <u>civilian</u> ship and several dozen souls were lost.

Tina often had a hard time at friends' parties when she was a child.
Growing up with <u>diabetes</u> meant that she had to watch what she ate.

LF-MP

Elspeth ran away from her parents' home when she was seventeen.
She joined a <u>cult</u> that promised to take her away on a space ship.

The wild winds on the hill walk had left Jon's hair all tangled.
At home, he used his <u>comb</u> but it took an hour to get out the snarls.

Colin couldn't resist the advances of the sexy new secretary.
He was overcome with <u>lust</u> and embraced her passionately.

Lucy returned home after another hard day at the office.
She slumped onto the <u>sofa</u> and turned on the television.

The bride chatted nervously to her dad before walking down the aisle.
When the music started, she lowered her <u>veil</u> and grabbed his arm.

The little boy enjoyed dressing up and pretending to be Superman.
He would put on a <u>cape</u> and zoom around the house as if he were flying.

The critically acclaimed restaurant was fully booked once again.
They had hired a talented <u>chef</u> who had transformed their menu.

When preparing a turkey, you do not have to throw away the giblets.
These can be used to make gravy to be served with the roasted bird.

The school children were impressed after their trip to the aquarium.
They admired the shark as it slipped through the water like a knife.

The bar brawl ended with Frank being hit hard square in the mouth.
The punch broke his tooth and would need to be capped.

The Emperor celebrated his victory by arranging a lavish banquet.
It was a sumptuous feast which was heartily devoured by his Generals.

Rory was going to dig all day in the potato fields.
He picked up his spade and headed off to work.

The magazine had a special feature dedicated to Britney Spears.
It included a full size poster of her from her latest concert tour.

Dave wanted to build a new bookcase but couldn't find his toolbox.
Eventually, he had to borrow a hammer and nails from his neighbour.

A recent biography revealed Cuthbert's passion for going on safari.
He was a ruthless hunter with a reputation for killing big game.

The Master insisted that his butler pressed his shirts immaculately.
Hobbs would carefully starch the collar of each shirt every morning.

Fred decided to make some chips to have with his dinner that evening.
He selected a large potato and sliced it up thinly for the fryer.

Dan set the table in preparation for his romantic meal that night.
In the middle of the table, he placed a candle which he later lit.

Lola admired the grace of the Bolshoi dancers performing "Swan Lake".
She loved going to the ballet whenever this company came to town.

Violet and Quentin were having a heated argument in their lounge.
Swearing loudly, she picked up a cushion and threw it at his head.

The school cafeteria was in a ghastly state after the pupils had left.
It was unfair to expect the cleaner to come in and sort out this mess.

Holidaymakers on Corfu were unprepared for the intense heat wave.
The next day, many of them had sunburn that needed medical attention.

Matt had a habit of continually hunching over his keyboard.
He knew that his bad posture could lead to future back problems.

The sun appeared from behind the clouds, making the golfer too warm.
He removed his sweater and placed it carefully into his golf bag.

Will's hair was a mess after his friends poured green paint over him.
He used nearly a whole bottle of shampoo to try and get it out.

In many parts of Africa it is common for no rain to fall for months.
It is known that drought often causes crop failure in these regions.

Kieran planned to get his wife an expensive birthday present.
He knew she really wanted a necklace which was made from pearls.

Working for the Foreign Office, Olivia met many interesting people.
She had recently started dating a diplomat from the Russian Embassy.

Thomas Edison was one of the great pioneers of the Industrial Era.
He is still highly respected as an inventor centuries after his death.

Returning from work, Holly saw that her house had been broken into.
She called to report the burglary and waited for the police to arrive.

LF-VHP

Gordon bought another replacement fuse for his unreliable kettle.
He removed the screws from the plug and noticed burn marks inside.

Protestors picketed the zoo about the conditions the lion was kept in.
They wanted it removed from its cage and allowed to roam in a paddock.

Jimmy ran down the hill, gripping the string in the strong winds.
He loved to play with his kite but rarely got the right conditions.

Zoë loved fresh flowers and often brought some in from her garden.
She put them in a vase with water and placed them on the window sill.

Martin lost his temper and broke his wife's favourite ornament in two.
He would need to find some glue to repair it before she got home.

Aladdin was in trouble and needed one of his wishes to be granted.
He rubbed his lamp and with a puff of smoke, the genie appeared.

The timer buzzed and Mum knew that her apple pie was finally ready.
She lifted it out of the oven and placed it on the counter to cool.

Alison gasped as she dropped a glass of red wine onto the carpet.
Hurriedly, she tried to remove the stain with some soap and water.

Joey excitedly told his parents he saw a striped horse at the zoo.
His parents explained that the animal was a zebra from Africa.

After his morning jog, Gregor was happy to take a long, hot shower.
When he stepped out, he reached for his towel but it wasn't there.

Old Mrs. Greeble was warty, haggard, and had a fearsome black cat.
The older kids said that she was a witch to scare the younger ones.

Ponies and horses are not suited to travelling across deserts.
The best animal for this is the camel as it rarely needs water.

The rebels decided to assassinate the President by tainting his food.
One of them infiltrated the kitchen and added the poison to his soup.

In the Muslim world, prayer congregations are held on a Friday.
People will go to their local mosque and offer up their praise.

Harry went to Saville Row in London to purchase his new suit.
He had an appointment to be measured by a tailor at great expense.

At work, the boiler had broken and we were freezing at our desks.
We arranged for a portable heater to be brought into the office.

At the party, Ryan discovered that all the beer cans were warm.
No one had put any in the fridge and they tasted unpleasant.

Brigit sat in admiration, examining the structure of the delicate web.
She was amazed that one spider could produce something so intricate.

Mick left his car headlights on overnight and his car wouldn't start.
He lifted up the bonnet and attached jump leads to the battery.

Little Kirsty spent hours dressing up as a witch on Halloween.
Everyone at school thought that her costume was the best this year.

The danger posed by mosquitoes in hot climates is well known.
The main threat is the spread of malaria which can cost lives.

Most retailers allow customers to return goods within thirty days.
However, they have to provide their receipt as proof of purchase.

Nick gazed hungrily into the tank at the expensive seafood restaurant.
He selected the biggest lobster to be taken away and cooked.

Emma was overcome by a strong scent at the store's beauty counter.
A bottle of expensive perfume had fallen from the shelf and smashed.

Diana's supply of clean clothes was diminishing rapidly.
She really needed to do her laundry before she completely ran out.

Gillian nicked her finger with the knife while chopping vegetables.
She rinsed the blood and put on a plaster before she continued.

The newlyweds left the church to loud cheers from their guests.
Everyone threw confetti as they made their way to the wedding car.

A local newspaper was covering the story of a kidnapping in the city.
They assigned their most experienced reporter to write the article.

Julie was getting ready for a date and nervously put on her make-up.
She wore red lipstick as it flattered her and matched her outfit.

Often, women are paid less than men for doing similar jobs.
The fight for equality is still ongoing in most professions.

HF-VLP

Polly went shopping to buy a new laptop to use for her college work.
She had needed to get a loan from her sister, but would pay it back.

After his mother's death, Leo was left with large medical bills.
He wanted to sell her land as quickly as he could to raise cash.

The zookeepers were busy preparing for their latest arrival.
They were getting a baby bear that had been born in America.

Chloe loved going outside to have fun with her assorted toys.
She loved to play with her ball in the yard when the sun shone.

The sales team were pushing hard as the end of the month loomed.
They had been set a certain goal by the director of the company.

Eugene was at the supermarket deciding which brand of milk to buy.
He checked the date on each carton and chose one that was freshest.

Bertie arrived in York without having arranged accommodation.
He checked into the first room he found that he could afford.

Juliet kissed her husband on the cheek as he was leaving for work.
She noticed that he had left his phone and ran outside after him.

The student in the flat was unhappy with their useless flatmate.
He was having his power cut off because of unpaid utility bills.

The men looked very presentable in their white shirts and black ties.
They were going to a party dressed as characters from Reservoir Dogs.

James had scratchy tonsils and suspected he was getting a bad cold.
The next morning, his voice was hoarse and it was painful to speak.

The burglar was quiet and efficient as he stole the valuables.
He quickly ran to the house across the street and robbed it too.

Local businesses donated to a regeneration fund for the town centre.
There were plans for a garden to be built with colourful flowers.

The politician was greeted with boos when he visited the school.
It was obvious that the public were not happy with his policies.

Meeting Winston, you would never have guessed he was as old as he was.
Age had not affected his memory the way it affected many other people.

Carlos spent thousands on drinking binges and gluttonous meals out.
He didn't think that health was something he needed to worry about.

The House of Commons was full to the rafters for the important debate.
There wasn't a single member of any of the parties who didn't attend.

Paddy was unsure about what to do next as he neared his thirties.
He didn't have a career which was either enjoyable or challenging.

The wealthy tycoon became more and more reclusive as he got older.
He recently moved to a large island in a remote part of the Pacific.

Dmitri was enjoying his work in the Immunology lab at the hospital.
He had to put each culture into refrigeration at the end of the day.

Elaine received bad news from home and needed to get time off work.
She asked to swap her weekend shift so that she could visit her Mum.

The new manager was finding it difficult to exert any real authority.
He realised that respect had to be earned, and wouldn't come easily.

There was uproar amongst the audience at the town planning meeting.
There were plans to build a factory on the local playing fields.

The General in charge of security in Afghanistan had to be tactful.
He had to take into account the history between the various tribes.

Greg was struggling to live off his student loans and savings.
He needed some extra support and turned to his parents for help.

It was difficult for the young soldier to be posted so far from home.
He received a picture that his daughter had drawn and he shed a tear.

Tanya had to draw a picture of something she had done on holiday.
She drew a picture of a mountain that she he had climbed near Oban.

Helen thought that going to the new romantic comedy would be fun.
She phoned her daughter to see if she would like to go with her.

The retired couple holidayed in Spain at least six months of the year.
It made sense when they bought a property and moved there for good.

Joanne had drunkenly fallen asleep in an awkward position.
When she woke up, she had a sore shoulder and a bad hangover.

HF-MP

Overall, Rose was very satisfied both personally and professionally.
She had a good life and hoped things would stay settled for a while.

Dianne was fed up dealing with sullen and un-cooperative colleagues.
It had been a difficult week but fortunately it would soon be over.

Last Christmas we visited my parents' house and it was very stressful.
I think that this year we will celebrate at home on our own.

Sue spent hours preparing a variety of dishes for her dinner party.
Her guests agreed that the food was wonderful so it was all worth it.

My favourite hobby is going to see musicals at the theatre.
I normally pay extra so that my seat is near to the stage.

A stray tom cat was mewing and pawing at my back door.
I gave it a bowl of milk because it seemed very thirsty.

I struggled to read the badly printed manual for my new computer.
It had little space between the lines of text and strained my eyes.

Trying to sleep on Christmas Eve was never easy when we were kids.
It was the most exciting night of the year without a doubt.

Inflation commonly rises by a small percentage every year.
The result is an increase in the price of goods that we purchase.

Mood around the office was glum and the boss needed to take action.
Organising a party for the staff would hopefully boost morale.

Edgar was worried about getting burgled when he went out at night.
He usually left a light on to make it look as if someone was home.

Ken had forgotten to water Isla's geranium while she was on holiday.
When she got home, she saw that the plant was completely dried out.

Mary felt bad about pretending to be sick to avoid dinner with Tim.
She hadn't been much of a friend and apologised the next day.

My neighbours and I wanted to commemorate the Queen's Golden jubilee.
We organised a big party in the street which went on all night.

Doug was annoyed when the commercials started blaring from his TV.
He quickly turned the volume down and went to make a cup of tea.

Many animals must hibernate in order to survive harsh climates.
At the end of the winter they will wake up and forage for food.

This was Maximillion's third appearance in court in five months.
He was sure he would be sent to prison this time for his crimes.

The group thought that Larry was the best decision maker amongst them.
They chose him to be the leader and he graciously accepted.

The opening at the gallery exhibited some beautiful new paintings.
A personal appearance by the artist had drawn in a large crowd.

The owner of the large estate built an ostrich farm on his land.
Everyone in the village thought that he was a bit of an eccentric.

Phil was excited about retiring soon as his finances were healthy.
He had put a lot into his pension so that he could afford to travel.

Hepatitis affects the liver and can be transmitted by transfusions.
It is a serious disease which requires immediate hospitalisation.

Angela loved to knit and saw a great idea for a nice spring jumper.
She cut out the pattern from the magazine and went to buy the wool.

Dr. Fox visited the ward to answer questions about the operation.
When he met his patient he assured him it was a routine procedure.

The supervisor thought she should speak to the student personally.
She planned to have a meeting to discuss the student's progress.

The UK is experiencing a vast influx of foreign migrant workers.
They come to our country to try and make better lives for themselves.

Geoff headed to the pub to watch the final of the F.A. Cup.
They would always watch football no matter who was playing.

Airports have recently taken numerous steps to prevent terror attacks.
There are now more security checks in order to protect our safety.

Sarah had battled through the Christmas Eve crowd in the supermarket.
She carried her bags of shopping to her car and put them in the boot.

Buddhism is growing in popularity and has many famous followers.
The principles of this religion emphasise finding inner contentment.

HF-VHP

Gary had just started a new job helping tidy up the barber's shop.
He had to sweep up the hair from the floor at the end of each day.

The campers spent the afternoon gathering pieces of dry timber.
They used them to build a fire to keep them warm in the night.

Detective Mills arrived at the murder scene early in the morning.
A neighbour discovered the body after hearing screams in the night.

Lisa had moved to London to start a new job at a large legal firm.
t was the first time she had lived in a big city and she was excited.

When Alex arrived at his friend's house, he rang the bell.
He heard footsteps behind the door as his friend came to let him in.

Richard proposed to his girlfriend on Valentine's Day.
She instantly put the ring on her finger and kissed him passionately.

Ron and Jen had especially requested a room on the hotel's top floor.
They knew that it would give them a fabulous view of the ocean.

Despite keeping spending to a limit, Liz struggled to budget properly.
She always ran out of money before the end of the month.

The night after her day at the zoo, Natalie fell into a deep sleep.
However, she had a very unusual dream about being chased by a chimp.

Joyce was responsible for arranging her tennis match with Molly.
She had booked the court at noon so they could lunch afterwards.

Adam's behaviour at school was getting out of control.
He kept disrupting the class and would have to be sent to the Head.

At the school play, Bill waited nervously for the curtain to rise.
When he went onto the stage he gave a breathtaking performance.

Businesses have simple models in which they try to maximise income.
They try to make as much profit as possible to please investors.

The traders arrived at AM to get their stalls ready for business.
Saturday was a busy day at the market and setting up early was vital.

The young boy recklessly kicked his ball in front of the house.
One day, he broke a window and blamed it on his little brother.

Emily was rushed to the maternity hospital after her waters broke.
She spent many hours in labour and eventually gave birth to a son.

Two men in the pub started fighting very viciously.
The barman phoned the police as more people began to get involved.

In the morning, most people brush their teeth and use mouthwash.
This freshens their breath before they go to work or school.

I planned a big celebration for my parents' th wedding anniversary.
I invited the whole of my family to a reception in a fancy restaurant.

Marion was tired of her spouse's feeble excuses for coming home late.
She accused her unreliable husband of cheating and threatened divorce.

Ian prepared his sandwiches for work before he went to bed.
This meant that in the morning he only had to put them in his bag.

Nicola was revising frantically for her end of year degree exams.
She would spend hours in the library with her head buried in books.

Ben slept through his alarm and was going to be late for his train.
He hurriedly drove to the station only to see it pulling away.

After nearly years with a mortgage, Jack only had one month left.
He only had to make one more payment and he'd finally own his house.

The binmen had not removed Stanley's garbage for nearly three weeks.
He decided to phone the council so that he could make a complaint.

I still receive letters for the previous tenants of my flat.
I wish that they would change their address as it is very annoying.

Interpol knew the thief of the Mona Lisa planned to keep it to himself.
It would be too difficult to sell the painting as it is too well-known.

The latest Cosmopolitan had a picture of George Clooney on the cover.
Sales of the magazine would receive a boost because of his popularity.

Travelling throughout Europe is easier since the Euro was introduced.
Having a single currency saves the need to convert money regularly.

Terry had just found out that his wife had gone into labour.
He rushed to the hospital to be present at the delivery.

Appendix IV

Target Word Specifications – Chapter 3

Note. VLP = very low predictability contexts; MP = medium predictability contexts; VHP = very high predictability contexts; HF = high-frequency target word; LF = low-frequency target word; #let = length of word; BNC = BNC frequency per million words; Cloze = cloze predictability rating; Rating = predictability rating (-3 = highly unpredictable; 3 = highly predictable).

VLP

HF					LF				
Target	**#let**	**BNC**	**Cloze**	**Rating**	**Target**	**#let**	**BNC**	**Cloze**	**Rating**
lime	4	6.87	0.00	0.06	loan	4	42.36	0.00	0.56
jail	4	13.24	0.00	0.72	land	4	233.26	0.00	-0.28
drum	4	10.29	0.00	0.00	bear	4	62.19	0.00	-0.17
dusk	4	6.71	0.00	0.33	ball	4	82.34	0.00	0.50
hive	4	2.57	0.00	0.89	goal	4	65.70	0.00	1.67
bark	4	6.20	0.05	0.00	date	4	190.84	0.05	0.89
peas	4	5.77	0.05	0.67	room	4	320.96	0.05	1.11
attic	5	6.89	0.00	-0.11	phone	5	84.98	0.00	-0.11
icing	5	8.84	0.00	0.00	power	5	351.02	0.00	0.00
stall	5	7.83	0.00	0.11	party	5	441.56	0.00	0.89
melon	5	2.19	0.05	-0.06	voice	5	275.40	0.05	1.94
sewer	5	2.13	0.05	-0.17	house	5	547.72	0.05	1.44
puzzle	6	6.13	0.00	-0.06	garden	6	120.57	0.00	-0.17
grease	6	4.12	0.00	1.28	public	6	428.80	0.00	0.50
pepper	6	10.40	0.00	-0.22	memory	6	82.34	0.00	0.17
rabbit	6	14.58	0.00	0.17	health	6	256.07	0.00	0.11
parrot	6	4.00	0.00	0.44	member	6	184.58	0.00	1.00
button	6	14.97	0.00	0.72	career	6	84.58	0.05	1.00
pillow	6	7.53	0.05	1.56	island	6	71.56	0.05	0.33
scooter	7	0.62	0.00	-0.83	culture	7	93.44	0.00	0.22
balloon	7	6.73	0.00	-0.61	weekend	7	72.79	0.00	-0.22
pottery	7	9.56	0.00	0.61	respect	7	60.84	0.00	1.06
refugee	7	9.16	0.00	1.11	factory	7	47.30	0.00	-0.11
convict	7	2.78	0.00	1.83	history	7	206.49	0.00	-0.17
blender	7	0.73	0.05	-0.11	support	7	308.67	0.00	1.33
reunion	7	6.01	0.05	1.00	picture	7	110.24	0.00	0.44
ornament	8	2.90	0.00	1.61	mountain	8	43.00	0.00	-0.44
farewell	8	7.73	0.00	0.06	daughter	8	98.71	0.00	-0.50
civilian	8	14.90	0.00	0.17	property	8	134.32	0.00	1.83
diabetes	8	7.04	0.00	-0.67	shoulder	8	51.07	0.00	0.67
Average	**5.87**	**6.98**	**0.01**	**0.35**		**5.87**	**171.79**	**0.01**	**0.52**

MP

HF					LF				
Target	**#let**	**BNC**	**Cloze**	**Rating**	**Target**	**#let**	**BNC**	**Cloze**	**Rating**
cult	4	10.03	0.35	0.28	life	4	595.46	0.20	1.00
comb	4	4.28	0.60	1.78	week	4	285.26	0.30	0.78
lust	4	5.22	0.60	1.83	year	4	727.18	0.40	1.39
sofa	4	10.97	0.65	1.72	food	4	197.59	0.45	2.39
veil	4	5.36	0.65	1.67	seat	4	65.21	0.55	1.33
cape	4	10.84	0.70	2.44	milk	4	46.68	0.65	1.72
chef	4	7.20	0.70	2.06	text	4	82.77	0.75	1.83
gravy	5	1.83	0.30	1.11	night	5	352.29	0.50	2.56
shark	5	3.38	0.35	1.28	price	5	190.71	0.65	2.06
tooth	5	6.10	0.50	1.44	staff	5	236.47	0.65	2.00
feast	5	9.54	0.65	2.28	light	5	224.99	0.75	1.56
spade	5	3.03	0.70	1.56	plant	5	86.87	0.75	2.11
poster	6	7.40	0.40	1.50	friend	6	175.41	0.40	0.61
hammer	6	11.76	0.40	1.39	street	6	202.03	0.45	1.17
hunter	6	14.19	0.45	0.78	volume	6	57.44	0.50	2.28
collar	6	14.62	0.60	1.22	winter	6	76.68	0.60	2.11
potato	6	7.98	0.60	2.33	prison	6	68.67	0.60	2.39
candle	6	8.59	0.70	2.11	leader	6	98.87	0.70	1.89
ballet	6	13.51	0.75	2.33	artist	6	43.99	0.75	2.33
cushion	7	5.30	0.20	-0.28	village	7	118.96	0.25	-0.22
cleaner	7	10.03	0.40	0.83	pension	7	108.51	0.45	2.00
sunburn	7	0.67	0.40	2.28	disease	7	96.52	0.60	2.39
posture	7	5.82	0.55	2.00	pattern	7	97.10	0.70	1.28
sweater	7	6.52	0.60	1.11	patient	7	89.02	0.70	2.50
shampoo	7	2.87	0.65	1.89	meeting	7	206.42	0.70	1.89
drought	7	6.94	0.70	2.17	country	7	330.94	0.75	2.17
necklace	8	2.78	0.20	1.06	football	8	65.36	0.40	2.56
diplomat	8	4.08	0.25	0.67	security	8	148.11	0.55	2.33
inventor	8	3.04	0.55	1.94	shopping	8	35.81	0.50	2.28
burglary	8	5.93	0.60	2.33	religion	8	46.58	0.60	2.39
Average	**5.87**	**6.99**	**0.53**	**1.57**		**5.87**	**171.93**	**0.56**	**1.84**

VHP

HF					LF				
Target	**#let**	**BNC**	**Cloze**	**Rating**	**Target**	**#let**	**BNC**	**Cloze**	**Rating**
plug	4	8.13	0.90	1.56	hair	4	150.79	0.90	2.72
cage	4	10.49	0.90	1.89	fire	4	151.06	0.90	2.33
kite	4	7.76	0.90	1.83	body	4	273.97	0.95	2.50
vase	4	5.09	0.95	2.28	city	4	254.44	0.95	2.11
glue	4	6.99	0.95	1.61	door	4	252.46	0.95	1.89
lamp	4	13.92	1.00	2.61	ring	4	75.09	1.00	2.44
oven	4	12.98	1.00	2.67	view	4	277.23	1.00	2.06
stain	5	5.26	0.95	2.22	money	5	341.77	0.95	2.61
zebra	5	2.21	1.00	2.72	dream	5	49.64	0.95	1.83
towel	5	8.84	1.00	2.11	court	5	316.46	1.00	2.22
witch	5	6.59	1.00	2.22	class	5	199.30	1.00	2.39
camel	5	4.22	1.00	2.50	stage	5	169.40	1.00	2.17
poison	6	10.31	0.95	2.28	profit	6	61.72	0.90	2.33
mosque	6	3.48	0.95	2.72	market	6	318.07	0.90	2.00
tailor	6	4.48	0.95	2.44	window	6	107.10	0.95	2.33
heater	6	4.82	1.00	2.67	labour	6	280.70	1.00	2.78
fridge	6	5.91	1.00	2.06	police	6	288.06	1.00	2.50
spider	6	6.28	1.00	2.28	breath	6	55.54	1.00	2.22
bonnet	6	4.13	1.00	1.50	family	6	363.53	1.00	2.39
costume	7	6.93	0.95	2.11	husband	7	115.77	0.95	2.00
malaria	7	2.99	0.95	2.44	morning	7	182.03	0.95	2.28
receipt	7	11.73	0.95	2.39	library	7	86.72	0.95	2.11
lobster	7	2.79	0.95	1.89	station	7	69.49	1.00	2.00
perfume	7	5.96	1.00	2.50	payment	7	57.44	1.00	2.50
laundry	7	5.80	1.00	2.28	council	7	299.39	1.00	1.94
plaster	7	9.03	1.00	2.44	address	7	70.22	1.00	2.44
confetti	8	0.71	0.85	2.17	painting	8	45.59	0.90	2.50
reporter	8	12.47	0.85	2.33	magazine	8	49.51	0.95	2.17
lipstick	8	4.16	0.85	2.50	currency	8	38.82	1.00	2.39
equality	8	16.22	1.00	2.39	hospital	8	156.67	1.00	2.39
Average	**5.87**	**7.02**	**0.96**	**2.25**		**5.87**	**171.93**	**0.97**	**2.29**

Appendix V

Target Word Specifications – Chapter 5: *Experiment 4a*

Note. HF = high frequency; LF = low frequency; LC = low-constraint word-initial letter combinations; HC = high-constraint word-initial letter combinations; Freq per million = frequency of occurrence per million words; #N 5-let / x-let = number of 5-letter / any length words sharing initial trigram; ∑ freq 5-let / x-let = sum of the frequencies of 5-letter / any length words sharing the initial trigram; %all 5-let / x-let = percentage of sum of frequency of occurrence accounted for by target word for 5-letter / any length words; Neu / Bia= target in neutral / biasing context; Rating = predictability rating (1=highly unpredictable, 7=highly predictable); Cloze = cloze predictability rating.

HF-LC	**Freq per million**	**#N 5-let**	**Σ freq 5-let**	**#N x-let**	**Σ freq x-let**	**%all 5-let**	**%all x-let**
forty	28.96	16	31142	332	1075415	8	0
proud	32.87	20	12149	619	576739	20	1
rough	35.40	6	30856	63	44138	9	7
cheap	36.73	18	13895	217	51066	19	6
sharp	52.78	32	44967	233	97304	10	5
quick	56.04	18	37803	115	53107	12	9
quiet	65.21	18	36978	115	53098	14	10
heavy	98.88	13	39187	192	159772	19	5
green	148.59	13	46803	158	102163	22	12
short	192.09	18	50668	176	243667	25	7
third	220.28	9	79902	70	533241	20	4
white	255.27	13	404819	165	421897	5	5
storm	25.57	26	51325	214	86086	4	3
trend	28.04	8	12827	127	63198	16	4
rival	28.43	4	9463	35	15271	21	14
shirt	28.72	18	8695	127	28308	23	8
ships	29.34	18	8639	127	28307	23	9
clock	29.47	14	26021	110	64535	9	4
sheep	29.77	16	10373	156	343223	21	1
prize	33.43	18	37624	191	150234	7	2
bread	34.91	12	11521	167	56763	21	5
chest	39.26	18	13668	217	51063	21	6
theme	41.50	9	618262	155	6907760	1	0
plate	42.08	18	75579	200	212001	5	2
grass	42.41	22	24528	294	90349	13	4
crowd	47.24	20	15859	160	35631	21	11
track	64.50	15	32565	415	180090	15	3
trial	68.93	24	20126	217	50357	24	11
speed	80.13	14	28890	183	146132	20	5
train	81.71	15	31016	415	180073	19	4
stone	86.52	26	45839	214	86025	15	8
plant	86.87	18	71548	200	211956	10	4
event	111.93	4	35480	54	192728	22	5
parts	122.11	22	46647	363	264355	19	4
story	141.00	26	40936	214	85970	24	13
start	213.12	32	97789	375	294205	16	6
words	247.94	11	96974	149	279650	19	7
teach	28.41	5	8257	58	64752	24	4
print	31.67	18	37783	191	150235	7	2
stand	107.46	32	107299	375	294205	8	3
average	**79.39**	**16.9**	**61367.6**	**204**	**350626.7**	**15.8**	**5.5**

HF-HC	Freq per million	#N 5-let	Σ freq 5-let	#N x-let	Σ freq x-let	%all 5-let	%all x-let
dirty	26.63	3	86	40	56169	97	4
dying	29.53	1	13	1	16	100	99
tired	40.24	3	97	17	1617	97	69
armed	51.42	3	39	54	36066	99	11
empty	59.77	1	10	63	54924	100	9
rural	66.24	0		2	83	100	99
older	92.07	2	61	16	49898	99	14
happy	110.08	1	34	21	37246	100	21
royal	160.10	3	261	19	3504	98	80
paper	166.04	6	1098	43	9684	93	61
light	224.99	0		47	12228	100	62
large	361.88	9	1047	51	23639	97	58
knife	27.89	2	92	28	7410	96	25
lists	29.73	3	350	38	29393	88	8
pitch	29.74	6	253	54	7686	91	26
cycle	34.11	0		24	3590	100	46
nurse	35.22	1	12	22	8051	100	28
rugby	35.99	1	13	14	2011	100	62
uncle	36.74	3	177	157	19209	95	15
sugar	37.40	2	62	19	32531	98	9
error	41.06	2	205	16	3552	95	51
novel	44.79	3	58	30	14307	99	22
agent	46.16	1	15	19	44118	100	9
doors	48.73	2	163	30	24963	96	15
teeth	49.02	4	392	30	5915	92	43
adult	54.67	0		14	3946	100	55
video	64.79	2	102	21	5674	98	51
fight	71.44	0		25	39576	100	14
joint	73.44	2	686	16	18488	91	26
image	80.39	3	54	24	16462	99	31
cells	83.33	7	1257	54	24814	86	23
girls	95.74	2	109	39	17150	99	33
glass	104.12	7	1246	81	24813	88	27
music	158.07	11	825	97	88228	95	14
hands	200.01	14	1972	160	72670	90	20
table	207.33	4	395	35	7011	98	73
human	210.97	6	436	92	14766	98	56
guard	32.52	2	47	44	12483	98	19
smoke	39.47	5	396	36	10536	90	25
cover	112.28	5	171	42	19940	98	34
average	**86.85**	**3.3**	**349.5**	**41**	**21609.2**	**96.4**	**36.2**

LF-LC	Freq per million	#N 5-let	Σ freq 5-let	#N x-let	Σ freq x-let	%all 5-let	%all x-let
chewy	0.32	18	17172	217	51102	0	0
salty	1.86	23	13894	152	38789	1	0
scary	1.94	20	9859	139	28542	2	1
stale	4.33	32	116580	375	294414	0	0
shaky	5.08	32	49260	233	97352	1	0
stain	5.26	32	116497	375	294413	0	0
bland	6.84	14	32451	183	49567	2	1
shiny	7.67	18	10590	127	28329	6	2
pearl	7.68	12	11001	53	23982	6	3
solar	14.32	13	5864	116	49028	18	3
brass	15.97	23	10418	221	37334	12	4
steep	17.22	20	21884	238	64928	7	2
salsa	0.17	23	14046	152	38791	0	0
froth	1.49	10	16494	70	430200	1	0
spade	3.03	15	21230	128	39089	1	1
flask	3.16	15	6013	165	33253	5	1
clown	3.86	14	28326	110	64561	1	1
scalp	3.96	20	9678	139	28540	4	1
steak	4.32	20	23045	238	64941	2	1
claws	4.51	23	34492	193	97155	1	0
drums	6.98	8	7438	43	15445	8	4
roofs	7.28	6	8014	35	42271	8	2
spoon	7.84	14	13001	97	44215	5	2
tribe	8.06	24	25605	217	50418	3	1
thief	8.07	9	99001	70	533453	1	0
beard	9.74	13	9087	126	48061	9	2
chalk	9.80	19	18095	402	246032	5	0
beast	9.87	13	9076	126	48061	9	2
salad	10.86	23	13084	152	38780	7	2
twins	12.08	8	7197	52	13621	13	7
stamp	14.23	32	115689	375	294311	1	0
sweat	14.33	6	7754	64	17273	14	7
chips	16.20	23	41575	192	107984	3	1
crops	17.43	20	18542	160	35661	8	4
cheek	20.14	18	15388	217	51082	11	3
cloud	23.07	14	26597	110	64541	7	3
grave	23.11	22	26265	294	90368	7	2
stack	6.98	32	116342	375	294411	1	0
burnt	12.24	16	5956	149	32831	16	3
faint	18.43	5	7782	69	49676	18	3
average	**9.24**	**18.1**	**29007.1**	**174**	**99320.2**	**5.5**	**1.8**

LF-HC	**Freq per million**	**#N 5-let**	**Σ freq 5-let**	**#N x-let**	**Σ freq x-let**	**%all 5-let**	**%all x-let**
itchy	0.84	0		6	400	100	16
fizzy	1.06	0		6	264	100	26
foggy	1.36	1	10	12	1141	92	10
baggy	2.64	0		26	7489	100	3
dizzy	4.06	0		4	189	100	66
muddy	6.70	1	10	20	2585	98	19
tweed	8.24	4	114	24	12742	87	6
dusty	8.28	3	126	17	4602	86	14
toxic	13.10	1	184	16	905	87	57
faded	15.34	2	153	6	1348	90	51
vague	15.89	1	21	17	2226	99	39
alert	17.32	1	45	43	8973	97	15
igloo	0.20	0		1	20	100	47
yolks	1.11	0	0	3	172	100	37
acorn	2.59	2	23	11	1009	91	19
foxes	3.68	1	23	16	2818	94	11
pizza	3.68	0		6	182	100	65
desks	3.74	1	28	162	116111	92	0
cigar	5.21	0		6	3266	100	13
onion	6.57	0		1	470	100	56
dwarf	6.62	0		6	525	100	53
veins	8.49	1	130	9	1686	85	31
peers	9.10	2	91	33	4698	90	15
cakes	9.24	1	67	3	2249	93	27
ivory	9.77	0		5	334	100	72
lions	10.04	0		9	1666	100	35
ankle	10.41	1	16	5	618	98	60
elbow	11.47	0		7	687	100	60
lemon	12.30	6	133	22	737	89	60
skull	12.34	3	100	8	444	92	71
jeans	12.81	1	22	13	3935	98	23
organ	13.89	1	11	44	40877	99	3
fibre	16.64	0		22	1697	100	47
fence	16.72	2	156	31	4205	91	26
piano	20.21	0		19	1292	100	58
ocean	21.39	0		11	946	100	67
album	23.01	3	139	40	6766	94	23
sober	6.68	0		13	1354	100	31
wiped	12.29	2	119	6	1297	90	46
punch	15.54	5	228	60	8873	86	14
average	**9.51**	**1.2**	**81.2**	**19**	**6295.0**	**95.4**	**34.8**

Appendix VI

Experimental Materials – Chapter 5: *Experiment 4b*

Note. Materials are listed as they would appear in the Biasing context condition. The Neutral condition is simply the second sentence of each item, containing the target word (underlined). Target words were low or high frequency (LF, HF) words with low or high constraint (LC, HC) word-initial trigrams. Items are sorted by these four conditions, with 22 items per condition. One participant group read half the items of each condition in a Biasing and half in a Neutral context. The other participant group read the same items in their opposite context condition.

LF-LC

Leon was unhappy with the tough bread he got with his soup.
He complained that it was stale and the waitress apologised.

Jill's friends were drinking red wine all night in her flat.
In the morning, she noticed an enormous stain on the carpet.

Robert was polishing his shoes before his big job interview.
He wanted them to be shiny enough to see his face in them.

Maude added two brown sugars to her cappuccino.
She put her spoon through the froth and stirred them in.

Sidney had tried a new shampoo for his terrible dandruff.
He massaged it into his scalp before rinsing it out well.

Eve's cat had begun to scratch her new furniture.
She would need to get his claws cut to prevent more damage.

Ray lived for six months with groups of pygmies in Africa.
He studied each tribe and learned about their customs.

Albert thought he looked good with his new facial hair.
His friends disagreed and thought his beard looked awful.

Lorna had gone on a five-mile run in the midday sun.
You could see the sweat running down her face by the end.

Luke's first job was working at the supermarket.
His responsibility was to stack the shelves.

When Geoffrey got a nosebleed, Dawn nearly keeled over.
We thought she was going to faint at the sight of his blood.

The child couldn't sleep after watching the monster movie.
It had been really scary and she was afraid to be alone.

Gavin placed the expensive necklace around his wife's neck.
It was a string of pearl beads and she adored him for it.

There were fingerprints all over the handrail at the bar.
They took away the shine from the brass and looked grubby.

Rory was going to dig all day in the potato fields.
He picked up his spade and headed off to work.

Pierre had entertained kids at the circus for fifty years.
He had enjoyed being a clown but it was time to retire.

The Big Ranch restaurant's specialty was high quality beef.
Bill ordered their biggest <u>steak</u> and a pitcher of beer.

Emily had never seen such an enormous bowl of ice cream.
She excitedly grabbed a <u>spoon</u> and began to stuff herself.

The shopkeeper suspiciously eyed the girl in the hooded top.
He knew she was a <u>thief</u> and hoped to catch her red-handed.

The teacher scrawled sentences onto the blackboard.
The noise of the <u>chalk</u> sent shivers up everyone's spine.

Tania first prepared the tomatoes, cucumber and lettuce.
She finished making the <u>salad</u> with oil and vinegar dressing.

The letter Lucas had posted was returned to him.
He had forgotten to put a <u>stamp</u> on it before posting it.

LF-HC

The heavy rain had washed the dirt and soil into the stream.
This made the water <u>muddy</u> and unsafe to drink.

I couldn't stop sneezing as I cleaned out the storage room.
Everything was <u>dusty</u> and it got up my nose as I worked.

After many washes, Karl's shirt had lost most of its colour.
It was so badly <u>faded</u> that he would need to buy a new one.

Betty only needed the egg whites to make her meringue nests.
Later, she used the <u>yolks</u> to make a separate dish.

Hounds used for hunting are trained in special kennels.
They are taught to chase <u>foxes</u> out of their burrows.

Heroin addicts often tie a belt tightly around their arms.
This makes it easier to find <u>veins</u> that they inject into.

Everyone was excited about going to see big cats at the zoo.
The children wanted to see the <u>lions</u> and tigers most of all.

Nadia had been practising her tennis stroke for six hours.
She now had a pain in her <u>elbow</u> and went to get an ice pack.

The cause of death was a hammer blow to the head.
The damage to the victim's <u>skull</u> was quite sickening.

Valerie's neighbour's Alsatian kept coming into her garden.
She got her son to build a <u>fence</u> to keep the dog out.

The boys got into a fist fight in the playground.
They began to furiously <u>punch</u> each other in the face.

Andrea constantly suffered from severe eczema.
Her skin was always <u>itchy</u> and she constantly scratched it.

The forecast warned drivers of poor visibility on the roads.
As Will drove home, it became <u>foggy</u> and he could barely see.

At the ceilidh, Steven vigorously spun Emma round and round.
This made her very <u>dizzy</u> but she still had a good time.

The grey squirrel was foraging at the foot of the oak tree.
He recovered the acorn that he had buried last winter.

Jamie loved basketball but he was very short for his age.
In gym class, he felt like a dwarf next to his classmates.

Poachers still illegally hunt elephants for their tusks.
It is possible to buy ivory items on the black market.

Karen had jumped and landed awkwardly while ice skating.
She badly hurt her ankle and would need to have an x-ray.

Leanne was thirsty so she ordered a diet coke from the bar.
It came with a slice of lemon and lots of ice and a straw.

Maintaining a healthy digestive system requires roughage.
Foods that are high in fibre are recommended by experts.

The music teacher hired removal men when he moved house.
He couldn't move his piano on his own as it was too heavy.

Tara had taken heaps of photos of her Egyptian holiday.
She would have to begin a new album to keep them together.

HF-LC

Maria's only son was graduating today from Oxford.
As she watched, she felt so proud of his achievements.

Marcus almost hurt himself badly lifting weights at the gym.
He had picked ones that were too heavy for him to lift.

During apartheid in South Africa, most races could not vote.
Only people who were white could take part in the elections.

Susan was bored in the lecture and time passed slowly.
She kept glancing at the clock and counted down the minutes.

The pirates located the spot where the treasure was buried.
They opened up the chest and marvelled at the booty inside.

Mary's young son gave her a kick as she washed the dishes.
She was so surprised, she dropped a plate and it smashed.

Tiger Woods was angry when he was distracted playing a shot.
Apparently, someone in the crowd cheered as he hit the ball.

Stuart did not want to travel to London by bus or plane.
He bought tickets for the train to Waterloo on the internet.

Terry went to the new gardening centre.
He bought a rare plant for his garden.

Harry was slightly late for the play in the theatre.
He missed the start but caught up with the plot quickly.

The toddler held onto the furniture to keep himself upright.
On his own, he was unable to stand without falling down.

The joiner hadn't smoothed the edges of the cabinets yet.
They were still quite rough and not ready to be varnished.

Nigel was struggling to cut the turkey with a blunt knife.
He asked his wife for a sharp one and he continued to carve.

During the War, German submarines targeted supply convoys.
They would attack the ships that carried weapons and food.

Every morning, Jeff would walk past the baker's shop.
He enjoyed the smell of bread and frequently bought a loaf.

Everyone knew that "EastEnders" was just beginning.
We recognised the familiar theme tune and sat down to watch.

The park-keepers took good care of the lawns.
They made sure that the grass was cut every day.

There had been a terrible crash at the weekend's Grand Prix.
Oil had leaked onto the track and caused a massive pile-up.

The yacht crew were pleased with the favourable strong wind.
They used it to gain speed and were sure to win the race.

I could feel something in my shoe which dug into my heel.
It was a small stone which had come from the gravel path.

Johnny liked his father to read to him before bedtime.
There was one particular story he liked about a tiger.

David increased his vocabulary by reading lots of books.
His knowledge of difficult words was far better than others.

HF-HC

Meg was driving and spotted a badly injured hedgehog.
She tried to prevent it from dying but it was too late.

Special police units rushed to the bank robbery in progress.
The men inside were armed and had taken customers hostage.

The couple finally got pregnant after trying for months.
They were extremely happy when they eventually succeeded.

Derek asked for a bacon double cheeseburger at Burger King.
He also ordered an extra large drink to wash it all down.

Sheena had to shop for many things in many different stores.
She made up several lists so that she remembered everything.

Henry had been injured in a scrum at school.
He was unable to play rugby for several weeks.

Ted was diabetic and had to monitor what he ate.
If he ate too much sugar he could become unwell.

Dan was traumatised by seeing the mutilated body as a child.
He could never get rid of the image from his mind's eye.

At school, Miss Jones told only the boys to leave early.
She wanted to talk to the girls about the incident.

Keith liked to listen to Mozart, the Beatles, and techno.
He liked all kinds of music with no particular preference.

The Sultan kept his gold bullion hidden in his palace.
There was always someone there to guard it around the clock.

It had rained all night and the footpath was very muddy.
Hannah's shoes were dirty and she trailed mud in the house.

The Queen has never voted in a General Election.
Members of the royal family are not allowed to.

Seth could easily carry six plastic chairs at a time.
They were incredibly light and could be stacked together.

Craig knew the law about carrying illegal weapons in public.
He still carried a knife despite the risk of being caught.

Jack's aunt was supposed to pick him up after school.
Instead, it was his uncle who was waiting for him.

The Ministry of Defence discovered a spy in their operation.
It was a Russian agent who was relaying details to Moscow.

Sarah had saved money to have veneers fitted at the dentist.
When they were finished, her teeth looked fabulous.

The DVD is now the most common form of movie entertainment.
It seems that the video will soon be a thing of the past.

Claire's knee was causing her a lot of pain after exercise.
The specialist said the joint was inflamed and needed rest.

It was a cold day and Barbara had forgotten her gloves.
She decided to keep her hands in her pockets for warmth.

Jennifer tried a cigarette for the first time and loved it.
She started to regularly smoke when she went out.

Appendix VII

Target Word Specifications – Chapter 5: *Experiment 4b*

Note. HF = high frequency; LF = low frequency; LC = low-constraint word-initial letter combinations; HC = high-constraint word-initial letter combinations; Freq per million = frequency of occurrence per million words; #N 5-let / x-let = number of 5-letter / any length words sharing initial trigram; ∑ freq 5-let / x-let = sum of the frequencies of 5-letter / any length words sharing the initial trigram; %all 5-let / x-let = percentage of sum of frequency of occurrence accounted for by target word for 5-letter / any length words; Neu / Bia= target in neutral / biasing context; Rating = predictability rating (1=highly unpredictable, 7=highly predictable); Cloze = cloze predictability rating.

LF-LC	**Freq per million**	**#N 5-let**	**Σ freq 5-let**	**#N x-let**	**Σ freq x-let**	**%all 5-let**	**%all x-let**	**Rating Neu**	**Rating Pred**	**Cloze Neu**	**Cloze Pred**
stale	4.33	32	116580	375	294414	0.33	0.13	3.69	5.62	0.00	0.54
stain	5.26	32	116497	375	294413	0.40	0.16	4.23	5.69	0.08	0.92
shiny	7.67	18	10590	127	28329	6.12	2.38	4.77	6.54	0.00	0.69
froth	1.49	10	16494	70	430200	0.81	0.03	2.23	5.31	0.00	0.46
scalp	3.96	20	9678	139	28540	3.55	1.23	3.69	6.54	0.00	0.77
claws	4.51	23	34492	193	97155	1.16	0.42	3.77	5.92	0.00	0.62
tribe	8.06	24	25605	217	50418	2.75	1.42	3.00	5.54	0.00	0.31
beard	9.74	13	9087	126	48061	8.80	1.79	2.46	5.69	0.00	0.54
sweat	14.33	6	7754	64	17273	14.26	6.95	4.23	6.85	0.00	0.38
stack	6.98	32	116342	375	294411	0.54	0.21	4.85	5.92	0.00	0.46
faint	18.43	5	7782	69	49676	17.57	3.23	4.62	6.23	0.00	0.46
scary	1.94	20	9859	139	28542	1.74	0.61	4.15	6.31	0.00	0.92
pearl	7.68	12	11001	53	23982	5.91	2.80	4.31	5.62	0.15	0.92
brass	15.97	23	10418	221	37334	12.12	3.71	2.62	4.38	0.00	0.08
spade	3.03	15	21230	128	39089	1.27	0.69	2.38	5.69	0.00	0.77
clown	3.86	14	28326	110	64561	1.21	0.53	2.00	5.85	0.00	0.62
steak	4.32	20	23045	238	64941	1.66	0.60	3.23	5.85	0.38	0.85
spoon	7.84	14	13001	97	44215	5.15	1.57	4.31	5.31	0.08	0.92
thief	8.07	9	99001	70	533453	0.73	0.14	4.23	6.00	0.00	0.62
chalk	9.80	19	18095	402	246032	4.65	0.36	3.69	6.00	0.00	0.77
salad	10.86	23	13084	152	38780	6.95	2.46	4.15	5.92	0.00	0.69
stamp	14.23	32	115689	375	294311	1.10	0.43	4.69	6.46	0.00	0.85
Average	**7.83**	**18.91**	**37893.18**	**187.05**	**138551.38**	**4.49**	**1.45**	**3.70**	**5.87**	**0.03**	**0.64**
SD	4.63	8.31	42313.11	118.99	152649.48	4.86	1.65	0.89	0.52	0.09	0.23

LF-HC	Freq per million	#N 5-let	Σ freq 5-let	#N x-let	Σ freq x-let	%all 5-let	%all x-let	Rating Neu	Rating Pred	Cloze Neu	Cloze Pred
muddy	6.70	1	10	20	2585	98.37	18.91	3.54	5.23	0.00	0.23
dusty	8.28	3	126	17	4602	85.53	13.93	3.23	6.23	0.00	1.00
faded	15.34	2	153	6	1348	90.03	50.60	3.46	5.62	0.00	0.69
yolks	1.11	0	0	3	172	100.00	36.76	2.08	6.31	0.00	0.77
foxes	3.68	1	23	16	2818	93.50	10.51	2.31	5.69	0.08	0.38
veins	8.49	1	130	9	1686	85.46	31.18	4.38	6.69	0.00	0.85
lions	10.04	0		9	1666	100.00	35.18	4.77	6.15	0.08	0.62
elbow	11.47	0		7	687	100.00	60.03	3.08	5.00	0.00	0.62
skull	12.34	3	100	8	444	91.74	71.45	3.31	6.15	0.23	0.54
fence	16.72	2	156	31	4205	90.61	26.36	4.69	5.46	0.00	0.46
punch	15.54	5	228	60	8873	85.99	13.62	3.85	6.15	0.00	0.54
itchy	0.84	0		6	400	100.00	15.97	4.77	6.62	0.00	0.62
foggy	1.36	1	10	12	1141	92.42	9.66	5.08	6.00	0.15	0.31
dizzy	4.06	0		4	189	100.00	65.88	2.38	5.69	0.00	0.85
acorn	2.59	2	23	11	1009	91.02	18.76	2.00	5.38	0.00	0.38
dwarf	6.62	0		6	525	100.00	53.17	2.08	5.31	0.00	0.46
ivory	9.77	0		5	334	100.00	72.46	2.77	6.23	0.00	0.69
ankle	10.41	1	16	5	618	98.32	60.26	3.62	4.23	0.15	0.46
lemon	12.30	6	133	22	737	89.27	60.03	5.00	6.08	0.15	0.77
fibre	16.64	0		22	1697	100.00	46.89	4.08	6.00	0.08	0.62
piano	20.21	0		19	1292	100.00	58.47	3.00	4.77	0.00	0.85
album	23.01	3	139	40	6766	93.71	23.44	2.08	5.69	0.00	0.62
Average	**9.89**	**1.41**	**89.07**	**15.36**	**1990.64**	**94.82**	**38.80**	**3.43**	**5.76**	**0.04**	**0.60**
SD	6.29	1.71	73.36	13.74	2260.70	5.44	21.58	1.04	0.60	0.07	0.19

HF-LC	Freq per million	#N 5-let	Σ freq 5-let	#N x-let	Σ freq x-let	%all 5-let	%all x-let	Rating Neu	Rating Pred	Cloze Neu	Cloze Pred
proud	32.87	20	12149	619	576739	19.58	0.51	5.62	6.62	0.00	0.92
heavy	98.88	13	39187	192	159772	18.51	5.28	4.77	6.08	0.00	0.92
white	255.27	13	404819	165	421897	5.37	5.16	2.62	6.15	0.00	0.77
clock	29.47	14	26021	110	64535	9.25	3.95	6.31	6.31	0.38	0.85
chest	39.26	18	13668	217	51063	20.54	6.47	5.00	6.00	0.00	0.77
plate	42.08	18	75579	200	212001	4.77	1.75	4.08	4.69	0.38	0.77
crowd	47.24	20	15859	160	35631	21.14	10.66	3.85	6.08	0.00	0.77
train	81.71	15	31016	415	180073	19.17	3.92	4.69	5.85	0.00	0.85
plant	86.87	18	71548	200	211956	9.85	3.56	5.77	5.77	0.08	0.38
start	213.12	32	97789	375	294205	16.40	6.12	4.77	6.15	0.00	0.00
stand	107.46	32	107299	375	294205	8.27	3.18	4.08	6.54	0.00	0.62
rough	35.40	6	30856	63	44138	9.36	6.73	2.38	5.92	0.00	1.00
sharp	52.78	32	44967	233	97304	9.55	4.65	3.15	5.77	0.00	0.23
ships	29.34	18	8639	127	28307	23.41	8.53	2.85	5.77	0.00	0.31
bread	34.91	12	11521	167	56763	21.43	5.24	6.46	6.23	0.00	0.62
theme	41.50	9	618262	155	6907760	0.60	0.05	3.85	6.08	0.00	0.54
grass	42.41	22	24528	294	90349	13.47	4.05	5.15	6.23	0.00	0.46
track	64.50	15	32565	415	180090	15.13	3.12	3.69	5.62	0.00	0.54
speed	80.13	14	28890	183	146132	19.98	4.70	3.77	5.62	0.00	0.69
stone	86.52	26	45839	214	86025	14.52	8.30	3.85	6.08	0.00	0.77
story	141.00	26	40936	214	85970	23.66	12.86	2.62	6.38	0.00	0.69
words	247.94	11	96974	149	279650	18.71	7.39	3.23	6.31	0.00	0.62
Average	**85.94**	**18.36**	**85405.05**	**238.27**	**477480.25**	**14.67**	**5.28**	**4.21**	**6.01**	**0.04**	**0.64**
SD	69.08	7.39	144779.75	128.87	1442739.02	6.61	3.05	1.19	0.40	0.11	0.25

	Freq per	#N	Σ freq	#N	Σ freq	%all	%all	Rating	Rating	Cloze	Cloze
HF-HC	**million**	**5-let**	**5-let**	**x-let**	**x-let**	**5-let**	**x-let**	**Neu**	**Pred**	**Neu**	**Pred**
dying	29.53	1	13	1	16	99.51	99.40	2.85	5.46	0.00	0.08
armed	51.42	3	39	54	36066	99.16	11.37	5.46	6.00	0.00	0.23
happy	110.08	1	34	21	37246	99.66	21.01	5.31	6.00	0.08	0.38
large	361.88	9	1047	51	23639	96.89	57.94	6.08	5.92	0.00	0.31
lists	29.73	3	350	38	29393	88.43	8.34	4.54	6.38	0.00	0.92
rugby	35.99	1	13	14	2011	99.60	61.70	3.00	5.38	0.00	0.38
sugar	37.40	2	62	19	32531	98.19	9.38	3.15	5.77	0.00	0.85
image	80.39	3	54	24	16462	99.26	30.53	5.38	5.15	0.00	0.92
girls	95.74	2	109	39	17150	98.75	33.44	2.62	6.08	0.00	1.00
music	158.07	11	825	97	88228	94.52	13.89	3.62	6.85	0.15	0.92
guard	32.52	2	47	44	12483	98.42	18.99	3.77	6.15	0.00	0.54
dirty	26.63	3	86	40	56169	96.54	4.09	5.23	6.15	0.00	0.23
royal	160.10	3	261	19	3504	98.22	80.44	4.46	6.38	0.00	0.46
light	224.99	0		47	12228	100.00	62.35	2.85	5.69	0.00	0.92
knife	27.89	2	92	28	7410	96.46	25.30	3.54	5.23	0.38	0.92
uncle	36.74	3	177	157	19209	94.92	14.69	2.31	4.69	0.00	0.54
agent	46.16	1	15	19	44118	99.64	8.61	5.15	5.92	0.15	0.38
teeth	49.02	4	392	30	5915	91.84	42.72	2.00	6.69	0.00	0.54
video	64.79	2	102	21	5674	98.28	50.68	3.69	5.54	0.00	0.92
joint	73.44	2	686	16	18488	90.60	26.34	4.00	5.08	0.00	0.08
hands	200.01	14	1972	160	72670	90.13	19.85	4.69	6.85	0.00	0.92
smoke	39.47	5	396	36	10536	89.97	25.21	3.77	6.85	0.00	0.85
Average	**89.64**	**3.50**	**322.48**	**44.32**	**25052.09**	**96.32**	**33.01**	**3.98**	**5.92**	**0.03**	**0.60**
SD	84.47	3.46	476.19	41.78	23257.18	3.74	25.66	1.15	0.61	0.09	0.32